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Agency frictions, managerial compensation, and disruptive innovations ☆

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ABSTRACT

Whether a manager leads the innovation efforts of a firm in line with shareholder preferences is key for firm value and growth. This, in turn, influences aggregate productivity growth and welfare. Data on US public firms reveals that (i) firms with better corporate governance tend to adopt highly incentivized contracts rich in stock options and (ii) such contracts are more likely to lead to disruptive innovations – patented inventions that are in the upper tail of the distribution in terms of quality and originality. Motivated by these empirical results, we develop and estimate a new dynamic general equilibrium model of firm-level innovation with agency frictions and endogenous determination of executive contracts. The model is used to study the joint dynamics of corporate governance, managerial compensation, and disruptive innovations, as well as the consequent aggregate implications on growth and welfare. Better corporate governance can reduce the influence of the manager in determining the compensation structure. This leads to more incentivized contracts and boosts innovation, with substantial benefits for the shareholders as well as the broader economy through knowledge spillovers. Removing agency frictions leads to contracts richer in stock options, boosting growth by 0.51pp, and welfare by 7.3% in consumption-equivalent terms. These findings are robust to incorporating short-termism. Short-termism itself is also detrimental, the removal of which increases welfare by 1.5%. Alleviating both frictions at the same time leads to amplified gains in growth and welfare.

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1. Introduction

Innovation is the primary engine of economic growth in economies at the technological frontier, and a path to higher profits and growth at the firm level. Companies such as Apple, Alphabet, Microsoft, and Amazon which dominate the list of top US public firms by market capitalization can dispel any doubts to the contrary. A firm's manager plays a crucial role in directing and overseeing its innovation efforts. This, however, creates a tension: The interests of the shareholders and those of the manager might not be perfectly aligned with each other, opening the door to agency frictions. In turn, these frictions can result in suboptimal investment in innovation, leading to losses in firm value for the shareholders, and low economic growth and welfare for the broader economy.

Better corporate governance can help align the interests of the managers and the shareholders, and thus alleviate the negative impact of agency frictions. Recent empirical studies confirm the significance of corporate governance in the growth process (see Nicolo et al. (2006), Claessens and Yurtoglu (2012), and Bloom and Van Reenen (2007) among others). A recent report by OECD (2012) summarizes this body of evidence by arguing that "corporate governance exerts a strong influence upon innovative activity and entrepreneurship. Better corporate governance, therefore, should manifest itself in enhanced corporate performance and can lead to higher economic growth."

Despite the substantial strands of literature on corporate governance, agency frictions, and firm innovation, little work has been done to quantify the effects of agency frictions between shareholders and managers on firm innovation, managerial compensation structure, economic growth, and social welfare. In this paper, we model the agency frictions between the manager and the shareholders of a firm regarding corporate investment, where the managerial compensation structure is endogenously determined, and affected by the quality of corporate governance. We nest this agency problem within a rich dynamic general equilibrium framework with endogenous productivity growth that can tractably accommodate firm heterogeneity. This novel framework allows us to shed light not only on the micro-level implications of agency frictions on managerial compensation structure and firm innovation, but also on the much less investigated macroeconomic implications of these micro-level frictions on economic growth and social welfare.

To achieve our purpose, we document motivating facts that shed light on the mechanisms through which corporate governance influences firm innovation. One popular method employed by US public companies is increasing the share of stock options in manager compensation. We find that firms with better governance (as proxied by high institutional ownership) tend to adopt executive compensation contracts with a higher share of stock options. The convex payoff structure of state-contingent stock options provides incentives to the managers to engage in risky innovative activities, thereby contributing to firm value and economic growth. We combine micro-data on patented inventions from the United States Patent and Trademark Office (USPTO) with data on US public firms from Compustat and executive compensation information from Execucomp databases for 1990-2004. Unlike the majority of papers using similar data, our focus is on the quality, not the quantity, of innovations. To this purpose, we employ three scale-independent measures of disruptive innovations: (i) average citations received by the patents of a firm, (ii) the fraction of a firm's patents that make it to the top 10% in terms of patent quality, and (iii) the average originality of the patents — a measure which captures the variety of distinct technology classes that the new innovation is combining and building upon. Consistent with previous literature, the stylized facts can be summarized as follows:

1. Higher institutional ownership is positively associated with disruptive innovations.
2. Higher institutional ownership is positively associated with more incentivized CEO contracts, which contain more stock options and restricted stock grants relative to the total compensation.
3. More incentivized CEO contracts are associated with more disruptive innovations.
4. The positive association between institutional ownership and disruptive innovations appears to be realized largely through the mechanism of more incentivized CEO contracts.

How much do agency frictions between managers and shareholders matter for innovation, firm growth, firm value, and economic growth? To what extent can the inefficiencies caused by agency frictions be alleviated through better corporate governance and more incentivized executive compensation contracts? Are there systematic differences in the degree of this inefficiency across time? Answering these questions in a purely empirical setting is challenging. First, agency frictions are not directly observable. To assess their impact, we must observe what would have happened in a parallel, counterfactual world in which there are no agency frictions. Evaluating this counterfactual is difficult, because it is hard to find exogenous shocks that eliminate agency frictions. Even if there were such a shock, it is likely to be limited in scope, raising concerns about external validity. Overall, it is unclear how to quantify the effect of agency frictions without a model.

We overcome these challenges by developing and structurally estimating a new dynamic general equilibrium model with firm-level innovation, and endogenously determined managerial compensation contracts. This tractable theoretical model and its quantification are our primary contributions. In the model, the firm's board determines the CEO's compensation contract. Taking the contract as given, the CEO makes the innovation decisions. The board, however, does not fully represent the preferences of the shareholders. The CEO's compensation structure is the product of a tug-of-war between the CEO and the shareholders. The CEO has some influence over the board's final decision, and his preferences enter the board's objective function along with those of the shareholders. Consequently, the agreed-upon compensation contract deviates from the shareholder-optimal contract that would maximize firm value. Better corporate governance acts to reduce the

CEO's influence, enabling the board to choose contracts with a higher fraction of stock options. This in turn motivates the manager to allocate more resources to innovation.[1] Better corporate governance thus leads to a higher rate of innovation and more knowledge spillovers, thereby increasing long-run productivity growth and social welfare. Despite this complex setting with rich dynamics, the model remains highly tractable and computationally feasible, where most of the relevant quantities admit closed-form solutions. Thus we can largely avoid the problem of a "black box" model with many indistinguishable moving internal parts. This facilitates a better understanding of the key mechanisms at play.

On the quantitative front, the model successfully replicates the above-mentioned stylized facts, and the measured correlations play a significant role in disciplining the quantitative implications of the estimated model. Using simulated method of moments (SMM), the model parameters are estimated to best fit a wide-ranging set of facts about US firms, such as the aggregate output growth rate, share of research and development (R&D) expenditures, ratio of CEO compensation to market capitalization, and the correlation structure between firm innovation, corporate governance, and the share of stock options in the CEO's total compensation. Using the estimated parameters, we document the model's implications for the US economy by conducting a series of counterfactual experiments. Through these experiments, we quantify the importance of the agency frictions between the CEO and the shareholders not only on micro-level observations such as firm innovation, but also their macroeconomic impact on aggregate productivity growth and social welfare. An experiment in which we remove agency frictions by shutting down CEO influence results in an increase in firm innovation by 26.6% of its value. The equilibrium output growth rate increases by 0.51% on top of its targeted value of 2.00%. This leads to a significant welfare gain of 7.3% in consumption-equivalent terms.[2] Another quantitative experiment that attempts to gauge the impact of FAS 123R, a change in accounting standards introduced in December 2004 which discourages firms from using stock options in employee compensation, reveals that it might have slightly reduced long-run economic growth while concentrating R&D in firms with better corporate governance. The overall effect is a fall in social welfare by 0.84%. We also investigate whether preferential taxation of stock options can alleviate the agency frictions. However, the welfare gain from not taxing stock options is a modest 0.91%.

The general equilibrium property of our framework matters for the precise assessment of the counterfactual implications of how agency frictions affect innovation, productivity growth, and welfare. Ignoring the endogenous responses of the wages, the interest rate, and the knowledge spillovers across firms would significantly exaggerate how firms would change their innovation policies. In particular, we demonstrate that ignoring the general equilibrium effects would increase the welfare impact of shutting down agency frictions from 7.3% to 13.7%, highlighting the importance of using a general equilibrium framework to quantify the impact of agency frictions. Our model's ability to tractably cast an agency problem with endogenous compensation structure in a dynamic general equilibrium model with endogenous growth helps in this respect.

A recent paper by Terry (2017) finds that short-term pressure on CEOs to meet earnings targets can force them to decrease investment in R&D. Motivated by this finding, we enrich our analysis by incorporating short-term earnings pressure on CEOs in our baseline model. We document new evidence on how short-termism is a more relevant problem for firms with high institutional ownership. In the extended model, CEOs are punished if they miss the short-term earnings target. This leads to a reduction in R&D spending and innovation especially for innovative firms when they face a low productivity shock. We find that this extension does not change our quantitative results significantly. Removing short-term pressure also leads to gains in growth and welfare, albeit at one quarter of the magnitudes achieved through shutting down CEO influence. Finally, the model predicts amplified gains if both frictions are alleviated simultaneously.

This paper is related to the literature exploring the effects of agency frictions and executive compensation on managerial risk-taking and investment decisions.[3] Glover and Levine (2015) provide evidence that managerial incentives, shaped by compensation contracts, help to explain the empirical relationship between uncertainty and investment. Glover and Levine (2017) find that the average CEO compensation contract incentivizes overinvestment in physical capital by 1.3 percentage points per year. Albuquerue and Wang (2008) develop a dynamic stochastic general equilibrium model to study asset pricing

[1] The model imposes no priors on whether the agency frictions are large, small, or even absent. In the model, the CEO can *under*- or *over-invest* in innovation depending on parameter values. Under the estimated parameter values, it turns out that the shareholders prefer more innovation than the CEOs on average. This is guided by the direction of the correlation patterns between firm innovation, corporate governance, and the share of stock options in executive compensation.

[2] This number is an upper bound, since we attribute all economic growth to firm innovation. In Online Appendix A.12, we relax this assumption where 50% of the observed productivity growth is exogenous, which halves the welfare gain.

[3] Morellec et al. (2012) develop a dynamic trade-off model to examine the importance of manager-shareholder conflicts in the choice of capital structure. They find that adding agency cost helps resolve the low leverage puzzle and the time series patterns of leverage ratios. They also find that the variations in agency costs are sizable, and the level of agency conflicts is correlated with commonly used proxies for corporate governance. Coles et al. (2006) argue that CEO compensation that features high sensitivity of CEO wealth to stock price volatility implements riskier policy choices such as higher R&D expenditures and leverage. Edmans et al. (2012) study optimal CEO compensation in a dynamic framework and find that the optimal contract can be implemented by escrowing the CEO's pay into a "dynamic incentive account." Ederer and Manso (2013) find that compensation based on the pay-for-performance principle is effective in inducing managerial effort and productivity. Dittmann and Maug (2007) calibrate a static structural model to find the best mix of straight equity, stock options, and cash compensation that keeps CEO effort at the same level while decreasing the costs to the firm. Eisfeldt and Rampini (2008) argue that substantial bonuses are required to incentivize managers to declare capital must be reallocated under information asymmetry. Eisfeldt et al. (2020) show that ignoring equity-based income causes incorrect measurement of the returns to high-skilled labor, with substantial effects on macroeconomic trends. Panousi and Papanikolaou (2012) maintain that compensation with stock options can mitigate the negative impact of managerial risk aversion on investment. Page (2018) estimates a dynamic model of CEO compensation and effort provision. He finds that variation in CEO attributes explains the majority of variation in compensation and removing CEO influence increases shareholder value.

and welfare implications of imperfect investor protection. Nikolov and Whited (2014) develop and estimate a dynamic model to study the impact of agency frictions on firm cash holdings. Despite the substantial literature on corporate governance and agency frictions, what is less well understood is the joint dynamics of agency frictions, managerial compensation, and firm innovation, as well as its aggregate implications. Our paper aims to shed light on this by developing and estimating a new dynamic general equilibrium model. Different from this strand of literature, which often treats executive compensation as exogenously given, we study the joint determination of managerial compensation, firm innovation, and economic growth in a united dynamic framework. Our general equilibrium framework offers significant value-added compared to what is previously done in the literature, given that taking the effect of knowledge spillovers into account, as well as the endogenous response of the firms to their competitors' innovation choices are key to assess the true welfare cost of managerial agency frictions.

The dynamic general equilibrium model featuring endogenous productivity and output growth links this paper to the literature on endogenous growth, pioneered by Aghion and Howitt (1992), Lucas (1988), and Romer (1990).[4] In terms of the particular model used in this paper, the closest two papers are Akcigit et al. (2016) and Celik (2022). The firm-level innovation decision determines the probability of a successful innovation, which results in a permanent increase in the firm's productivity. The increase in productivity benefits from Romer-type productivity spillovers, resulting in under-investment in innovation from a social planner's point of view. Firms have an incentive to invest in costly R&D to improve the innovation probability, since their profits are linearly increasing in their relative productivity compared to the average productivity in the broader economy. This model differs from these two papers in that the CEO of a firm chooses the innovation probability under an endogenous contract determined by the board, subject to CEO influence. Due to the misalignment of incentives between the firm's CEO and its shareholders, the CEO might *under-* or *over-invest* in innovation depending on how his contract is structured. Therefore, the agency frictions between the CEO and the shareholders generate an additional mechanism through which the innovation in a competitive equilibrium might be further below the value in the Pareto efficient allocation. Another closely related paper is Greenwood et al. (2022), which focuses on how the monitoring frictions between venture capitalists and the start-ups they support can influence economic growth and welfare. In their setting, the venture capitalists play a similar role to that of the institutional owners in our current model. Iacopetta and Peretto (2018) show that modest differences in corporate governance can account for large income differences across countries using a growth model with governance distortions and resource diversion. Our framework also adds to the broader endogenous growth literature with firm dynamics, such as Peters (2020), Akcigit et al. (2021a), Akcigit et al. (2022), and Ates and Saffie (2021). We contribute by embedding a complicated agency problem where the endogenous compensation contract is the result of a tug-of-war between the manager and the shareholders without abstracting away from rich firm dynamics, or losing tractability.

This paper adds to a growing strand of literature studying the impact of corporate governance on firm innovation. Francis and Smith (1995), Eng and Shackell (2001), and Aghion et al. (2013) find that greater institutional ownership is associated with more innovation. Our paper is related to Aghion et al. (2013). We show that the effect of institutional ownership is realized chiefly through the channel of managerial compensation.[5] Balsmeier et al. (2016) investigate the impact of board independence on innovation. We find that their metric is positively correlated with our measures of disruptive innovation. Chemmanur and Tian (2018) find that anti-takeover provisions and institutional ownership spur corporate innovation. Iacopetta and Peretto (2018) provide evidence that better corporate governance can lead to economic growth through innovation in a cross-country setting. Although a large strand of previous literature documents the positive impact of corporate governance on firm innovation, relatively less is known about the channel through which it operates. This paper aims to provide a micro-foundation to shed light on the mechanisms that underlie these empirical facts. Moreover, the existing literature mostly focuses on the quantity rather than the quality of innovation, as discussed earlier. We use scale-independent measures, and focus on highly cited disruptive innovations instead, as these are more likely to represent new ideas that result in significant knowledge spillovers and fuel economic growth.[6]

This paper is also related to a large strand of literature studying how institutional investors affect the executive compensation structure. Smith (1996) and Gillan and Starks (2000) report that public fund managers often voice the opinion that managerial compensation should be linked to corporate performance. Hartzell and Starks (2003) and Chidambaran and John (2008) document that institutional ownership is positively related to the pay-for-performance sensitivity of executive compensation. Consistent with the existing literature, we also find that firms with higher institutional ownership tend to adopt compensation contracts with high pay-for-performance sensitivity, owing to a high fraction of stock options. We structurally quantify the impact of agency frictions on managerial compensation. We also move one step further to study the impact of executive compensation on firm innovation, productivity growth, and social welfare in a novel dynamic general equilibrium framework with endogenous productivity growth.

The paper is organized as follows. In Section 2, we develop a general equilibrium framework with endogenous growth and managerial compensation contracts to study the joint dynamics of corporate governance, managerial compensation, and

[4] See Aghion and Howitt (2009) and Acemoglu (2009) for literature surveys.

[5] In an extended model with a direct effect of institutional ownership on innovation (i.e., through mechanisms other than managerial compensation), the estimate of the parameter that governs the strength of this mechanism is revealed to be very low, consistent with the empirical evidence as shown in Section 3.

[6] The results are robust to considering scale-dependent innovation quantity measures. See Section B.4.

firm innovation. In Section 3, we summarize stylized facts on the relationships among institutional ownership, executive compensation contracts, and disruptive innovation. In Section 4, we estimate the model and document its implications for US firms by carrying out a series of counterfactual experiments. In Section 5, we extend the analysis by incorporating short-term earnings pressure on the CEO. Concluding remarks are offered in Section 6.

2. Model

In this section, we develop a new dynamic general equilibrium model with firm-level innovation, and endogenously determined managerial compensation contracts which can be distorted by agency frictions. Time is discrete and denoted by $t \in \{0, 1, 2, \ldots\}$. There are three types of agents: the representative household, the firms, and their CEOs. The representative household supplies labor in exchange for wages, and owns all the assets in the economy. There is a continuum of firms with measure one, and each firm has a CEO. At time $t = 0$, the contract between the firm and the CEO are determined endogenously. Given the contract, the CEO chooses the production inputs and the innovation probability of the firm he is managing. If corporate governance is not perfect, the CEO can influence the determination of the structure of his own compensation and distort the contract he is offered away from the contract that would be optimal for the shareholders. Consequently, the firm can end up *under-* or *over-investing* in innovation as a result of the agency frictions.[7]

2.1. Representative household's problem

The representative household is infinitely lived. It supplies labor $L = 1$ inelastically and receives the wage rate w_t. It can freely borrow and save at the real interest rate r_t. There are no aggregate fluctuations in the model, so the representative household's problem is deterministic. The decision problem is stated as:

$$\max_{\vec{C},\vec{A}} \left\{ \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\omega}}{1-\omega} \right\}, \text{such that} \tag{1}$$

$$C_t + A_{t+1} \leq (1 + r_t)A_t + w_t, \forall t \in \mathbb{N} \tag{2}$$

with $\vec{C} = \{C_t\}_{t=0}^{\infty}$ and $\vec{A} = \{A_t\}_{t=1}^{\infty}$, given A_0. The Euler equation of this standard problem is

$$C_t^{-\omega} = \beta(1 + r_{t+1})C_{t+1}^{-\omega} \tag{3}$$

2.2. Static profit maximization

There is a continuum of firms with measure one. A firm can produce the final good in the economy under perfect competition according to the production function

$$y_t = z_t^{\zeta} k_t^{\kappa} l_t^{\lambda} \tag{4}$$

where z_t is the firm-specific productivity, l_t is the labor input, and k_t is the capital input. We impose $\zeta \in (0, 1)$, $\kappa \in (0, 1)$, $\lambda \in (0, 1)$, and $\zeta + \kappa + \lambda = 1$. Since $\kappa + \lambda < 1$, there are decreasing returns to scale, and therefore the firm has positive profits that are increasing in productivity z_t which is shown below. The static profit maximization of the firm can be written as:

$$\max_{k_t, l_t \geq 0} \left\{ z_t^{\zeta} k_t^{\kappa} l_t^{\lambda} - (r_t + \delta)k_t - w_t l_t \right\} \tag{5}$$

Define the average productivity of all firms at time t as $\bar{z}_t$. In the Appendix, it is shown that the static profits of a firm along a balanced growth path are given by

$$\Pi(z_t, \bar{z}_t) = \pi \frac{z_t}{\bar{z}_t^{\lambda/(\lambda+\zeta)}} \tag{6}$$

where π is a time-invariant constant. For now, denote the static profits as $\Pi(z, \Theta)$ where Θ denotes all the relevant state variables for the aggregate economy.

[7] The model imposes no priors on whether the agency frictions are large, small, or even absent. We let the data tell us how much the contracts are distorted, and in which direction through our structural estimation. For any set of parameters, there exists a threshold CEO disutility parameter $\bar{\nu}$ above which the CEO wants to over-invest, and below, under-invest.

2.3. Dynamic profit maximization without agency frictions

First, we state a firm's dynamic profit maximization problem where it can choose its own innovation rate. In the next subsection which introduces agency frictions, the firm's CEO will take on this decision, and maximize his own utility subject to his contract instead of the value of the firm.

The firm can increase its productivity z_t over time through innovation. Innovation is stochastic. If the firm is successful in innovation, its new productivity becomes $z_{t+1} = z_t + \gamma \bar{z}_t$, where $\gamma > 0$ is a scale parameter. If the firm fails to innovate, its productivity remains as is ($z_{t+1} = z_t$), but its relative productivity falls due to growth in average productivity $\bar{z}_t$ along the balanced growth path. Let $i \in [0, 1]$ denote the probability of succeeding in innovation. To generate a probability i of successful innovation, the firm must incur R&D costs given by

$$C(i, \bar{z}) = \hat{C}(i) \frac{\bar{z}}{\bar{z}^{\lambda/(\lambda+\zeta)}} \tag{7}$$

where $\hat{C}(i) = -\chi(\ln(1 - i) + i)$.[8] The parameter $\chi > 0$ is the scale parameter that governs how efficient the firm is in coming up with new innovations, with a lower value of χ indicating a more innovative firm. Given these components, the dynamic profit maximization of the firm (without any agency frictions) can be written as follows:

$$V_{\text{nf}}(z, \Theta) = \max_{i \in [0,1]} \left\{ \Pi(z, \Theta) - C(i, \bar{z}) + \frac{i}{1+r} V_{\text{nf}}(z + \gamma \bar{z}, \Theta') + \frac{1-i}{1+r} V_{\text{nf}}(z, \Theta') \right\} \tag{8}$$

The subscript "nf" stands for "no (agency) frictions." The first expression denotes the static profit of the firm that depends on the firm's own productivity z, and the aggregate state of the economy Θ. The second term denotes the R&D costs the firm incurs so that it can successfully innovate to improve its productivity in the next period by $\gamma \bar{z}$. The third term denotes the continuation value of the firm conditional on a successful innovation, discounted by the real interest rate. The final term is the continuation value of the firm conditional on a failed innovation attempt.

Theorem 1. *Along a balanced growth path equilibrium, the value function of the firm without agency frictions takes the form:*

$$V_{nf}(z, \bar{z}) = v_1^{nf} \hat{z} + v_2^{nf} \tilde{z} \tag{9}$$

where $\hat{z} \equiv \frac{z}{\bar{z}^{\lambda/(\lambda+\zeta)}}$, *and* $\tilde{z} \equiv \frac{\bar{z}}{\bar{z}^{\lambda/(\lambda+\zeta)}}$, *whereas* v_1^{nf} *and* v_2^{nf} *are time-invariant constants.*

Proof of Theorem 1. This is shown as a part of the proof of Theorem 2 in Appendix A. □

Corollary 1. *The optimal innovation policy i in the dynamic profit maximization problem of the firm without agency frictions must satisfy*

$$\frac{\partial C(i, \bar{z})}{\partial i} = \frac{1}{1+r} \left[v_1^{nf} \gamma \tilde{z} \right] \Leftrightarrow \frac{\partial \hat{C}(i)}{\partial i} = \frac{v_1^{nf} \gamma}{1+r}. \tag{10}$$

This equation pins down the shareholder-optimal innovation rate i that maximizes firm value. Note that it does not depend on the firm's productivity z, the aggregate productivity $\bar{z}$, or time.

2.4. Preferences and compensation structure of the CEO

Next, we introduce agency frictions to the setting. Each firm in the model has a CEO who chooses the level of production inputs k and l, as well as the probability of successful innovation i. A CEO has standard time-separable constant relative risk aversion (CRRA) preferences over consumption, and receives disutility from exerting effort to oversee the firm's innovation efforts.[9] The preferences are represented by:

$$U(\vec{c}, \vec{i}) = \mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\omega}}{1-\omega} - \nu(i_t) \tilde{z}_t^{1-\omega} \right) \right] \tag{11}$$

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[8] Any function that is increasing and convex with $\hat{C}(0) = 0$ and $\lim_{i \to 1} \hat{C}(i) = \infty$ would serve the same purpose. The first derivative of this function is $\chi \frac{i}{1-i}$.

[9] Note that we do *not* require the CEO to desire less innovation than the shareholders. This will be determined through the estimation of the R&D cost parameter of the firm, χ, and the innovation disutility parameter of the CEO, ν. In practice, a CEO can desire a higher i than the shareholders due to empire building or prestige concerns (see Jensen and Meckling (1976) and Jensen (1986) among others). These would imply a lower value for ν in estimation.

with $\vec{c} = \{c_t\}_{t=0}^{\infty}$, $\vec{i} = \{i_t\}_{t=0}^{\infty}$, $\beta \in (0,1)$, and $\omega \neq 1$ is the CRRA parameter.[10] The term $v(i)$ captures the disutility from overseeing innovation[11] and is given by:

$$v(i) = -\nu(\ln(1-i) + i) \tag{12}$$

where ν is the scale parameter which determines the efficiency of the CEO in overseeing innovation, with a lower value of ν indicating a more innovative CEO.[12]

CEO compensation consists of two components: salary, which is not state-contingent, and stock options, which have a state-contingent payoff.[13] Define the strike price of the firm at time t, as in Glover and Levine (2015):

$$S(z_t, \Theta_t) = V(z_t, \Theta_t) - [\Pi(z_t, \Theta_t) - C(i_t, \bar{z}_t)] \tag{13}$$

where $V(z, \Theta)$ denotes the value function of the firm with agency frictions.[14] CEO compensation in period t is written as[15]:

$$c_t = s_t \tilde{z}_t + o_t \max\{0, V(z_t, \Theta_t) - (1 + r_t) S(z_{t-1}, \Theta_{t-1})\} \tag{14}$$

In this equation, s_t denotes the salary (normalized by output) received by the CEO, whereas o_t denotes the share options granted to the CEO as a fraction of the total shares of the firm. The second term has a positive value if the value of the firm in the next period exceeds the strike price this period, and is zero otherwise.[16] Therefore, the option part of CEO compensation is convex in the future value of the firm.

We should highlight that this compensation structure is much more general than it first appears. Consider an arbitrary Markov Perfect compensation scheme that delivers $(c_d, c_u) \in \mathbb{R}_+^2$ where the CEO is paid c_d contingent on a failed innovation $\mathbb{I} = 0$, and c_u contingent on a successful innovation $\mathbb{I} = 1$. Then, (s, o) with $s = c_d$ and $o = (c_u - c_d)\frac{G_\zeta}{\gamma(1-i)}$ exactly implements (c_d, c_u) as shown in Theorem 2. In other words, directly targeting innovation in CEO pay is already within the contract space our formulation spans.[17]

2.5. CEO's decision problem

Given a compensation structure, the CEO of the firm chooses the level of production inputs k and l, as well as the probability of successful innovation i. The CEO's contract is time-invariant, that is $s_t = s$, $\forall t$ and $o_t = o$, $\forall t$.[18] Note that choosing the optimal levels of capital k and labor l is costless for the CEO. Therefore, he will choose the optimal levels in the static profit maximization problem. That only leaves the decision for the innovation rate i. Theorem 2 establishes intuitive closed-form results for the CEO's innovation policy $\hat{i}(s, o)$ and the associated balanced growth path equilibrium.

Theorem 2. *Given a contract (s, o) for the CEOs, the following are true for a balanced growth path equilibrium[19] where the average productivity level $\bar{z}$ grows at the constant rate g_z:*

[10] The multiplicative term $\tilde{z}_t^{1-\omega}$ is included to make sure that the disutility from the innovation effort does not shrink over time along the balanced growth path. This can be thought of as the value of time spent on leisure increasing in tandem with aggregate productivity.

[11] This term captures the effects of mechanisms that might affect the innovation chosen by the CEO such as the "quiet life hypothesis" in Bertrand and Mullainathan (2003) and Ikeda et al. (2018), future career concerns studied in Holmstrom and Costa (1986) and Holmstrom (1999), and empire building or prestige concerns as in Jensen and Meckling (1976) and Jensen (1986). The model is flexible enough to generate both over- and under-investment.

[12] Any function that is increasing and convex with $v(0) = 0$ and $\lim_{i \to 1} v(i) = \infty$ would serve the same purpose.

[13] Our focus on salary and options is motivated by the empirical evidence in Section 3. We find that it is primarily the stock options that are highly positively correlated with innovation. Salary, on the other hand, is negatively correlated. An alternative model with state-contingent salary would therefore be rejected by the data, while state-incontingent salary is consistent with empirical observation. Additionally, our contract structure is much more general than it appears, and can implement any arbitrary Markov Perfect compensation scheme as discussed below.

[14] See Appendix A.13 for the detailed derivation of the option exercise value.

[15] Note that we do not model manager savings in the baseline model. However, the extended model with manager savings does not lead to significant differences. This is because we have infinitely-lived agents and focus on the stationary equilibrium. Along a BGP, the savings of all managers start near their long-run wealth target, and there is only a small amount of ergodic movement around the target (failure to innovate marginally increases innovation effort due to the income effect, and vice versa). We opt for a simpler setting in the baseline model which helps maintain tractability.

[16] The $(1 + r_t)$ term that appears in this equation is the relative price of period $t - 1$ final good in terms of period t final good.

[17] We thank our anonymous referee for bringing this alternative compensation scheme to our attention.

[18] Time-invariance of the contract is an equilibrium outcome without the ability to credibly commit to future actions given renegotiation. Time-varying contracts would require exogenous restrictions on the action set to maintain sequential rationality, or strong labor market frictions must exist such that self-enforcing contracts are feasible. Time-varying contracts would also violate the balanced growth path property, which is necessary given our focus on aggregate productivity growth. Such commitment problems are more suited to be studied in a microeconomic setting with partial equilibrium, and remain outside our focus. In Section 4.7, we show that ignoring the general equilibrium effects would nearly double the estimated impact on innovation, growth, and welfare, highlighting the importance of using a general equilibrium framework to quantify the impact of agency frictions.

[19] A balanced growth path equilibrium and an associated stationary (relative) firm size distribution exist despite growth rate heterogeneity. This is due to the additive spillover term in the law of motion for productivity, which ensures that the firms that innovate at a higher rate do not completely break away from the less innovative firms. More innovative firms are larger on average, but the laggard firms grow faster conditional on success, whereas the leader firms grow slower conditional on success, and this keeps all firms together. For the details of the proof, see Akcigit et al. (2016).

1. *Static profits of a firm with productivity z are given by* $\Pi(z,\bar{z}) = \pi\hat{z}$ *where* π *is a time-invariant constant.*
2. *The CEO's optimal innovation decision* $\hat{i}(s,o)$ *is a time-invariant constant and solves the equation:*

$$v'(i) = \beta G_\zeta^{1-\omega}\left[\frac{\left(s+\frac{o\gamma v_1}{G_\zeta}(1-i)\right)^{1-\omega}}{1-\omega} - \frac{s^{1-\omega}}{1-\omega} - \frac{io\gamma v_1}{G_\zeta}\left(s+\frac{o\gamma v_1}{G_\zeta}(1-i)\right)^{-\omega}\right] \tag{15}$$

   It does not depend on the firm's productivity z or the average productivity level $\bar{z}$.
3. *For a given time-invariant innovation decision i, the value function of the firm takes the form*

$$V(i,z,\bar{z}) = v_1\hat{z} + v_2(i)\tilde{z} \tag{16}$$

   where v_1 *is a time-invariant constant, and* $v_2(i)$ *is a function of i.*
4. *The growth rate of the average productivity level is* $g_z = \gamma\hat{i}(s,o)$.
5. *The aggregate variables output* Y_t, *household consumption* C_t, *capital stock* K_t, *aggregate R&D spending* X_t, *aggregate manager consumption* $C_{m,t}$ *and the real wage rate* w_t *grow at the constant gross rate* $G_\zeta = (1+g_z)^{\lambda/(\lambda+\zeta)}$. *The real interest rate r is time-invariant.*

2.6. Determination of CEO compensation

Ideally, the CEO's compensation would be directly chosen by the shareholders. In reality, CEOs have some influence over the determination of their compensation; hence, they can distort the compensation structure to suit their own preferences as opposed to those of the shareholders.[20] To model this in a simple way, the objective function used in the determination of CEO compensation will put some weight on both the utility of the CEO and the utility of the shareholders.[21] In Section A.10 of the Theory Appendix we microfound the inverse relationship between institutional ownership and CEO influence in detail.[22] Let $\eta \in (0,1)$ denote the weight of the CEO's preferences, and $1-\eta$ denote that of the shareholders. The compensation determination problem is written as:

$$\max_{s\geq 0, o\in[0,1]} \left\{\eta\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega}\right)\right] + (1-\eta)\mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right]\right\} \tag{17}$$

$$c_t = s\tilde{z}_t + o\max\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\}, \forall t \tag{18}$$

$$i_t = \hat{i}(s,o), \forall t \tag{19}$$

$$\underline{\mathrm{U}} = \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right] \tag{20}$$

The first term in the objective function represents the CEO's influence in the determination of his compensation structure between salary s and stock options o, which is increasing in η. The second term in the objective function represents the shareholders' influence, where their preferences are simply the expected value of the firm at time $t=0$ minus the present discounted value of the expected payments to the CEO. The first set of constraints is the CEO compensation at different periods. The second set of constraints recognizes what level of innovation i_t the CEO will choose given his compensation structure (incentive compatibility). The last constraint requires the present discounted value of the expected payments to the CEO to be equal to $\underline{\mathrm{U}}$.[23]

Theorem 3 establishes that the problem can be further simplified, where all terms and constraints admit closed-form solutions, and the only relevant choice is the amount of stock options o which lies in a compact domain.

Theorem 3. *The compensation determination problem can be rewritten as follows:*

$$\max_{o\in[0,1]} \left\{\frac{\eta\tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{i}(s,o)}{1-\omega}\left(s+\frac{o\gamma v_1(1-\hat{i}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{i}(s,o))\right]\right.$$

[20] See Bebchuk and Fried (2003) for an overview.

[21] This objective function can be thought of as the board's objective function. Higher CEO influence manifests as the board favoring the CEO. This is in the same spirit as Page (2018).

[22] The model in Section A.10 describes an endogenous economic mechanism where the size distribution of shareholders affects the composition of the board, and thereby board independence and CEO influence. This creates an endogenous link between institutional ownership and CEO influence.

[23] We consider three alternative specifications for the compensation determination problem and their differences in Section 2.9.

$$\left. +(1-\eta)v_2(\hat{i}(s,o))\tilde{z}_0 \right\}, \textit{such that} \tag{21}$$

$$\underline{U} = \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o)(1-\hat{i}(s,o))\right]\tilde{z}_0 \tag{22}$$

Solving this problem allows the computation of a balanced growth path equilibrium of the economy given parameter values. In Online Appendix A.11, we provide some comparative statics results showing how the innovation decisions of the firms, the compensation structure, output growth rate, and social welfare react to changes in the parameter values.

2.7. Introducing firm and CEO type heterogeneity

In the model described thus far, the only difference across firms is firm-specific productivity z. The value of z only influences static profit maximization (the choice of k and l), whereas it has no influence on the dynamic decisions (the choice of i by the CEO, or the choice of s and o by the board at time $t = 0$). The CEOs are completely homogeneous. We will now generalize the model to allow for firm and CEO type heterogeneity.

Let there be a finite number of firm types indexed by $m \in \{1, 2, ..., M\}$ and a finite number of CEO types indexed by $n \in \{1, 2, ..., N\}$. For simplicity, we can define firm-CEO pair types indexed by $j = \{1, 2, ..., J\}$ where $J = M \times N$. From this point on, we refer to a firm-CEO pair type as a firm type for brevity. The firms are allowed to differ from each other in the cost of R&D χ_j, productivity gain from successful innovation γ_j, and CEO influence[24] parameter η_j. The CEOs are allowed to differ from each other in disutility from innovation ν_j, and expected present discounted value of future compensation $\underline{U}_j$. Hence, each firm type j can be summarized by a five dimensional vector $(\chi_j, \gamma_j, \eta_j, \nu_j, \underline{U}_j)$.[25]

Despite the richer environment, solving for the balanced growth path equilibrium of the economy remains the same except for a few changes which are discussed in detail in Section A.2 of the Appendix. In essence, introducing firm and CEO type heterogeneity is a matter of solving J similar problems side by side. The interaction between the firm types comes through the general equilibrium effects on the real wage rate w, the productivity distribution $Z(z)$, and the growth rate of its mean, g_z. Let $\mu_j \in [0, 1]$ denote the fraction of firms of type j in the economy, such that $\sum_{j=1}^{J} \mu_j = 1$. The average productivity level for all the firms in the economy is the weighted sum of average productivity levels for particular firm types, that is, $\bar{z}_t = \sum_{j=1}^{J} \mu_j \bar{z}_t^j$. Consequently, the growth rate of the average productivity level $\bar{z}$ along a balanced growth path equilibrium is given by:

$$g_z = \sum_{j=1}^{J} \mu_j \gamma_j i_j \tag{23}$$

2.8. Competitive equilibrium and the social planner's solution without agency frictions

To assess the impact of the agency frictions that arise as a result of CEO influence over the board's decision, one can compute the competitive equilibrium allocation where the firms can choose the quantities that are optimal for the shareholders. However, even the economy with no agency frictions does not attain the first-best, since the firms do not internalize the positive spillovers of their own innovation to the rest of the economy, which happens through their positive effect on the average productivity level $\bar{z}$. To compute the first-best allocation, one needs to solve the social planner's problem where the effects of innovation are internalized. The balanced growth path equilibria for the competitive equilibrium with no agency frictions, and the social planner's problem and solution are presented and calculated in Section A.3 of the Theory Appendix.

2.9. Alternative specifications for determination of the CEO's contract

Section 2.6 introduced the compensation determination problem where the board assigned the weight η to the CEO's utility, and $(1-\eta)$ to that of the firm's shareholders. Beyond the standard incentive compatibility constraint, the board was required to provide a certain present discounted value of future compensation to the CEO. It is important to consider whether alternative specifications of this particular section of the model can influence the qualitative and quantitative implications one can derive.

We consider three alternative specifications for the compensation determination problem, which can be found in the Theory Appendix. Section A.4 drops the present discounted value of CEO compensation constraint. In this flexible compensation specification, the board can choose both the composition and the level of the CEO's compensation (as opposed to only the composition in the baseline model). Section A.5 replaces the same constraint by another one which promises the CEO a certain level of utility instead. Consequently, the CEO's influence parameter η loses its meaning, and the board's problem is

[24] Hence we introduce heterogeneity in corporate governance quality, which is inversely related to CEO influence.

[25] Note that we could also introduce heterogeneity in CEO time discount factor β or CRRA parameter ω if needed following the same idea.

reduced to a standard principal-agent problem where the principal's utility is equal to that of the shareholders.[26] Section A.6 takes another approach and considers the problem where the CEO and the shareholders are both risk-neutral agents. In this setting, it is possible to get simpler closed-form solutions, and the present discounted value of future compensation becomes equivalent to the individual rationality constraint of a principal-agent problem.

3. Motivating evidence

In this section, we summarize the empirical evidence which motivates our model and disciplines the structural estimation. In particular, we are interested in the relationship between institutional ownership, managerial compensation structure, and innovation. This information is used to discipline the same elasticities in our model through indirect inference. For brevity, the details of the empirical analysis are relegated to Online Appendix B.

We combine information from USPTO Utility Patents Grant Data, Compustat North American Fundamentals, Execucomp, and Thomson-Reuters Institutional Holdings database to construct our sample. The three main measures of innovation we use are average patent citations (corrected for truncation and technology class bias as in Hall et al. (2001)), tail innovations (Acemoglu et al. (2022)), and average originality (Hall et al. (2001)). The three measures of CEO compensation are option/income ratio, share/income ratio, and the sum of the two, called deferred ratio. We use the fraction of shares held by institutional owners to capture the positive effect of institutional ownership on corporate governance through the reduction of CEO influence. We establish the following stylized facts:

1. Higher institutional ownership is positively associated with disruptive innovations (Table B1).
2. Higher institutional ownership is positively associated with more incentivized CEO contracts, which contain more stock options and restricted stock grants relative to the total compensation (Table B.2).
3. More incentivized CEO contracts are associated with more disruptive innovations (Table B3, Columns 1, 4, and 7).
4. The positive association between institutional ownership and disruptive innovations appears to be realized largely through the mechanism of more incentivized CEO contracts, and especially option/income ratio (Table B3, Columns 2-3, 5-6, and 8-9).
5. The positive effect of institutional ownership on more incentivized contracts and disruptive innovations remains significant even when using instrumental variables proposed by Aghion et al. (2013) and Hartzell and Starks (2003), lending credence to the hypothesis that the effect might be causal. (Table B4).

The rest of Online Appendix B discusses various robustness checks, such as dividing the sample into high-tech versus low-tech industries, excluding pharmaceuticals, using different fixed effects, excluding non-patenting firms or years with no patents, adding more control variables, using alternative innovation variables, and controlling for option vesting and distance-to-default.

4. Quantitative analysis

4.1. Estimation

The computation of the equilibrium requires assigning values to the parameters, and choosing the number of distinct firm types. In our baseline estimation, we introduce firm heterogeneity in terms of the CEO influence parameter η – that is, the firms in the model differ from each other in terms of firm-specific productivity z, and the quality of corporate governance which is inversely related to CEO influence. This is accomplished by assuming a discrete uniform distribution over η, with the upper bound η_{ub} and the lower bound $\eta_{lb} \approx 0$.[27] Under this specification, eleven parameter values must be determined: $\omega, \beta, \zeta, \kappa, \lambda, \delta, \gamma, \nu, \chi, \eta_{ub}$, and $\underline{U}$. Some common parameters are chosen from existing studies, whereas the rest are structurally estimated following a simulated method of moments approach as in Erickson and Whited (2002). We discuss the sources of the externally estimated parameters below:

1. *CRRA parameter:* The constant relative risk aversion parameter is taken to be $\omega = 2.00$, consistent with the estimates listed in Kaplow (2005).
2. *Discount factor:* We pick the discount factor to be $\beta = 0.9815$, a standard value for annual real business cycle models.
3. *Factor shares in production:* Corrado et al. (2009) calculate the shares of tangible capital, labor, and intangible capital to be $\kappa = 0.25$, $\lambda = 0.60$, and $\zeta = 0.15$ respectively. The share of intangible capital calculated is mapped to a firm's share of productivity in generating output in the model. Alternatively, the markup over average cost in the economy, $\zeta/(1-\zeta)$, is consistent with the values used in Midrigan and Xu (2014) and well within the range of other values commonly used in the literature.

[26] In this alternative model, the CEO influence η is absent from the problem. This is because fixing the CEO's utility to $\underline{U}$ removes any possibility of negotiating a compensation structure that favors the CEO. Consequently, the board always chooses a contract that implements the shareholder-optimal contract, and the agency friction is assumed away. This is the reason why we opt for our baseline framework.

[27] Adding η_{lb} to the set of internally estimated parameters also results in $\eta_{lb} \approx 0$ being picked by the estimation routine.

Table 1
Baseline model parameters and target moments.

A. Parameter estimates

Parameter	*Value (stde)*	*Description*	*Identification*
		External Estimation	
δ	0.069	capital depreciation rate	US NIPA
ς	0.150	productivity share in production	Corrado et al. (2009)
κ	0.250	capital share in production	Corrado et al. (2009)
λ	0.600	labor share in production	Corrado et al. (2009)
ω	2.00	CRRA parameter	Kaplow (2005)
β	0.982	discount factor	risk-free rate
		Internal Estimation	
γ	0.398 (0.0114)	innovation productivity increase	output growth rate
ν	203.55 (0.7156)	CEO disutility	$\beta(innovation, option\,ratio)$
χ	0.800 (0.0289)	R&D cost scale parameter	R&D intensity
η_{ub}	0.0013 (0.0001)	upper bound of CEO influence	$\beta(innovation, inst\,own)$, $\beta(option\,ratio, inst\,own)$
$\underline{U}$	0.338 (0.0119)	PDV of CEO compensation	mean option ratio, CEO pay/market cap

B. Moments

Target Moments	Data	Model
$\beta(innovation, inst\,own)$	0.048	0.037
$\beta(innovation, option\,ratio)$	0.025	0.038
$\beta(option\,ratio, inst\,own)$	0.029	0.033
R&D intensity	2.91%	2.77%
CEO pay/market cap	0.31%	0.32%
Output growth rate	2.00%	2.00%
Mean option ratio	36.16%	36.10%

Notes: The estimation is done with the simulated method of moments, which chooses model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A reports the estimated parameters. Panel B reports the simulated and actual moments. All correlations are standardized correlation coefficients (betas), i.e. the variables are standardized by subtracting their mean and dividing by their standard deviation, both in the model and the data. See Section 4.1 for details.

4. *Depreciation rate for capital:* The annual depreciation rate of physical capital is chosen as 6.9%, which is consistent with the US National Income and Product Accounts.

4.2. Targeted moments and identification

Five parameters remain to be determined: the productivity increase parameter conditional on successful innovation γ, the CEO disutility parameter ν, the R&D cost parameter χ, the upper bound of the distribution of CEO influence across firm types η_{ub}, and the present discounted value of managerial compensation, $\underline{U}$. All these parameters are jointly estimated to match the following targeted data moments:

1. *Long-run output growth:* Since 1945, the aggregate output in the US has grown at about 2% per year. The parameter γ determines the increase in productivity a successful innovation generates and, hence, it plays the foremost role in determining the output growth rate in the model.
2. *R&D intensity:* To discipline the R&D spending in the model, we target the ratio of R&D expenditures to GDP in the US. Akcigit et al. (2021b) report this number to be 2.91%. This target plays the largest role in pinning down the R&D cost parameter χ in the model.
3. *Mean option ratio and CEO compensation over market capitalization:* In the model, the parameter $\underline{U}$ determines the expected total CEO compensation under the optimal contract. We discipline this parameter by targeting two moments. The first target is the mean option ratio, which is calculated by dividing the value of option compensation by total compensation for each CEO. This number is 36.16% in our sample. The second moment is the average ratio of CEO compensation to the market capitalization of the firm. In our data, this ratio is calculated to be 0.31%.
4. *Correlation between innovation and option ratio:* The disutility parameter of the CEO ν largely determines the response of a CEO's innovation decision to the option to income ratio implied by his contract. To discipline this elasticity, we require the correlation[28] between the innovation outcome and option/income ratio in the model to match the correlation between tail innovations and option/income ratio in the data, which has the value 0.025.[29] In this regression, as well

[28] All correlations are standardized correlation coefficients (betas); that is, the variables are standardized by subtracting their mean and dividing by their standard deviation, in both the model and the data. Furthermore, the correlations from the data are calculated after the effects of all control variables are removed, as in Section 3, to make the quantities comparable.

[29] This choice maps a successful innovation realization in the model to highly cited patents in the data (top 10%), whereas an unsuccessful innovation realization is linked to low-quality patents that receive few citations. Note that the R&D expenditure is a deterministic input, whereas the innovation realization is a stochastic output. In both the model and the data, we focus on the latter. Using average citations, originality, or patent value metrics

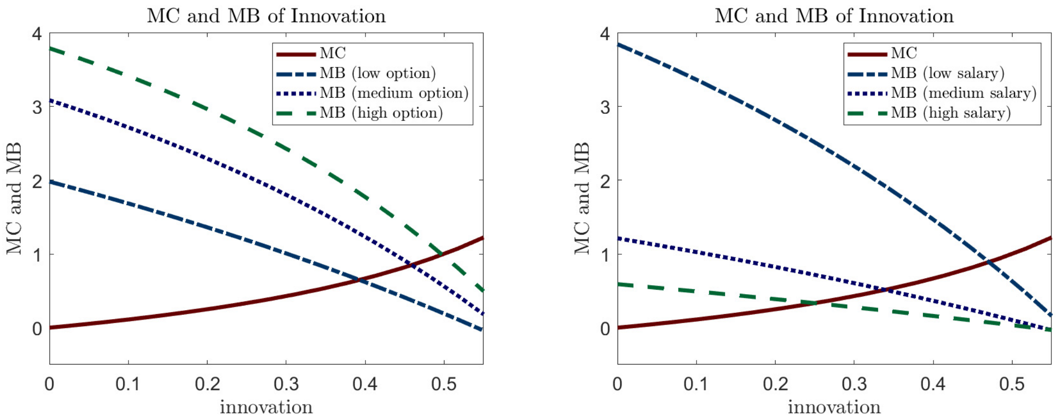

Fig. 1. Marginal cost and benefit of innovation for the CEO. Notes: This figure displays the marginal cost and marginal benefit of innovation for the CEO under different option and salary values.

as the ones discussed below, we use the same controls as in the empirical section. Doing so helps purge out the effects of factors left out of the model, as in Li et al. (2018).

5. *Correlation of institutional ownership with innovation and option/income ratio:* In the model, CEO influence η, which is inversely related to corporate governance quality, directly affects the option to income ratio in the optimal contract, and indirectly influences the innovation rate chosen by the CEO. In our empirical analysis, we focus on institutional ownership as our prime measure of corporate governance. To estimate the upper bound of CEO influence η_{ub}, we target the correlation of institutional ownership with the innovation outcome and the option/income ratio, where we impose the model counterpart of institutional ownership to simply be $1 - \eta$.[30] The values of the two correlations in the data are 0.048 for innovation, and 0.029 for option/income ratio.

The detailed estimation procedure is illustrated in Section A.14. Panel A of Table 1 reports the values of the parameters and the associated standard errors in the case of internally estimated parameters, whereas Panel B provides an overview of the values of the targeted moments in the data and the estimated model. The model tightly matches the seven data moments. While the estimation routine only targets pairwise correlations between successful innovation, institutional ownership, and option ratio, the model does a good job in matching the overall nonlinear relationship between the three variables, as shown in Fig. 3 in Section 4.5. The Jacobian matrix of the model moments with respect to the model parameters in percentage terms is displayed in Table C4.

4.3. Marginal cost and marginal benefit of the CEO's innovation decision

To better visualize the trade-offs the CEO faces in choosing the innovation probability under different contracts (s, o), as shown in equation (15), we plot the marginal cost and marginal benefit of innovation for the CEO in Fig. 1. The marginal cost of the CEO is the disutility from innovation, and depends solely on the disutility parameter ν of the CEO. The left panel depicts the marginal benefit curve under three different levels of stock options: low, medium, and high. Holding salary constant, an increase in stock options in the contract shifts the marginal benefit curve up, inducing the CEO to choose a higher rate of innovation in equilibrium. Similar to the previous exercise, the right panel depicts the marginal benefit curve under three different levels of state-noncontingent salary: low, medium, and high. Holding the stock options constant, increasing the level of the salary component results in an income effect. Since the CEO is now wealthier, an increase in the salary reduces the CEO's incentives to engage in disruptive innovation.

4.4. Board objective function and innovation decision rule

We plot the board objective function and the CEO's innovation policy function for firms with $\eta = \eta_{ub}/2$ in Fig. 2. The left panel depicts the board objective as a function of the stock options offered to the CEO. The right panel plots the CEO's innovation decision as a function of the stock options as well. The board objective function is maximized at the amount of stock options marked by the dashed line. Given the stock options (and the implied salary) chosen by the board, the manager chooses the innovation level that maximizes his own utility under the contract.

developed in Kogan et al. (2017) instead of tail innovations does not lead to significant changes in the targeted moments or the resultant parameter estimates.

[30] Note that the value of η has no cardinal interpretation in the model, since the preferences of the CEO and the shareholders are ordinal – for instance, multiplying the CEO's utility function by 2 would reduce the estimated value of η_{ub} to half of its value. Therefore, any inverse relationship is acceptable. We only care about η's influence on the observables, which the estimation correctly captures.

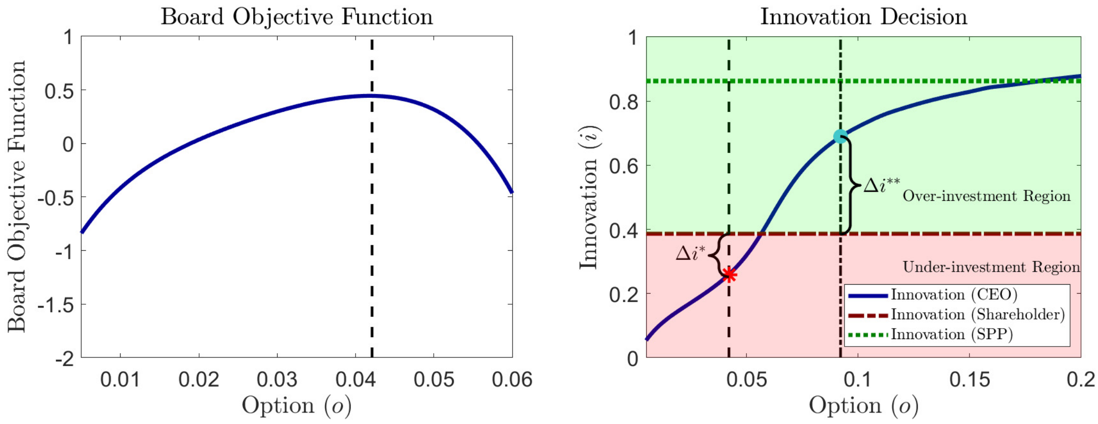

Fig. 2. Board objective function and innovation decision. Notes: This figure displays the board objective function and the CEO's innovation decision as a function of options o.

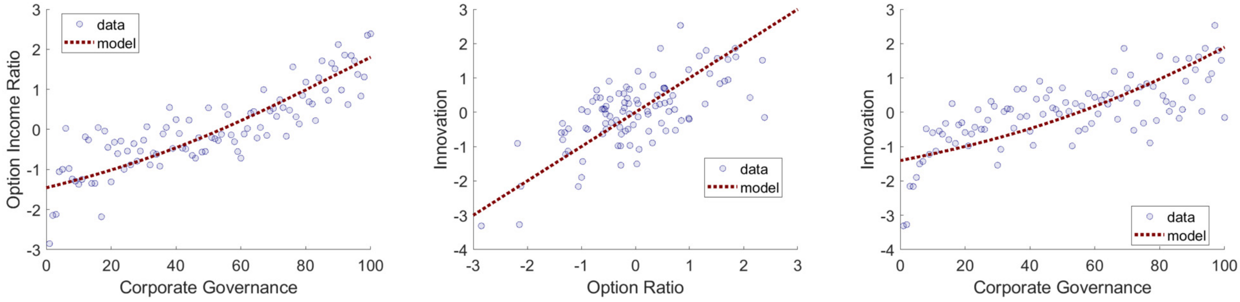

Fig. 3. Corporate governance, CEO compensation structure, and disruptive innovations. Notes: This figure displays the relationship between corporate governance, option/income ratio, and innovation in the model and the data.

In the right panel of Fig. 2, we plot the innovation level chosen by the CEO as a function of options o in the contract with the blue curve. In this particular example, the contract-implied innovation level (denoted by the red star) is lower than the shareholder-optimal innovation level, which is the one the firm would have chosen under the no agency frictions case (the dashed red line). Therefore, $\Delta i^* < 0$ captures the *under-investment* in innovation. Alternatively, one could also think of a scenario where the CEO chose to *over-invest* in innovation compared to the shareholder-optimal innovation level. The blue dot denotes such an example, where $\Delta i^{**} > 0$ captures the *over-investment* in innovation.

The green dashed line in the right panel depicts the optimal innovation that would be chosen by the social planner. Since the social planner also internalizes the positive externalities resulting from knowledge spillovers, the social planner's optimal innovation rate is much higher than that of the decentralized economy, which implies that there is room for policy intervention such as R&D subsidies. For details on the calculation of the social planner's allocation, see Section A.3 of the Theory Appendix.[31]

4.5. Key relationships: model vs. data

The left panel of Fig. 3 depicts the relationship between the option ratio and corporate governance in the model and data. To measure corporate governance in the data, we first divide firms into 100 quantiles based on their institutional ownership fraction. Then for each governance quantile, we calculate the average option ratio in the CEO compensation contract. We centralize the measure by demeaning it and then dividing it by its standard deviation. Each blue dot in the figure represents the value of the mean option ratio for a corporate governance index quantile. Similarly, the mean option ratio is calculated for different values of CEO influence parameters in the model and is plotted as the red dashed curve. In both the model and the data, we observe a positive correlation between firms' corporate governance and disruptive innovation. The model tightly matches the elasticity between corporate governance and the option ratio. In both the model and the data, contracts adopted by firms with better corporate governance tend to have a higher fraction of stock options.

The right panel of Fig. 3 depicts the relationship between innovation and corporate governance in both the model and the data. For firms in each governance quantile in the data, we calculate their average tail innovation. We centralize the measure

[31] Note that even a uniformly diversified shareholder would not internalize all of the spillovers to the rest of the economy since shareholders aim to maximize firm value (i.e., the profits) rather than aggregate output (which also includes labor and capital income).

Table 2
Counterfactual experiment I: the impact of reduced agency frictions.

	Baseline	Reduced CEO Influence (25%)	Reduced CEO Influence (50%)	Reduced CEO Influence (100%)
Output growth rate	2.00%	2.10%	2.21%	2.51%
R&D intensity	2.77%	3.07%	3.46%	4.70%
Mean option ratio	36.10%	39.69%	43.96%	54.13%
Mean innovation probability	26.21%	27.49%	29.06%	33.17%
Consumption/output	0.79	0.79	0.78	0.77
Welfare change	-	1.5%	3.3%	7.3%

Notes: This table displays the effects of reducing the CEO influence parameter η.

of innovation by demeaning it and then dividing it by its standard deviation. Each blue dot in the figure represents the value of the mean option ratio for a corporate governance index quantile. Similarly, the mean innovation ratio is calculated for different values of CEO influence parameters in the model and is plotted as the red dashed curve. In both the model and the data, we observe a positive correlation between firms' corporate governance and disruptive innovation. The model also tightly matches the elasticity between corporate governance and firm innovation. In both the model and the data, firms with better corporate governance tend to come up with more disruptive innovations.

4.6. Welfare analysis

To calculate welfare, we need to compute the consumption stream of the representative household. Two components are required for this: the growth rate of consumption $G_\zeta - 1$ and the initial consumption level C_0.[32] In a balanced growth path equilibrium, social welfare is given by

$$W = \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\omega}}{1-\omega} = \frac{C_0^{1-\omega}}{(1-\omega)(1-\beta G_\zeta^{1-\omega})} \tag{24}$$

Welfare comparisons between different economies are conducted by comparing the balanced growth path equilibria.[33] To make two different economies A and B comparable, both economies are started at the same average productivity level $\bar{z}_0^A = \bar{z}_0^B = 1$. Let $x > 0$ be the scalar such that multiplying the representative consumer's consumption in economy A by x results in a welfare number equivalent to the one in economy B. Simple algebra reveals that x is given by

$$x = (W^B/W^A)^{1/(1-\omega)} \tag{25}$$

where W^A and W^B denote the welfare in economies A and B respectively. The welfare gain or loss of a move from economy A to economy B provides in consumption-equivalent terms is given by $x - 1$. This welfare measure is used in all quantitative exercises.

4.7. The impact of reduced agency frictions

To quantify the economic significance of the agency frictions between the CEO and the shareholders, we undertake a counterfactual experiment where the impact of agency frictions is successively reduced. This is accomplished by reducing the CEO influence η by the same ratio in all firms in the economy. This is equivalent to increasing the quality of corporate governance in all firms.

The results of this counterfactual experiment are summarized in Table 2. Table 2 presents the impact of reduced agency frictions on the output growth rate, R&D intensity, mean option ratio, mean innovation probability, consumption/output ratio, and implied consumption-equivalent social welfare change. The first column reports the results from the baseline model. The second column reports the results of a counterfactual economy with the upper bound of CEO influence η_{ub} set to 75% of its baseline value, keeping the value of the other parameters the same as in the baseline model. The third column reports the results of the model with the upper bound of CEO influence η_{ub} set to 50% of its value. The last column shuts down frictions completely by setting $\eta = 0$ for all firms.

The reduction in CEO influence η results in CEO contracts that are richer in options being adopted by the boards of firms in the economy. The mean option ratio increases from its baseline value of 36.10% to 39.69% in column 2, 43.96% in column 3, and 54.13% in column 4. These highly incentivized contracts encourage the CEOs to increase the innovation

[32] See Section A.7 for the derivation of the initial consumption level C_0.

[33] Hence, this analysis ignores the welfare effects of the transition to the new steady state. However, the bias is downwards, not upwards: In experiments where the growth rate is increased, the steady-state capital stock is lower than the baseline economy. For instance, when we shut agency frictions down, the steady-state capital stock falls from 2.85 to 2.53. This means taking the transition into account would further magnify, not diminish, the positive effect on social welfare, since there would be further gains from consuming the excess capital stock.

success probability they pick, increasing the mean innovation probability in the economy from 26.21% to 27.49% in column 2, 29.06% in column 3, and 33.17% in the last column. As the CEOs choose higher rates of innovation, more resources are allocated to R&D, increasing the overall R&D intensity in the economy from 2.77% to 3.07% in column 2, 3.46% in column 3, and 4.70% in column 4. The increased spending on R&D reduces the fraction of the output consumed by the representative household, slightly reducing it from 79% to 78% in column 3, and 77% in column 4.

If there were no impact on the rate of economic growth, the drop in consumption would reduce welfare. However, increased innovation results in significant gains in economic growth. The output growth rate increases from its baseline value of 2.00% to 2.10% in column 2, 2.21% in column 3, and 2.51% when the frictions are completely shut down. The positive impact of increased economic growth dominates the negative impact of reduced consumption. The consumption equivalent welfare gain of the representative household is 1.5% in column 2, and 3.3% in column 3. Shutting down all agency frictions lets boards choose a contract that implements the shareholder optimal innovation rate, which results in a quite sizable welfare gain at 7.3%.[34]

We should highlight that whether one uses a partial equilibrium or general equilibrium model to assess the impact of agency frictions leads to significant differences. If we had used a partial equilibrium framework (i.e. ignored the general equilibrium impact on the real wage rate, the interest rate, and the knowledge spillovers between firms), the estimated impact of removing CEO influence would be much larger. In such an experiment, firms would ignore the effects of their peers on the knowledge spillovers and prices, and the mean innovation probability would be 39%, and the calculated welfare impact would be much larger at 13.7%. The general equilibrium framework dampens the reaction of the firms to the change. As the overall increase in innovation speeds up aggregate productivity growth, firms forecast that their competitors will also become more productive, and will compete more fiercely in the labor market, which drives up the wage. Any relative productivity advantage they obtain will revert back to the mean at a faster pace, reducing its contribution to firm value, and lowering the incentives to innovate. Coupled with the increase in the real interest rate that increases the cost of capital and firms' discount rate, taking the general equilibrium forces into account significantly reduces the welfare impact from 13.7% to 7.3%. This shows the importance of studying the agency conflict between managers and shareholders in a general equilibrium framework if one wishes to quantify its impact on firm innovation, aggregate productivity growth, and welfare.

Also note that the significant welfare results depend in part on our assumption that firm innovation is the only source of aggregate productivity growth. In Online Appendix A.12, we relax this assumption where 50% of the observed productivity growth is exogenous. Consequently, the welfare gain of shutting down agency frictions is further reduced to 3.5%.[35] Therefore, our baseline welfare numbers should be considered as an upper bound.

Our baseline results suggest that agency frictions between the managers and shareholders do not only reduce firm innovation, but also are quite significant for the long-run economic growth rate and social welfare. How can the negative effects be alleviated? First, we can think of understanding why some firms have better corporate governance. In Online Appendix A.10, we develop a microfoundation where better-informed investors can help reduce CEO influence. This is by no means the only potential explanation. Preliminary analysis suggests that different types of institutional owners are heterogeneous in their effectiveness in promoting innovation. Further investigations in this direction have the potential to elicit best practices to reduce CEO influence.

Second, given the importance of managerial compensation structure through which corporate governance affects firm innovation, it is possible to think of policies that change the optimal contract chosen in the presence of agency frictions. In practice, these policies can be more cost-efficient than trying to improve corporate governance. In the following subsections, we first investigate the effects of a policy that was issued in December 2004 and analyze its effects, and then consider preferential taxation of stock options.

4.8. The impact of FAS 123R

In December 2004, the Financial Accounting Standards Board (FASB) changed reporting requirements with the issuance of FAS 123R, making option compensation relatively less attractive.[36] Prior to this change in accounting standards, firms were not required to expense equity compensation to their employees in their financial statements. After issuance of FAS 123R, firms were required to expense stock options offered to their employees at their fair value, reducing the reported profitability of firms that relied heavily on equity compensation compared to those that did not. US public firms reacted to this change in accounting standards by substantially lowering the stock options they offer to their CEOs, from 35.86% of total compensation in 2003 to 31.06% in 2005, an overall reduction of 13.4% in the frame of two years.

How did issuance of FAS 123R affect long-run economic growth and social welfare? To answer this question, in the spirit of Glover and Levine (2017), we model the change in the accounting standards as an increase in the cost of paying a CEO in stock options. A wedge $\tau_o \in [0, 1]$ is introduced between what the company pays as option grants to the CEO, and what the CEO receives. The equations for the shareholders remain unchanged, whereas CEO compensation takes the form:

$$c_t = s_t \tilde{z}_t + (1 - \tau_o) o_t \max\{0, V(z_t, \Theta_t) - (1 + r_t) S(z_{t-1}, \Theta_{t-1})\} \tag{26}$$

[34] To put this number into context, this welfare gain is equivalent to subsidizing R&D by 49%.
[35] This time, the welfare gain is equivalent to subsidizing R&D by 37%.
[36] See Financial Accounting Standard Board FAS 123 (Revised 2004) (http://www.fasb.org/pdf/fas123r.pdf) for details.

Table 3
Counterfactual experiment II: the impact of FAS 123R.

	Before FAS 123R	After FAS 123R
Growth rate	2.00%	1.95%
R&D intensity	2.77%	2.63%
Mean option ratio	36.10%	31.05%
Mean innovation probability	26.21%	25.53%
Consumption/output	0.79	0.79
Welfare change (the difference is removed from the economy)	-	-0.84%
Welfare change (the difference is transmitted to the consumer)	-	-0.71%

Notes: This table displays the effects of the issuance of FAS 123R.

Section A.8 of the Theory Appendix details how the closed-form solutions change as a result of introducing this wedge. We can assume the resource difference that is generated by the wedge is removed from the economy or transmitted to the consumer. We calculate the welfare under both assumptions. To simulate the effect of the issuance of FAS 123R, we calculate the value of τ_o which reduces the mean option ratio in the economy by 13.4% of its value to mimic the change observed in the data. Other parameters remain unchanged.

Table 3 presents the impact of FAS 123R on the output growth rate, R&D intensity, mean option ratio, mean innovation probability, consumption/output ratio, and implied consumption-equivalent social welfare change through the lens of our model under the two assumptions. The first column reports the model moments in the baseline estimation. The second column reports the results from a simulated economy, where the wedge $\tau_o = 0.275$ causes a drop in the mean option ratio from 36.1% to 31.1%.

The output growth rate of the economy falls after the issuance of FAS 123R, dropping from 2.00% to 1.95%. This is because the mean innovation probability in the economy drops from 26.2% to 25.5%.[37] The ratio of R&D expenditures to output decreases from 2.77% to 2.63%, but the consumption gains are virtually nonexistent at 0.1%. The negative welfare effect of decreased output growth rate dominates the positive effect of increased consumption, which results in a 0.84% drop in social welfare in consumption equivalent terms if the difference is removed from the economy, and 0.71% otherwise. The welfare impact is quite substantial for a simple change in accounting standards. While we acknowledge that our model abstracts away from potential gains from more transparent financial reporting as a result of FAS 123R, we find that these unmodeled gains must be quite significant to overcome the negative effects on innovation and long-run economic growth.

Beyond the implications for the aggregate economy, the reform has heterogeneous implications for firms that differ in their quality of corporate governance. The left panel of Fig. 4 presents the innovation rate chosen by firms before and after the reform according to their corporate governance percentile, ranging from the firms with highest CEO influence $\eta = \eta_{ub}$ to firms with perfect corporate governance $\eta = 0$. In the right panel of Fig. 4, the dashed line depicts the percentage change in innovation due to the reform, whereas the straight line depicts the average decrease in innovation for all firms. One can see that firms with worse corporate governance decrease their innovation more than the economy average. At the same time, most firms with better corporate governance experience a limited reduction. In fact, the top 10% of firms actually increase their rate of innovation, picking up the slack generated by other firms thanks to the general equilibrium effect of the growth rate. Overall, the issuance of FAS 123R makes innovation more concentrated in firms with better corporate governance. Since R&D costs are convex in the innovation probability i, this results in more resources being spent on R&D to generate the same success probability, which is one reason behind the lackluster gain in the level of consumption. Hence the growth effect dominates the level effect, leading to a sizable drop in social welfare.

4.9. Taxation of stock options

Thus far, we have established that the composition of manager compensation plays a crucial role in firm innovation. One natural policy experiment to consider is differential taxation of salary versus stock options. In the US there are two different types of stock options in terms of how they are taxed: incentive stock options (ISOs) and non-qualified stock options (NQs). Income from ISOs is treated as capital income, whereas income from NQs is considered personal income. Since capital income taxes are lower than personal income taxes at income levels faced by the average CEO, ISOs have the potential to be more lucrative for the managers. However, ISOs are quite rare compared to NQs, which is primarily due to an annual cap of $100,000 on the value of the stock at the grant date.

Given the rarity of ISOs, we treat all stock options as NQs in the baseline specification. Therefore both salary and options are taxed as personal income at the top marginal rate of 37%. The collected tax revenues are remitted to the representative consumer. In our first experiment, we treat all stock options as ISOs, which means they are taxed at the top marginal capital income tax rate of 20%. In our second experiment, we go further and make all stock options tax free. The results of the two experiments are presented in Table 4. Treating all stock options as ISOs instead of NQs encourages the firms to rely more on stock options, increasing the mean option ratio from 36.11% to 40.02%. Consequently, the output growth rate increases

[37] This decline in innovation is consistent with the empirical findings in Mao and Zhang (2018) who note that both the quantity and the quality of innovation have fallen in response to the issuance of FAS123R.

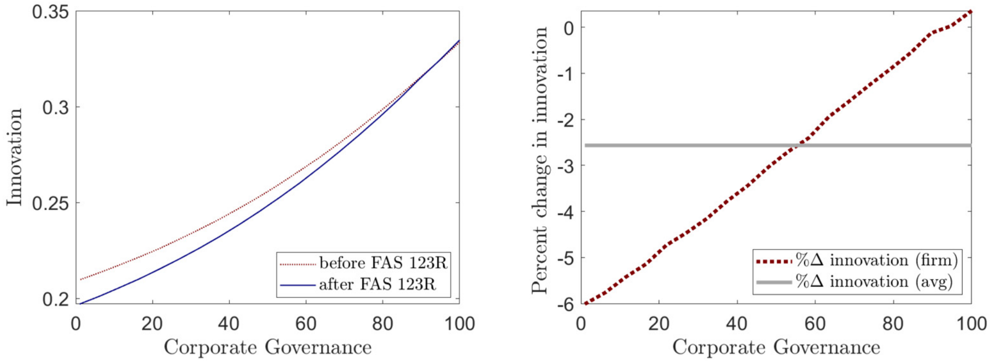

Fig. 4. The impact of FAS 123R: innovation policy decomposition. Notes: This figure displays how innovation changes as a function of corporate governance in absolute terms and in percentages in response to the issuance of FAS 123R.

Table 4
Counterfactual experiment III: changes in the taxation of stock options.

	Baseline Tax (37%)	Reduced Taxes (20%)	No Taxes (0%)
Output growth rate	2.00%	2.03%	2.06%
R&D intensity	2.77%	2.87%	2.94%
Mean option ratio	36.11%	40.02%	43.74%
Mean innovation probability	26.21%	26.65%	27.00%
Consumption/output	0.79	0.79	0.79
Welfare change	-	0.40%	0.68%

Notes: This table displays the effects of changing the taxation of stock options.

by 0.03 percentage points, leading to a consumption equivalent welfare gain of 0.40%. Removing all taxes from stock options results in increasing the output growth rate by 0.06 percentage points, with a higher welfare gain at 0.68%.

The results suggest that reducing the tax rate on stock options can deliver respectable increases in innovation, economic growth, and welfare. However, given the welfare impact of removing CEO influence (7.3%) and the issuance of FAS 123R (-0.84%) presented earlier, these gains seem rather underwhelming. Our model suggests that taxing stock options at lower rates can help increase innovation and welfare. However, quantitatively, this can only alleviate a small fraction of the inefficiency caused by agency frictions between the managers and the shareholders.

4.10. Estimation with early and late subsamples

In our baseline estimation, we use the data from between 1991 and 2004 as a whole. However, there have been several important changes throughout this period such as a significant increase in the share of stock options in manager compensation, and a slowdown in firm growth for US public firms coupled with an increase in R&D intensity. These call into question how the intensity of agency frictions between the shareholders and the managers changes throughout the time period.

To answer this question, we split our data into early (1991-1997) and late (1998-2004) subsamples, and re-estimate the model. The details of the estimation exercise are shown in Table C2. All data moments that are derived from micro-data are obtained by using data from the subsamples only. For the aggregate growth rate, we pick 2.54% for the early subsample and 1.54% for the late subsample, both of which are obtained by modifying the 2.00% target proportionally according to the relative average firm growth in the two subsamples.

Inspecting the parameter estimates, one can see that the productivity increase from each successful innovation γ goes down over time, while the scale parameter of R&D cost χ increases. This is in line with the productivity slowdown observed in the early 2000s. At the same time, the ratio of CEO compensation to market capitalization increases, which pushes the expected present discounted value of CEO compensation $\bar{U}$ higher. Interestingly, the distribution of CEO influence does not change significantly between the two time periods.

We use the estimated models to repeat the CEO influence shutdown experiment so that we can measure the severity of the agency frictions in the two subsamples. The results are presented in Table 5. The output growth rate increase is 21.4% of the baseline value for the early period, and 24.0% for the late period. Despite the slightly higher growth rate increase in the late period, the consumption-equivalent welfare change is higher for the early period at 6.94% compared to 5.94% for the late period. This is because the gains from reducing agency frictions are potentially larger when innovation is more productive (higher γ and lower χ). The results suggest that the agency frictions are more severe in the early period, but the difference is not very sizable. The increase in stock options over time seems to have alleviated the problem to an extent, but the equilibrium is still quite distant to the first-best.

Table 5
Counterfactual experiment IV: reduced agency frictions in early and late subsamples.

	Early Subsample		Late Subsample	
	Baseline	$\eta = 0$	Baseline	$\eta = 0$
Output growth rate	2.53%	3.07%	1.54%	1.91%
R&D intensity	3.04%	4.69%	2.87%	4.65%
Mean option ratio	31.39%	47.33%	40.29%	56.61%
Mean innovation probability	29.70%	36.40%	23.44%	29.24%
Consumption/output	0.79	0.78	0.78	0.77
Welfare change	-	6.94%	-	5.94%

Notes: This table displays the effects of shutting down CEO influence in the early and late subsample estimations.

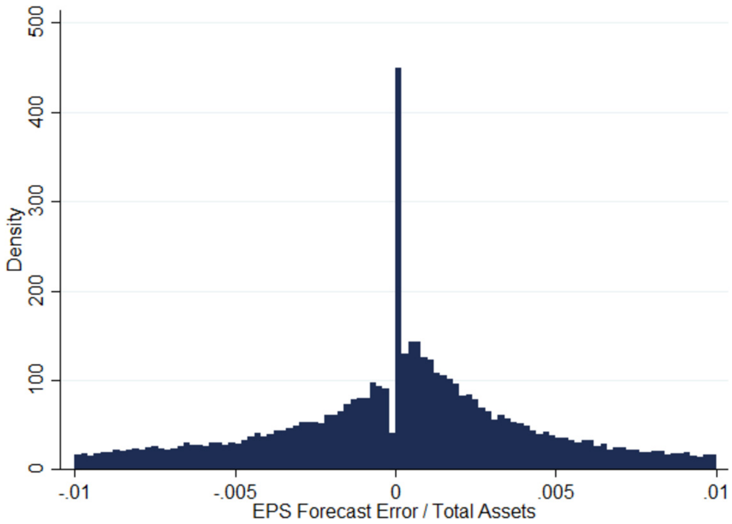

Fig. 5. The bunching of firm profit forecast error above zero. Notes: Forecast errors are realized firm profits minus median analyst profit forecast from a 2-quarter horizon, scaled by firm assets and expressed as a percentage. The histogram represents a panel of 26,129 firm years, covering 1990-2004 for 5,454 firms. 68.2% of the sample lies within the bounds plotted above. Bin size is 0.01% of firm assets. Discontinuity or sorting is detected in the forecast error distribution at 0 at the 1% level according to the McCrary (2008) statistic.

5. Model extension: the impact of short-termism

The composition of managerial compensation plays a considerable role in a firm's innovation outcomes. However, there can be other channels that influence a manager's innovation decision. One such channel is the short-term pressure exerted on CEOs to deliver high earnings in the short-run. As Terry (2017) documents, managers of US public firms try to hit the earnings per share (EPS) targets forecast by stock analysts, because failing to do so can lead to a reduction in total compensation. To increase earnings in the short-run, a manager can reduce R&D spending. This helps meet the target at the cost of reducing innovation, which decreases the firm's long-run profitability. Therefore, short-term pressure can deepen the agency frictions between the manager and the shareholders regarding innovation.

Using analyst forecast data from the Institutional Broker's Estimate System (I/B/E/S), we extend the empirical analysis in Terry (2017) by focusing on our sample of firms and investigate the interaction between short-termism and institutional ownership. Fig. 5 shows that the forecast error – the difference between the median EPS prediction of the analysts and its realization – exhibits a considerable amount of bunching right above zero, consistent with our reasoning. In Table 6, a local linear regression reveals that just falling short of the target results in a 9.21% decrease in total CEO compensation, which is comparable to the 6.78% found in Terry (2017).[38] We further split the firms into two subsamples based on their institutional ownership fraction. Column 2 shows no statistically significant decrease in CEO compensation for firms with lower institutional ownership. Column 3, on the other hand, exhibits a statistically significant effect at 8.63% for the firms with a high fraction of institutional ownership. Since firms with higher institutional ownership are also more innovative, short-termism might be a greater issue for exactly those firms that are crucial for aggregate productivity growth.

[38] We should stress that the results in this table do not present any treatment effect, nor is it possible to claim causality. The local linear regression is used as a detection device. The firms endogenously sort themselves to the region slightly above zero, which is consistent with firm behavior in our model with short-term pressure. We rely on our structural model to infer the growth and welfare implications.

Table 6
Local discontinuities at the zero forecast error threshold.

Sample	Full Sample	Low Inst. Ownership	High Inst. Ownership
Observations	55,013	32,621	22,392
Dependent Variable	CEO Total Income	CEO Total Income	CEO Total Income
Running Variable	Forecast Error	Forecast Error	Forecast Error
Cut Point	0	0	0
Discontinuity	0.0921***	-0.0690	0.0863**
	(0.0330)	(0.0856)	(0.0347)

Notes: The regression discontinuity estimation relies on local linear regressions and a uniform kernel, with bandwidth chosen via the optimal Imbens and Kalyanaraman (2012) approach. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The second and third column show the regression discontinuity estimates for subsamples of firms with low institutional ownership and high institutional ownership, respectively. The full sample is divided into two subsamples based on the institutional ownership threshold obtained using the threshold estimation method in the spirit of Cecchetti et al. (2011). We run a local linear regression where the indicator variable for non-negative forecast error is also interacted with another indicator for belonging to the high institutional ownership group. We run this regression for all possible cut-off values of high institutional ownership, and pick the one that delivers the highest fit as measured by adjusted R^2. *** p<0.01, ** p<0.05, * p<0.1.

5.1. Extended model with short-termism

These empirical findings motivate us to extend our baseline model to include short-term pressure. Our aim in doing so is to discover its interaction with our main mechanism of compensation composition, and to assess its quantitative importance.

To introduce short-termism into the model, we enrich the production technology with temporary productivity shocks. In the model, the reason behind CEO short-termism is the pressure by investors for the firm to provide period dividends D_t above a certain threshold $\bar{D}_t$. This target is more difficult to hit when a low productivity shock is realized. If the CEO fails to meet the dividend target, he or she experiences a punishment that will be calibrated to match the fraction of compensation lost seen in Table 6.

The production technology is updated as

$$y_t = (e^{\epsilon_t} z_t)^{\zeta} k_t^{\kappa} l_t^{\lambda} \tag{27}$$

where ϵ_t is an i.i.d. temporary productivity shock with $\mathbb{E}[e^{\epsilon_t}] = 1$. We assume that the productivity shock is observed before the labor, physical capital, and innovation decisions are made. Repeating the derivation of static profits in a stationary equilibrium, we obtain:

$$\Pi(z_t, \epsilon_t, \bar{z}_t) = \pi \frac{e^{\epsilon_t} z}{\bar{z}^{\lambda/(\lambda+\zeta)}}. \tag{28}$$

Since $\mathbb{E}[e^{\epsilon_t}] = 1$, the expected profit before the realization of the temporary productivity shock is the same as before. The updated preferences of the CEO are represented by:

$$U(\vec{c}, \vec{i}) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\omega}}{1-\omega} - \left(v(i_t) + \hat{\mathbb{I}}_t \xi\right) \tilde{z}_t^{1-\omega}\right)\right] \tag{29}$$

where $\hat{\mathbb{I}}_t$ is an indicator which takes the value one if $\Pi(z_t, \epsilon_t, \bar{z}_t) - C(i_t, \bar{z}_t) - s_t \tilde{z}_t < \bar{D}_t(i, z_t, \bar{z}_t, s_t)$ and zero otherwise. $\bar{D}(i, z_t, \bar{z}_t, s_t)$ stands for the dividend target below which the investors punish the CEO, and ξ is the parameter that determines the severity of the punishment. The dividend target is linearly increasing in the expected profits of the firm $\pi \hat{z}_t$ with the factor $\Lambda > 0$ that captures how stringent the dividend target is.[39] A higher Λ will translate into a larger fraction of firms reducing innovation in equilibrium, in a larger amount. The remaining details of the model are discussed in Appendix A.9.

Fig. 6 shows how short-term pressure affects the CEO's innovation decision. In the left panel the dashed curve depicts the CEO's utility under a positive productivity shock, and the non-dashed curve shows the same under a negative productivity shock. When the productivity shock is high, so are period profits. Since the firm can still hit the dividend target under what the CEO would have chosen without the short-term pressure, the innovation decision represented by the blue marker is unaffected. However, when the productivity shock is sufficiently low, choosing the same amount would result in punishment. Therefore, the CEO chooses to cut down the R&D spending such that the firm exactly hits the EPS target, reducing firm innovation. On the other hand, this constraint does not need to bind for all firms. The right panel depicts such a situation, where the CEO is not punished for choosing the interior solution regardless of the productivity shock realization.

Due to the positive relationship between institutional ownership and innovation in our model, firms with more institutional owners choose a higher innovation rate i. Since productivity shocks are identically distributed for all firms, exactly these firms end up having a sufficiently high innovation rate to be affected by the short-termism constraint. Consequently, this prediction of our model matches the data patterns observed in Table 6.

[39] Terry et al. (2022) propose that the CEOs can also manipulate information disclosure and report higher short-term profits. Introduction of a similar mechanism into our setting would reduce short-term pressure which would be captured by a lower value for the parameter Λ.

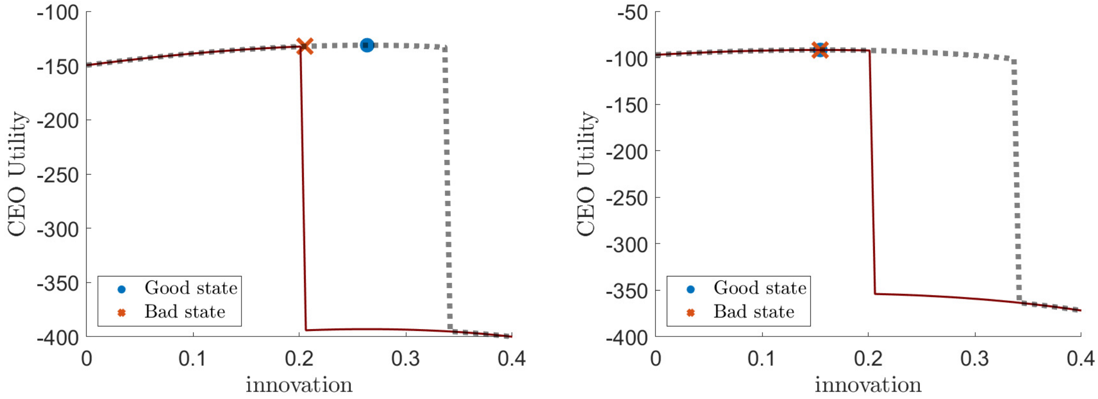

Fig. 6. The impact of short-termism on CEO's innovation decision. Notes: This figure illustrates how short-termism can affect a CEO's innovation decision.

Table 7
Counterfactual experiment V: the impact of reduced agency frictions in the short-termism model.

	Baseline	Reduced CEO Influence (25%)	Reduced CEO Influence (50%)	Reduced CEO Influence (100%)
Output growth rate	2.00%	2.08%	2.15%	2.39%
R&D intensity	2.76%	2.97%	3.21%	4.19%
Mean option ratio	35.48%	38.48%	41.83%	54.94%
Mean innovation probability	19.91%	20.66%	21.46%	23.97%
Consumption/output	0.79	0.79	0.79	0.78
Welfare change	-	1.2%	2.4%	5.8%

Notes: This table displays the effects of reducing the CEO influence parameter η in the short-termism model.

5.2. Quantitative results with short-termism

We re-estimate the extended model with short-termism to conduct quantitative experiments. Table C.1 summarizes the results of this exercise. The new parameters are the standard deviation of the productivity shock σ_ϵ, the cost of missing the EPS target ξ, and the stringency of the dividend target Λ. We calibrate σ_ϵ externally by matching the standard deviation of profitability.[40] ξ is estimated by matching the compensation loss from missing the EPS target in the model with that in the data obtained from column 3 of Table 6. To discipline Λ, we target the share of firms in the sample that are affected by short-termism. Firms with an institutional ownership share higher than 43% are affected, which constitute 40.7% of the firms in our data.[41] After estimation, the top 40% of firms in terms of institutional ownership are affected by short-termism through binding EPS constraints, which tightly matches the data.

The first question we are interested in is whether taking short-termism into consideration influences the quantitative results of reducing agency frictions that we discussed in Section 4.7. We repeat the same exercise using the extended model. Table 7 presents the findings. Inclusion of the short-termism margin slightly dampens the gains from reducing CEO influence. The increase in the output growth rate falls from 0.51% to 0.39%, resulting in a smaller welfare gain of 5.8% as opposed to 7.3%. The reasoning behind this change is simple: Short-termism has a negative effect only when innovation is sufficiently high, as shown in Fig. 6. Lowering agency frictions allows firms that were previously less innovative to increase their innovation, which in turn subjects them to the short-termism problem. When agency frictions are completely removed, the fraction of firms affected increases from 40% to the whole economy. The welfare gains from reducing agency frictions are still substantial, which we interpret as our results' robustness to inclusion of the short-termism mechanism.

A second reasonable question to ask is which of the two frictions we consider matters more for economic growth and welfare. To answer this question, we successively reduce Λ to 80% of its value in the second column of Table 8, and reduce it to zero in the last column. As a result, the fraction of firms that are affected falls from 40% to 15% and 0% respectively. Removing short-termism increases the output growth rate by 0.11% and the consumption equivalent welfare gain is 1.5%.[42] The gains are quite significant, and the magnitudes for both are approximately one quarter of those we obtained by shutting

[40] Profitability is defined as operating income before depreciation divided by total assets; winsorized above and below at 5%.

[41] In Table 6, we use the following methodology to split the firms into the high and low institutional ownership subsamples: We run a local linear regression where the indicator variable for non-negative forecast error is also interacted with another indicator for belonging to the high institutional ownership group. We run this regression for all possible cutoff values of high institutional ownership, and pick the one that delivers the highest fit as measured by adjusted R^2, which is 43%.

[42] The growth gain of 0.11% we calculate is quite similar to the 0.10% found in Terry (2017).

Table 8
Counterfactual experiment VI: the impact of reduced short-termism.

	Baseline	Reduced Short-Termism (20%)	Reduced Short-Termism (100%)
Output growth rate	2.00%	2.08%	2.11%
R&D intensity	2.76%	3.08%	3.20%
Mean option ratio	35.48%	36.78%	36.94%
Mean innovation probability	19.91%	20.74%	20.96%
Consumption/output	0.79	0.79	0.79
Welfare change	-	1.2%	1.5%

Notes: This table displays the effects of reducing short-termism.

Table 9
Counterfactual experiment VII: the impact of reduced agency frictions in the short-termism model with lower Λ.

	Baseline	Reduced CEO Influence (25%)	Reduced CEO Influence (50%)	Reduced CEO Influence (100%)
Output growth rate	2.08%	2.17%	2.28%	2.57%
R&D intensity	3.08%	3.34%	3.68%	4.82%
Mean option ratio	36.78%	40.07%	44.07%	54.06%
Mean innovation probability	20.74%	21.65%	22.77%	25.81%
Consumption/output	0.79	0.78	0.78	0.77
Welfare change	-	1.4%	3.0%	6.9%

Notes: This table displays the effects of reducing the CEO influence parameter η in the short-termism model with lower Λ.

down CEO influence. We conclude that short-termism is also detrimental to growth and welfare, although the quantitative impact is smaller compared to the managerial compensation channel as captured by our model.

Finally, we are also interested in whether the two channels interact; that is, whether there are any amplification effects from reducing both frictions at the same time. This is found to be true. Table 9 presents the results of an experiment where we first reduce Λ to 80% of its value, and then repeat the exercise of reducing CEO influence. The growth gain from removing CEO influence increases from 0.39% to 0.49%, and the welfare gain increases from 5.8% to 6.9%. The amplification is quite sizable, which means a reform that can alleviate both problems simultaneously would yield amplified benefits.

6. Conclusion

We examine the impact of agency frictions between managers and shareholders on the managerial compensation structure, firm innovation, and the consequent aggregate implications on economic growth and social welfare. Firms with better corporate governance tend to adopt executive compensation contracts with a high fraction of stock options, which incentivizes managers to engage in innovative activities, and thereby improve firm value and boost economic growth. First, we develop a tractable quantitative framework to shed light on the key mechanisms that underlie these facts, and assess their quantitative significance. We contribute to the literature by being the first to build a dynamic general equilibrium model with endogenous CEO compensation and economic growth to study the joint dynamics of agency frictions, CEO compensation, and firm innovation. In the model, the CEO can influence the board's decision such that the final compensation contract deviates from the shareholder-optimal contract that would maximize firm value. Better corporate governance reduces the CEO's influence, thereby enabling the board to choose contracts that have a higher fraction of stock options, which motivates the manager to allocate more resources to innovation. The model predictions are consistent with the stylized facts we document regarding the correlation patterns of corporate governance, managerial compensation, and disruptive innovations.

Next, we estimate the model using comprehensive micro-data to discipline the sensitivity of the innovation decision to the CEO compensation structure and corporate governance. We find that the impact of agency frictions on disruptive innovation and output growth is quite sizable. Shutting down CEO influence can increase the average innovation rate by 26.6% of its value, increase output growth by 0.51 percentage points, and improve consumption-equivalent welfare by around 7.3%. Another experiment that attempts to quantify the impact of FAS 123R issued by FASB in December 2004, a change in accounting standards which reduced the incentives to pay CEOs using stock options, suggests that it might have reduced long-run economic growth slightly by 2.5% of its value, while concentrating R&D spending in firms with better corporate governance, which results in a 0.84% drop in social welfare, a quite sizable drop for a simple change in accounting standards. Extending the analysis by introducing short-term earnings pressure on the manager slightly dampens the quantitative results. Shutting down short-termism by itself generates around one quarter of the effects of removing CEO influence. There are amplified gains from reducing both frictions simultaneously.

We show that the general equilibrium property of our framework matters for the precise assessment of the counterfactual implications of how agency frictions affect innovation, productivity growth, and welfare. Ignoring the endogenous responses of the wages, the interest rate, and the knowledge spillovers across firms would significantly exaggerate how firms would change their innovation policies. In particular, we demonstrate that ignoring the general equilibrium effects would increase the welfare impact of shutting down agency frictions from 7.3% to 13.7%, highlighting the importance of using a general equilibrium framework to quantify the impact of agency frictions. Our model's ability to tractably cast an agency problem with endogenous compensation structure in a dynamic general equilibrium model with endogenous growth helps in this respect.

The quantitative findings suggest significant room for policy intervention to bring the economy closer to the efficient allocation through the alleviation of agency frictions. While no magic recipe exists for improving corporate governance, understanding how and why institutional investors pick the firms they do might be valuable as a future research avenue. Another option is changing how various components of CEO compensation are taxed by the government, which can provide more incentives for firms to increase the state-contingent parts of CEO compensation. Furthermore, the social planner's optimal rate of innovation is much higher than that of the decentralized economy, which implies that there is room for subsidizing innovation. Reducing R&D costs, through an R&D tax credit or other subsidies, may improve the innovation level and output growth. In particular, our paper implies that the optimal subsidy rates depend on the severity of agency frictions.

Despite the complex setting with rich dynamics, our model remains highly tractable and computationally feasible, where most of the relevant quantities admit closed-form solutions. Thus we can largely avoid the problem of a "black box" model with many indistinguishable moving internal parts. This facilitates a better understanding of the key mechanisms at play. We intentionally keep the model as parsimonious as possible for tractability and clarity of the theoretical results. However, the key mechanism of the model is likely to carry over to an alternative model with additional features. It would be interesting to see how the main mechanism interacts with other channels, as we did for the case of short-term earnings pressure on the manager. Another important direction for future research is to study the optimal managerial compensation contract while also considering the synergy between the manager and the inventors – the economic agents who operate under the CEO to come up with the disruptive innovations. We expect future studies along these lines to be both promising and fruitful.

Data availability

The data and computer code can be found online at https://ideas.repec.org/c/red/ccodes/22-118.html.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.red.2022.11.004.

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Online Appendices:
Agency Frictions, Managerial Compensation, and Disruptive Innovations (Not for Publication)

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A Theory Appendix

A.1 Proofs

Proof of Theorem 2. We use the guess-and-verify method. Start with the derivation of the value function of the firm given a time-invariant innovation decision i. The value function of the firm can be written recursively as:

$$V(i,z,\bar{z}) = \Pi(z,\bar{z}) - C(i,\bar{z}) + \frac{i}{1+r}V(i,z+\gamma\bar{z},\bar{z}') + \frac{1-i}{1+r}V(i,z,\bar{z}') \tag{30}$$

For clarity, define $G_\lambda = (1+g_z)^{\lambda/(\lambda+\zeta)}$ and $G_\zeta = (1+g_z)^{\zeta/(\lambda+\zeta)}$. Plugging in the guesses for the value function and static profits, we get:

$$\begin{aligned} v_1\hat{z} + v_2(i)\tilde{z} &= \pi\hat{z} - \hat{C}(i)\tilde{z} + \frac{i}{1+r}\left[\frac{v_1}{G_\lambda}\hat{z} + \frac{v_1\gamma}{G_\lambda}\tilde{z} + v_2(i)G_\zeta\tilde{z}\right] \\ &\quad + \frac{1-i}{1+r}\left[\frac{v_1}{G_\lambda}\hat{z} + v_2(i)G_\zeta\tilde{z}\right] \end{aligned} \tag{31}$$

$$v_1\hat{z} + v_2(i)\tilde{z} = \left[\pi + \frac{v_1}{(1+r)G_\lambda}\right]\hat{z} + \left[-\hat{C}(i) + \frac{iv_1\gamma}{(1+r)G_\lambda} + \frac{v_2(i)G_\zeta}{1+r}\right]\tilde{z} \tag{32}$$

Hence:

$$v_1 = \left(1 - \frac{1}{(1+r)G_\lambda}\right)^{-1}\pi \tag{33}$$

$$v_2(i) = \left(1 - \frac{G_\zeta}{1+r}\right)^{-1}\left(\frac{i\gamma v_1}{(1+r)G_\lambda} - \hat{C}(i)\right) \tag{34}$$

Note that the shareholder-optimal innovation rate must maximize $v_2(i)$, and the maximized value corresponds to v_2^{nf} in Theorem 1, whereas $v_1 = v_1^{nf}$. Next, we turn to the CEO's decision problem. Before writing the problem explicitly, we show that the value of an option can be greatly simplified. Consider the non-zero term $V(z,\Theta) - S(z_{-1},\Theta_{-1})$. Let $\mathbb{I}_{-1}$ be the indicator function for whether the previous period's innovation succeeded or failed. Consequently, we have $z = z_{-1} + \mathbb{I}_{-1}\gamma\bar{z}_{-1}$. Plugging in the definitions and the guess for the firm's value function, we get:

$$V(z,\Theta) - (1+r)S(z_{-1},\Theta_{-1}) \tag{35}$$

$$= V(z,\Theta) - (1+r)\left(V(z_{-1},\Theta_{-1}) - [\Pi(z_{-1},\Theta_{-1}) - C(i_{-1},\bar{z}_{-1})]\right) \tag{36}$$

$$= V(z,\Theta) - (1+r)\left(\frac{i_{-1}}{1+r}V(z_{-1}+\gamma\bar{z}_{-1},\Theta) + \frac{1-i_{-1}}{1+r}V(z_{-1},\Theta)\right) \tag{37}$$

$$= \frac{v_1}{G_\lambda}\hat{z}_{-1} + \mathbb{I}_{-1}v_1\gamma\tilde{z}_{-1} + v_2(i)\tilde{z} - \left(\frac{v_1}{G_\lambda}\hat{z}_{-1} + i_{-1}v_1\gamma\tilde{z}_{-1} + v_2(i)\tilde{z}\right) \tag{38}$$

$$= [\mathbb{I}_{-1} - i_{-1}]\frac{v_1\gamma}{G_\zeta}\tilde{z} \tag{39}$$

Note that this term is greater than zero if and only if $\mathbb{I}_{-1} = 1$, i.e. if the innovation effort in the previous period succeeded. Hence, an option will deliver a non-zero return if and only if last period's innovation was successful. Define $x = \max\{0, \mathbb{I}_{-1} - i_{-1}\}$. The lifetime utility of the CEO can be written as:

$$U(\vec{c}, \vec{i}) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \tilde{z}_t^{1-\omega} \left(\frac{(s + \frac{o\gamma v_1}{G_\zeta} \max\{0, \mathbb{I}_{t-1} - i_{t-1}\})^{1-\omega}}{1-\omega} - v(i_t) \right)\right] \tag{40}$$

Determination of $\vec{i}$ completely pins down the values of $\vec{c}$. In turn, the first order condition with respect to i_t is given by:

$$v'(i_t) = \beta G_\zeta^{1-\omega} \left[\frac{\left(s + \frac{o\gamma v_1}{G_\zeta}(1 - i_t)\right)^{1-\omega}}{1-\omega} - \frac{s^{1-\omega}}{1-\omega} - \frac{i_t o \gamma v_1}{G_\zeta} \left(s + \frac{o\gamma v_1}{G_\zeta}(1 - i_t) \right)^{-\omega} \right] \tag{41}$$

Note that all the terms except i_t are time-independent. The unique solution to this equation pins down $\hat{i}(s, o)$. The first term is the utility from consumption at time $t + 1$ conditional on successful innovation. The second term is the same for the case where innovation fails. The last term captures the fact that increasing i_t actually reduces the payout of the option conditional on success, since the payout is linear in $(1 - i_t)$.

Next, we show that $\Pi(z, \bar{z}) = \pi \hat{z}$. The static profit maximization of a firm is stated as follows:

$$\Pi(z, \Theta) = \max_{k,l \geq 0} \{z^\zeta k^\kappa l^\lambda - (r + \delta)k - wl\} \tag{42}$$

First order conditions imply $l^* = \frac{\lambda y^*}{w}$ and $k^* = \frac{\kappa y^*}{r+\delta}$, hence we have

$$\begin{aligned} y^* &= z^\zeta \left(\frac{\kappa y^*}{r + \delta}\right)^\kappa \left(\frac{\lambda y^*}{w}\right)^\lambda \\ y^* &= \left[\left(\frac{\kappa}{r + \delta}\right)^\kappa \left(\frac{\lambda}{w}\right)^\lambda\right]^{1/\zeta} z \end{aligned} \tag{43}$$

and the profits are simply equal to $\Pi(z, \Theta) = \zeta y^*$. Let $Z(z)$ denote the distribution of firm productivities. From the labor market clearing condition, we get

$$
\begin{aligned}
L &= \int l^*(z)dZ(z) \\
L &= \frac{\lambda}{w}\left[\left(\frac{\kappa}{r+\delta}\right)^{\kappa}\left(\frac{\lambda}{w}\right)^{\lambda}\right]^{1/\zeta}\int zdZ(z) && (44) \\
\left(\frac{w}{\lambda}\right)^{\frac{\lambda+\zeta}{\zeta}} &= \left(\frac{\kappa}{r+\delta}\right)^{\kappa/\zeta}\frac{\bar{z}}{L} && (45) \\
w &= \lambda\left(\frac{\kappa}{r+\delta}\right)^{\frac{\kappa}{\lambda+\zeta}}L^{-\frac{\zeta}{\lambda+\zeta}}\bar{z}^{\frac{\zeta}{\lambda+\zeta}} && (46) \\
w &= \lambda\left(\frac{\kappa}{r+\delta}\right)^{\frac{\kappa}{\lambda+\zeta}}\tilde{z} && (47)
\end{aligned}
$$

where the last line is due to the normalization of the inelastic labor supply to $L = 1$. The identity shows that the wage rate grows with the gross rate G_ζ along the balanced growth path. The Euler equation of the representative consumer pins down the time-invariant real interest rate r along the balanced growth path. Since the consumption of the representative household grows at the gross rate G_ζ, we have

$$r = G_\zeta^{\omega}\beta^{-1} - 1 \tag{48}$$

Plugging the expressions for the wage and the interest rate into profits yields

$$
\begin{aligned}
\Pi(z,\Theta) &= \zeta\left[\left(\frac{\kappa}{r+\delta}\right)^{\kappa}\left(\frac{\lambda}{w}\right)^{\lambda}\right]^{1/\zeta} z && (49) \\
&= \zeta\left(\frac{\kappa}{r+\delta}\right)^{\frac{\kappa}{1-\kappa}}\hat{z} && (50) \\
&= \zeta\left(\frac{\kappa}{G_\zeta^{\omega}\beta^{-1}-1+\delta}\right)^{\frac{\kappa}{1-\kappa}}\hat{z} && (51) \\
&= \pi\hat{z} && (52)
\end{aligned}
$$

where $\pi \equiv \zeta\left(\frac{\kappa}{G_\zeta^{\omega}\beta^{-1}-1+\delta}\right)^{\frac{\kappa}{1-\kappa}}$ is a time-invariant constant. Since $y^* = \frac{\pi\hat{z}}{\zeta}$, the aggregate output Y is calculated as

$$Y = \int \frac{\pi}{\zeta}\hat{z}dZ(z) = \frac{\pi}{\zeta}\tilde{z}. \tag{53}$$

This verifies that the aggregate output grows at the gross rate G_ζ. Finally, since all firms choose the same innovation probability $\hat{\imath}$, the average productivity level $\bar{z}$ grows according to the law of motion

$$\bar{z}' = \bar{z} + \hat{\imath}\gamma\bar{z} \tag{54}$$

which implies that the growth rate is $g_z = \hat{\imath}\gamma$. $\square$

Proof of Theorem 3. First, note that given $i_t = \hat{\imath}(s,o)$, the expected utility of the CEO can be written as

$$
\begin{aligned}
& \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega}\right)\right] && (55)\\
= & \sum_{t=0}^{\infty}(\beta G_\zeta^{1-\omega})^t\left[\frac{\hat{\imath}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{\imath}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{\imath}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{\imath}(s,o))\right]\tilde{z}_0^{1-\omega} && (56)\\
= & \frac{1}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{\imath}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{\imath}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{\imath}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{\imath}(s,o))\right]\tilde{z}_0^{1-\omega} && (57)
\end{aligned}
$$

Next, the expected utility of the shareholders becomes

$$
\begin{aligned}
& \mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right] && (58)\\
= & v_1\hat{z}_0 + v_2(\hat{\imath}(s,o))\tilde{z}_0 - \underline{\mathrm{U}} && (59)
\end{aligned}
$$

The first and third terms are independent of the choice of s or o; so they can be moved out of the maximization. Note that the real interest rate is constant in the balanced growth path equilibrium. Then:

$$
\underline{\mathrm{U}} = \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{(1+r)^t}\right] = \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{\imath}(s,o)(1-\hat{\imath}(s,o))\right]\tilde{z}_0 \tag{60}
$$

Hence, choosing either s or o completely determines the other. Thus, the maximization problem has a single relevant dimension. Since the domain of o is compact, it makes sense to search over the values of $o \in [0,1]$, which maximizes the objective function. Putting all components together, the problem can be rewritten as follows:

$$
\begin{aligned}
\max_{o\in[0,1]} \quad & \left\{\frac{\eta\tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{\imath}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{\imath}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{\imath}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{\imath}(s,o))\right]\right.\\
& \left. +(1-\eta)v_2(\hat{\imath}(s,o))\tilde{z}_0\right\}, \text{such that} && (61)\\
\underline{\mathrm{U}} = & \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{\imath}(s,o)(1-\hat{\imath}(s,o))\right]\tilde{z}_0 && (62)
\end{aligned}
$$

$\square$

A.2 Introducing Firm and CEO Type Heterogeneity

The determination of CEO compensation structure for firm type j is given by:

$$\max_{o_j\in[0,1]} \quad \left\{ \frac{\eta_j \tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}} \left[\frac{i_j}{1-\omega} \left(s_j + \frac{o_j\gamma_j v_1(1-i_j)}{G_\zeta} \right)^{1-\omega} + \frac{(1-i_j)s_j^{1-\omega}}{1-\omega} - v_j(i_j) \right] \right.$$
$$\left. +(1-\eta_j)v_{2,j}(i_j)\tilde{z}_0 \right\}, \text{such that} \tag{63}$$

$$\underline{\mathrm{U}}_j \;=\; \frac{1+r}{1+r-G_\zeta}\left[s_j + \frac{o_j\gamma_j v_1}{G_\zeta} i_j(1-i_j) \right]\tilde{z}_0 \tag{64}$$

$$v_j'(i_j) \;=\; \beta G_\zeta^{1-\omega}\left[\frac{\left(s_j + \frac{o_j\gamma_j v_1}{G_\zeta}(1-i_j)\right)^{1-\omega}}{1-\omega} - \frac{s_j^{1-\omega}}{1-\omega} - \frac{i_j o_j\gamma_j v_1}{G_\zeta}\left(s_j + \frac{o_j\gamma_j v_1}{G_\zeta}(1-i_j)\right)^{-\omega} \right] \tag{65}$$

where

$$v_j(i_j) \;=\; -\nu_j(\ln(1-i_j)+i_j), \tag{66}$$
$$\hat{C}_j(i_j) \;=\; -\chi_j(\ln(1-i_j)+i_j), \text{ and} \tag{67}$$
$$v_{2,j}(i_j) \;=\; \left(1-\frac{G_\zeta}{1+r}\right)^{-1}\left(\frac{i_j\gamma_j v_1}{(1+r)G_\lambda} - \hat{C}_j(i_j)\right). \tag{68}$$

In essence, this is nothing but solving J similar problems side by side. The interaction between the firm types comes through the general equilibrium effects on the real wage rate w, the productivity distribution $Z(z)$, and the growth rate of its mean, g_z. Let $\mu_j \in [0,1]$ denote the fraction of firms of type j in the economy, such that $\sum_{j=1}^{J}\mu_j = 1$. Consider the law of motion for productivity of a type j firm:

$$z_{t+1}^j = z_t^j + \gamma_j \bar{z}_t \mathbb{I}_j \tag{69}$$

where $\mathbb{I}_j$ is the innovation indicator function which equals 1 with probability i_j, and zero otherwise. Taking the unconditional expectation of both sides delivers the law of motion for the average productivity of all firms with type j:

$$\bar{z}_{t+1}^j = \bar{z}_t^j + \gamma_j \bar{z}_t i_j \tag{70}$$

The average productivity level for all the firms in the economy is the weighted sum of average productivity levels for particular firm types, i.e. $\bar{z}_t = \sum_{j=1}^{J} \mu_j \bar{z}_t^j$. Consequently,

$$\begin{aligned}
\bar{z}_{t+1} &= \sum_{j=1}^{J} \mu_j \bar{z}_{t+1}^j && (71)\\
&= \sum_{j=1}^{J} \mu_j \left(\bar{z}_t^j + \gamma_j \bar{z}_t i_j \right) && (72)\\
&= \sum_{j=1}^{J} \mu_j \bar{z}_t^j + \bar{z}_t \sum_{j=1}^{J} \mu_j \gamma_j i_j && (73)\\
&= \bar{z}_t \left(1 + \sum_{j=1}^{J} \mu_j \gamma_j i_j \right) && (74)
\end{aligned}$$

Therefore, the growth rate of the average productivity level $\bar{z}$ along a balanced growth path equilibrium is now given by:

$$g_z = \sum_{j=1}^{J} \mu_j \gamma_j i_j \tag{75}$$

A.3 Competitive Equilibrium and the Social Planner's Solution with No Agency Frictions

A.3.1 Competitive Equilibrium with No Agency Frictions

First, we calculate the optimal innovation decision i for a firm with no agency frictions:

$$\begin{aligned}
\frac{\partial C(i, \bar{z})}{\partial i} &= \frac{1}{1+r} \left[V_{\mathrm{nf}}(z + \gamma \bar{z}, \Theta') - V_{\mathrm{nf}}(z, \Theta') \right] && (76)\\
\chi \frac{i}{1-i} &= \frac{v_1^{\mathrm{nf}} \gamma}{(1+r) G_\lambda} && (77)\\
i \left(\chi + \frac{v_1^{\mathrm{nf}} \gamma}{(1+r) G_\lambda} \right) &= \frac{v_1^{\mathrm{nf}} \gamma}{(1+r) G_\lambda} && (78)\\
i &= \frac{v_1^{\mathrm{nf}} \gamma}{\chi (1+r) G_\lambda + v_1^{\mathrm{nf}} \gamma} && (79)
\end{aligned}$$

where we have

$$\begin{aligned}
v_1^{\mathrm{nf}} &= \left(1 - \frac{1}{(1+r) G_\lambda} \right)^{-1} \pi, && (80)\\
\pi &= \zeta \left(\frac{\kappa}{G_\zeta^\omega \beta^{-1} - 1 + \delta} \right)^{\frac{\kappa}{1-\kappa}}, \text{ and} && (81)\\
g_z &= \gamma i && (82)
\end{aligned}$$

Initial consumption level C_0 is calculated as:

$$C_0 = \left[\frac{\pi}{\zeta} - \frac{\kappa\pi(G_\zeta - 1 + \delta)}{\zeta(r+\delta)} - \hat{C}(i)\right]\tilde{z}_0 \tag{83}$$

A.3.2 Social Planner's Solution with No Agency Frictions

The social planner seeks to maximize the lifetime utility of the representative consumer subject to the production and innovation technologies. We will assume the initial value of the physical capital to output ratio is equal to its steady-state level, and focus on balanced growth path allocations. Let $\mathbb{I}(n,t)$ denote the indicator function which equals one if innovation effort at time t in firm n succeeds, and equals zero otherwise. The history of innovation realizations up until time t is given by $h_t \equiv \{[\mathbb{I}(n,T)]_{n\in[0,1]}\}_{T=0}^{t-1}$. The problem can be stated as follows:

$$\max_{\{[l(n,t),k(n,t),i(n,t)]_{n\in[0,1]},C_t,K_{t+1},X_t\}_{t=0}^{\infty}} \left\{\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\frac{C_t^{1-\omega}}{1-\omega}\right]\right\}, \text{such that} \tag{84}$$

$$\begin{aligned}
Y_t &= \int z(n,t)^\zeta k(n,t)^\kappa l(n,t)^\lambda dn, \forall t, \forall h_t &(85)\\
K_t &= \int k(n,t)dn, \forall t, \forall h_t &(86)\\
L_t &= \int l(n,t)dn, \forall t, \forall h_t &(87)\\
X_t &= \int \hat{C}(i(n,t))\tilde{z}_t dn, \forall t, \forall h_t &(88)\\
C_t + K_{t+1} + X_t &= Y_t + K_t(1-\delta), \forall t, \forall h_t &(89)\\
z(n,t+1) &= z(n,t) + \gamma\bar{z}_t\mathbb{I}(n,t), \forall n, \forall t, \forall h_t &(90)
\end{aligned}$$

Similar to the competitive equilibrium case, all aggregate variables will turn out to be non-stochastic, and the expectation operator will only be relevant for the choice of $i(n,t)$, the innovation probability chosen at time t for firm n, as the realization of a successful innovation is stochastic at this level. The Lagrangian is written as follows:

$$\begin{aligned}
\mathcal{L} = \mathbb{E}\Bigg[\sum_{t=0}^{\infty}\Bigg[&\beta^t\frac{C_t^{1-\omega}}{1-\omega} + \mu_{Y,t}\left(\int z(n,t)^\zeta k(n,t)^\kappa l(n,t)^\lambda dn + K_t - \delta\int k(n,t)dn - C_t - K_{t+1} - X_t\right)\\
&+\mu_{K,t}\left(K_t - \int k(n,t)dn\right) + \mu_{L,t}\left(L_t - \int l(n,t)dn, \forall t, \forall h_t\right) + \mu_{X,t}\left(X_t - \int \hat{C}(i(n,t))\tilde{z}_t dn\right)\Bigg]\Bigg]
\end{aligned}$$

We start with solving the static problem of choosing physical capital and labour to be used by each firm n. The first order conditions with respect to $k(n,t)$ and $l(n,t)$ are:

$$\begin{aligned}
\frac{\partial\mathcal{L}}{\partial k(n,t)} &= \frac{\mu_{Y,t}\kappa}{k(n,t)}z(n,t)^\zeta k(n,t)^\kappa l(n,t)^\lambda - \mu_{K,t} - \mu_{Y,t}\delta = 0, \forall n, \forall t &(91)\\
\frac{\partial\mathcal{L}}{\partial l(n,t)} &= \frac{\mu_{Y,t}\lambda}{l(n,t)}z(n,t)^\zeta k(n,t)^\kappa l(n,t)^\lambda - \mu_{L,t} = 0, \forall n, \forall t &(92)
\end{aligned}$$

Therefore we have:

$$
\begin{aligned}
y(n,t) &= z^{\zeta}\left(\frac{\kappa y(n,t)}{\frac{\mu_{K,t}}{\mu_{Y,t}}+\delta}\right)^{\kappa}\left(\frac{\lambda y(n,t)}{\frac{\mu_{L,t}}{\mu_{Y,t}}}\right)^{\lambda} && (93)\\
y(n,t) &= \left[\left(\frac{\kappa}{\frac{\mu_{K,t}}{\mu_{Y,t}}+\delta}\right)^{\kappa}\left(\frac{\lambda}{\frac{\mu_{L,t}}{\mu_{Y,t}}}\right)^{\lambda}\right]^{1/\zeta} z(n,t) && (94)
\end{aligned}
$$

Define $r_t \equiv \frac{\mu_{K,t}}{\mu_{Y,t}}$ and $w_t \equiv \frac{\mu_{L,t}}{\mu_{Y,t}}$ for convenience. Labor feasibility constraint implies:

$$
\begin{aligned}
L_t &= \int \frac{\lambda}{w_t} y(n,t)dn && (95)\\
L_t &= \frac{\lambda}{w_t}\left[\left(\frac{\kappa}{r_t+\delta}\right)^{\kappa}\left(\frac{\lambda}{w_t}\right)^{\lambda}\right]^{1/\zeta}\int z_t dZ_t(z_t) && (96)\\
w_t &= \lambda\left(\frac{\kappa}{r_t+\delta}\right)^{\frac{\kappa}{\lambda+\zeta}} L_t^{-\frac{\zeta}{\lambda+\zeta}}\tilde{z}_t && (97)\\
w_t &= \lambda\left(\frac{\kappa}{r_t+\delta}\right)^{\frac{\kappa}{\lambda+\zeta}}\tilde{z}_t && (98)
\end{aligned}
$$

where the last line comes from the normalization $L_t = 1, \forall t$. Next, consider the dynamic problem of choosing how much physical capital to save for the next period. The first order conditions for C_t and K_{t+1} are given by:

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial C_t} &= \beta^t C_t^{-\omega} - \mu_{Y,t} = 0, \forall t && (99)\\
\frac{\partial \mathcal{L}}{\partial K_{t+1}} &= -\mu_{Y,t} + \mu_{Y,t+1} + \mu_{K,t+1} = 0, \forall t && (100)
\end{aligned}
$$

Combining the two, we obtain the standard Euler equation:

$$
\begin{aligned}
\beta^t C_t^{-\omega} &= \beta^{t+1}C_{t+1}^{-\omega} + r_{t+1}\beta^{t+1}C_{t+1}^{-\omega}, \forall t && (101)\\
\frac{1}{1+r_{t+1}} &= \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\omega}, \forall t && (102)
\end{aligned}
$$

As mentioned, we are interested in a balanced growth path allocation. Assume that aggregate variables grow at the gross rate $G_{\zeta} = (1+g_z)^{\zeta/(\lambda+\zeta)}$ as in the competitive equilibrium case. Then we have:

$$
r \equiv r_{t+1} = \beta^{-1}G_{\zeta}^{\omega} - 1, \forall t \qquad (103)
$$

Hence, the output of firm n at time t becomes:

$$\begin{aligned} y(n,t) &= \left[\left(\frac{\kappa}{r+\delta}\right)^{\kappa}\left(\frac{\lambda}{w_t}\right)^{\lambda}\right]^{1/\zeta} z(n,t) && (104)\\ &= \left(\frac{\kappa}{r+\delta}\right)^{\frac{\kappa}{1-\kappa}} \frac{z(n,t)}{\bar{z}_t^{\lambda/(\zeta+\lambda)}} && (105)\\ &= \left(\frac{\kappa}{G_{\zeta}^{\omega}\beta^{-1}-1+\delta}\right)^{\frac{\kappa}{1-\kappa}} \hat{z}(n,t) && (106)\\ &= \frac{\pi}{\zeta}\hat{z}(n,t) && (107)\end{aligned}$$

where $\pi \equiv \zeta\left(\frac{\kappa}{G_{\zeta}^{\omega}\beta^{-1}-1+\delta}\right)^{\frac{\kappa}{1-\kappa}}$ is a time-invariant constant. Then aggregate output Y_t is simply:

$$Y_t = \int \frac{\pi}{\zeta}\hat{z}(n,t)dn = \frac{\pi}{\zeta}\tilde{z}_t \quad (108)$$

We are left with the dynamic innovation decision. This is more delicate, as the choice of innovation probability $i(n,t)$ influences the allocation through its effects on $z(n,t+T), \forall T \in \mathbb{Z}^{++}$. This, in turn has two effects: (1) the direct effect on the future production of firm n, $y(n,t+T), \forall T \in \mathbb{Z}^{++}$, and (2) the indirect effect of positive technological spillovers due to increasing average firm productivity $\bar{z}_{t+T}, \forall T \in \mathbb{Z}^{++}$. We will first show that $i(n,t) \equiv i_t, \forall n, \forall t$. From the law of motion of firm productivity, we have:

$$\begin{aligned} \mathbb{E}_t[z(n,t+T)] &= z(n,t) + \gamma\bar{z}_t\mathbb{E}_t[\mathbb{I}(n,t)] + \gamma\mathbb{E}_t\left[\sum_{\hat{t}=t+1}^{T}\bar{z}_{\hat{t}}\mathbb{I}(n,\hat{t})\right], \forall t, \forall T \in \mathbb{Z}^{++} && (109)\\ \mathbb{E}_t[z(n,t+T)] &= z(n,t) + \gamma\bar{z}_t i(n,t) + \gamma\mathbb{E}_t\left[\sum_{\hat{t}=t+1}^{T}\bar{z}_{\hat{t}}\mathbb{I}(n,\hat{t})\right], \forall t, \forall T \in \mathbb{Z}^{++} && (110)\\ \frac{\partial\mathbb{E}_t[z(n,t+T)]}{\partial i(n,t)} &= \gamma\bar{z}_t, \forall t, \forall T \in \mathbb{Z}^{++} && (111)\end{aligned}$$

Note that the term does not depend on the value of $z(n,t+T)$, but only $\bar{z}_t$. This is due to the additive structure of the law of motion. Now, focus on the direct effect on the future production of firm n at time $t+T$:

$$\begin{aligned} \frac{\partial\mathbb{E}_t[y(n,t+T)]}{\partial i(n,t)} &= \frac{\partial\mathbb{E}_t\left[\frac{\pi}{\zeta}\frac{z(n,t+T)}{\bar{z}_{t+T}^{\lambda/(\zeta+\lambda)}}\right]}{\partial i(n,t)} && (112)\\ &= \frac{\pi}{\zeta\bar{z}_{t+T}^{\lambda/(\zeta+\lambda)}}\frac{\partial\mathbb{E}_t[z(n,t+T)]}{\partial i(n,t)} && (113)\\ &= \frac{\pi}{\zeta\bar{z}_{t+T}^{\lambda/(\zeta+\lambda)}}\gamma\bar{z}_t && (114)\end{aligned}$$

Then:

$$\frac{\partial}{\partial i(n,t)}\mathbb{E}_t\left[\sum_{T=1}^{\infty}\mu_{Y,T}y(n,t+T)\right] = \sum_{T=1}^{\infty}\mu_{Y,t+T}\frac{\pi}{\zeta\bar{z}_{t+T}^{\lambda/(\zeta+\lambda)}}\gamma\bar{z}_t \tag{115}$$

$$= \frac{\pi\gamma\bar{z}_t}{\zeta}\sum_{T=1}^{\infty}\frac{\beta^{t+T}C_{t+T}^{-\omega}}{\bar{z}_{t+T}^{\lambda/(\zeta+\lambda)}} \tag{116}$$

$$= \frac{\pi\gamma\bar{z}_t}{\zeta}\frac{\beta^t C_t^{-\omega}}{\bar{z}_t^{\lambda/(\zeta+\lambda)}}\sum_{T=1}^{\infty}\left(\frac{\beta G_\zeta^{-\omega}}{G_\lambda}\right)^T \tag{117}$$

$$= \frac{\pi\gamma\mu_{Y,t}\tilde{z}_t}{\zeta}\sum_{T=1}\left(\frac{1}{(1+r)G_\lambda}\right)^T \tag{118}$$

$$= \frac{\pi\gamma\mu_{Y,t}\tilde{z}_t}{\zeta}\left(1-\frac{1}{(1+r)G_\lambda}\right)^{-1} \tag{119}$$

$$= \frac{\gamma v_1^{\mathrm{nf}}}{\zeta}\mu_{Y,t}\tilde{z}_t \tag{120}$$

First, note that the term does not depend on n. Second, the expression is very similar to the marginal benefit from innovation to a private firm in the competitive equilibrium. We have an additional factor $1/\zeta$, since we are looking at total output of the firm as opposed to its profits. Next, we consider the costs of increasing the innovation probability $i(n,t)$. The first order condition with respect to X_t delivers $\frac{\partial\mathcal{L}}{\partial X_t} = -\mu_{Y,t} + \mu_{X,t} = 0$, so $\mu_{X,t} = \mu_{Y,t}, \forall t$. Then we have:

$$\frac{\partial}{\partial i(n,t)}\left[-\mu_{X,t}\hat{C}(i(n,t))\tilde{z}_t\right] = -\chi\frac{i(n,t)}{1-i(n,t)}\mu_{Y,t}\tilde{z}_t \tag{121}$$

So the cost does not depend on n either; and it is multiplied by the same factor $\mu_{Y,t}\tilde{z}_t$ as the marginal benefit from innovation from the direct effect on production. Since the direct benefit, the indirect benefit, and the cost are all independent of n, we conclude $i(n,t) = i_t, \forall n, \forall t$. Then we can write the aggregate law of motion for average productivity level as:

$$\bar{z}_{t+1} = \bar{z}_t + \gamma\bar{z}_t i_t \tag{122}$$

$$\Rightarrow g_{z,t} = \gamma i_t \tag{123}$$

Along a balanced growth path, the growth rate is constant, so we have $g_z = \gamma i$. With all these results, we can restate the social planner's problem as follows:

$$\max_{i\in[0,1]} \quad \left\{ \frac{C_0^{1-\omega}}{(1-\omega)(1-\beta G_\zeta^{1-\omega})} \right\} \text{, such that} \tag{124}$$

$$C_0 = \left[\frac{\pi}{\zeta} - \frac{\pi}{\zeta}\frac{\kappa}{r+\delta}(G_\zeta - 1 + \delta) - \hat{C}(i) \right] \tilde{z}_0 \tag{125}$$

$$G_\zeta = (1+\gamma i)^{\zeta/(\lambda+\zeta)} \tag{126}$$

$$\pi = \zeta \left(\frac{\kappa}{G_\zeta^\omega \beta^{-1} - 1 + \delta} \right)^{\frac{\kappa}{1-\kappa}} \tag{127}$$

$$r = \beta^{-1} G_\zeta^\omega - 1 \tag{128}$$

All the constraints can be plugged into the objective function, so we have one equation to maximize by choosing $i \in [0,1]$ with no other constraints. As expected, the only difference of the social planner's allocation from the competitive equilibrium allocation is due to the social planner's internalization of the positive spillover effects of innovation. The physical capital and labor allocations between the firms with different productivities are the same.

A.4 Determination of CEO Compensation with Flexible Total Compensation

In this section, we drop the last constraint that requires the present discounted value of the expected payments to the CEO to be equal to $\underline{U}$. Therefore both the composition and the level of the payment are endogenously determined.

$$\max_{s\geq 0, o\in[0,1]} \quad \left\{ \eta \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega} \right) \right] + (1-\eta)\mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty} \frac{c_t}{\prod_{T=1}^{t}(1+r_T)} \right] \right\} \tag{129}$$

$$\text{s.t.} \quad c_t = s\tilde{z}_t + o \max\left\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\right\}, \forall t \tag{130}$$

$$i_t = \hat{i}(s,o) \tag{131}$$

First, notice that given $i_t = \hat{i}(s,o)$, the expected utility of the CEO can be written as

$$\mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega} \right) \right] \tag{132}$$

$$= \sum_{t=0}^{\infty} (\beta G_\zeta^{1-\omega})^t \left[\frac{\hat{i}(s,o)}{1-\omega} \left(s + \frac{o\gamma v_1 (1-\hat{i}(s,o))}{G_\zeta} \right)^{1-\omega} + \frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{i}(s,o)) \right] \tilde{z}_0^{1-\omega} \tag{133}$$

$$= \frac{1}{1-\beta G_\zeta^{1-\omega}} \left[\frac{\hat{i}(s,o)}{1-\omega} \left(s + \frac{o\gamma v_1 (1-\hat{i}(s,o))}{G_\zeta} \right)^{1-\omega} + \frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{i}(s,o)) \right] \tilde{z}_0^{1-\omega} \tag{134}$$

Next, the expected utility of the shareholders becomes

$$\mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty} \frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right] \tag{135}$$

$$= v_1\hat{z}_0 + v_2(\hat{i}(s,o))\tilde{z}_0 - \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{(1+r)^t}\right] \tag{136}$$

$$= v_1\hat{z}_0 + v_2(\hat{i}(s,o))\tilde{z}_0 - \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o)(1-\hat{i}(s,o))\right]\tilde{z}_0 \tag{137}$$

The first term is independent of the choice of s or o; so it can be moved out of the maximization. Notice that the real interest rate is constant in the balanced growth path equilibrium. The maximization problem has two choice variables: s and o. Since the domain of o is compact, it makes sense to search over the values of $o \in [0,1]$ which maximizes the objective function. Putting all components together, we have:

$$\max_{s\geq 0, o\in[0,1]} \left\{ \frac{\eta\tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{i}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{i}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{i}(s,o))\right]\right.$$
$$\left. +(1-\eta)\left(v_2(\hat{i}(s,o)) - \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o)(1-\hat{i}(s,o))\right]\right)\tilde{z}_0\right\} \tag{138}$$

Without loss of generality, set $\bar{z}_0 = 1$, which implies $\tilde{z}_0 = \tilde{z}_0^{1-\omega} = 1$.

Unlike a standard principal-agent problem, a unique solution to this maximization problem always exists for any $\eta \in (0,1)$. However, unlike our baseline framework, the present discounted value of CEO compensation approaches to zero as $\eta \to 0$. This is an undesirable property, since it implies that the no CEO influence counterfactual that we would like to consider results in an unrealistic scenario where the shareholders fully exploit the CEO, paying him virtually nothing, yet still providing incentives that implement the shareholder-optimal innovation rate. This is one reason to prefer the baseline framework over this alternative specification.

A.5 Determination of CEO Compensation Using Standard Principal-Agent Framework

In this section, we change the last constraint that requires the present discounted value of the expected payments to the CEO to be equal to $\underline{U}$ with a CEO utility constraint instead.[43] As a result of this, the solution set of the problem becomes equal to the solution set of a standard principal-agent problem, which is shown to assume away the agency friction due to CEO influence η.

[43] If we write the CEO utility constraint as an inequality, two scenarios are possible. When the constraint binds, the solution set is the same as what we will discuss in this section. When the constraint does not bind, this time the solution set is identical to that obtained in the flexible total compensation specification which is already calculated and discussed in the previous subsection (Section A.4).

$$\max_{s\geq 0, o\in[0,1]} \left\{\eta\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega}-v(i_t)\tilde{z}_t^{1-\omega}\right)\right]+(1-\eta)\mathbb{E}\left[V(z_0,\Theta_0)-\sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right]\right\} \tag{139}$$

$$c_t = s\tilde{z}_t + o\max\{0, V(z_t,\Theta_t)-(1+r_t)S(z_{t-1},\Theta_{t-1})\}, \forall t \tag{140}$$

$$i_t = \hat{i}(s,o), \forall t \tag{141}$$

$$\underline{\mathrm{U}} = \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega}-v(i_t)\tilde{z}_t^{1-\omega}\right)\right] \tag{142}$$

This turns the first term in the objective function into a constant $\eta\underline{\mathrm{U}}$; so it can be moved out of the maximization. Likewise, the factor $(1-\eta)>0$ in front of the expression for shareholder utility also becomes inconsequential, and it can be moved out of the maximization.

First, note that given $i_t = \hat{i}(s,o)$, the expected utility of the CEO can be written as

$$\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega}-v(i_t)\tilde{z}_t^{1-\omega}\right)\right] \tag{143}$$

$$= \sum_{t=0}^{\infty}(\beta G_\zeta^{1-\omega})^t\left[\frac{\hat{i}(s,o)}{1-\omega}\left(s+\frac{o\gamma v_1(1-\hat{i}(s,o))}{G_\zeta}\right)^{1-\omega}+\frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega}-v(\hat{i}(s,o))\right]\tilde{z}_0^{1-\omega} \tag{144}$$

$$= \frac{1}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{i}(s,o)}{1-\omega}\left(s+\frac{o\gamma v_1(1-\hat{i}(s,o))}{G_\zeta}\right)^{1-\omega}+\frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega}-v(\hat{i}(s,o))\right]\tilde{z}_0^{1-\omega} \tag{145}$$

Since the expected utility of the CEO must equal $\underline{\mathrm{U}}$, choosing either s or o completely determines the other. Next, the expected utility of the shareholders becomes

$$\mathbb{E}\left[V(z_0,\Theta_0)-\sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right] \tag{146}$$

$$= v_1\hat{z}_0 + v_2(\hat{i}(s,o))\tilde{z}_0 - \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{(1+r)^t}\right] \tag{147}$$

$$= v_1\hat{z}_0 + v_2(\hat{i}(s,o))\tilde{z}_0 - \frac{1+r}{1+r-G_\zeta}\left[s+\frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o)(1-\hat{i}(s,o))\right]\tilde{z}_0 \tag{148}$$

The first term is independent of the choice of s or o; so it can be moved out of the maximization. Note that the real interest rate is constant in the balanced growth path equilibrium. The maximization problem has two choice variables: s and o, but since choosing one completely determines the other, we can restrict the attention to choosing o only. Since the domain of o is compact, it makes sense to search over the values of $o \in [0,1]$ which maximizes the objective function. Putting all the components together, we have:

$$\max_{o\in[0,1]} \quad \left\{ v_2(\hat{\imath}(s,o)) - \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{\imath}(s,o)(1-\hat{\imath}(s,o))\right]\right\}, \text{such that} \tag{149}$$

$$\underline{U} = \frac{1}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{\imath}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{\imath}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{\imath}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{\imath}(s,o))\right]\tilde{z}_0^{1-\omega} \tag{150}$$

Without loss of generality, set $\bar{z}_0 = 1$, which implies $\tilde{z}_0 = \tilde{z}_0^{1-\omega} = 1$.

As noticed, the CEO influence η is absent from the problem. This is because fixing the CEO's utility to $\underline{U}$ removes any possibility of negotiating a compensation structure that favors the CEO. Consequently, the board always chooses a contract that implements the first-best for the shareholders. In other words, the agency problem is assumed away. This is the reason why we opt for our baseline framework over this alternative.

If formulate a standard principal-agent problem from the get-go, it is stated as follows:

$$\max_{s\geq 0, o\in[0,1]} \quad \left\{\mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right]\right\}, \text{s.t.} \tag{151}$$

$$c_t = s\tilde{z}_t + o\max\{0, V(z_t,\Theta_t) - (1+r_{t-1})S(z_{t-1},\Theta_{t-1})\}, \forall t \tag{152}$$

$$i_t = \hat{\imath}(s,o), \forall t \tag{153}$$

$$\underline{U} \leq \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega}\right)\right] \tag{154}$$

After algebraic derivations, it becomes:

$$\max_{s\geq 0, o\in[0,1]} \quad \left\{ v_2(\hat{\imath}(s,o)) - \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{\imath}(s,o)(1-\hat{\imath}(s,o))\right]\right\}, \text{such that} \tag{155}$$

$$\underline{U} \leq \frac{1}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{\imath}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{\imath}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{\imath}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{\imath}(s,o))\right]\tilde{z}_0^{1-\omega}$$

Note that the IR constraint is a weak inequality at the outset. However, since the principal's utility is decreasing in total compensation, the constraint must bind with equality.[44] So the solution set of this standard principal-agent problem is equal to the solution set of the problem:

[44]Suppose not. Then, for any (s,o) with $\underline{U} < U(\vec{c},\hat{\imath}(s,o))$, $\exists(s',o')$ with $\underline{U} > U(\vec{c}',\hat{\imath}(s',o'))$ which delivers the same innovation $\hat{\imath}(s',o') = \hat{\imath}(s,o)$ with lower compensation cost to the principal, while still delivering the same $v_2(\hat{\imath}(s,o))$. All contracts (s,o) with $\underline{U} < U(\vec{c},\hat{\imath}(s,o))$ are thus dominated, which contradicts that the constraint does not bind with equality.

$$\max_{o\in[0,1]} \quad \left\{ v_2(\hat{i}(s,o)) - \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o)(1-\hat{i}(s,o))\right]\right\}, \text{such that} \tag{156}$$

$$\underline{\mathrm{U}} \;=\; \frac{1}{1-\beta G_\zeta^{1-\omega}}\left[\frac{\hat{i}(s,o)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{i}(s,o))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{i}(s,o))s^{1-\omega}}{1-\omega} - v(\hat{i}(s,o))\right]\zeta_0^{1-\omega} \tag{157}$$

Since (156)-(157) are equivalent to (149)-(150), the solution sets are the same.

A.6 CEO's Decision Problem with Stocks and Taxes (Risk Neutral)

In this section, we consider the decision problem of a risk neutral CEO with a richer contract structure. Each firm in the model has a CEO who chooses the levels of production inputs k and l, as well as the probability of successful innovation i. The CEO is risk-neutral in terms of consumption, discounts the future at rate β, and receives disutility from exerting effort to oversee the firm's innovation efforts. The preferences are represented by:

$$U(\vec{c},\vec{i}) = \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(c_t - v(i_t)\tilde{z}_t\right)\right] \tag{158}$$

with $\vec{c} = \{c_t\}_{t=0}^{\infty}$, $\vec{i} = \{i_t\}_{t=0}^{\infty}$, $\beta \in (0,1)$, and $v(i)$ captures the disutility from exerting effort ($v'(i) \geq 0, v''(i) > 0$).[45]

CEO compensation consists of three components: Salary s_t which is not state-contingent, dividend payments from stocks d_t which depend on the productivity of the firm z_t and the aggregate state of the economy Θ_t, and stock options o_t which have a state-contingent payoff. These three sources of CEO income are taxed at the linear rates, τ_s, τ_d, and $\tau_o \in (0,1)$ respectively. CEO compensation in period t is written as:[46]

$$c_t = (1-\tau_s)s_t\tilde{z}_t + (1-\tau_d)d_t(\Pi(z,\Theta) - \hat{C}(i)\tilde{z}) + (1-\tau_o)o_t\max\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\} \tag{159}$$

In this equation, s_t denotes the (normalized) salary received by the CEO, whereas d_t denotes the fraction of the firm's dividends that are paid to the CEO as a result of his stock ownership. Finally, o_t denotes the share options granted to the CEO as a fraction of the total shares of the firm. The third term has a positive value if the value of the firm next period exceeds the strike price this period, and is zero otherwise. Therefore, the option part of the CEO compensation is convex in the future value of the firm.

Assuming the value function of the firm given a time-invariant innovation decision i is given by $V(i,z,\bar{z}) = v_1\hat{z} + v_2(i)\tilde{z}$, the lifetime utility of the CEO along a balanced growth path equilibrium is

[45] The multiplicative term $\tilde{z}_t$ is to make sure that the disutility from the innovation effort does not shrink over time along the balanced growth path. It can be thought of as the value of time spent on leisure increasing in tandem with aggregate productivity.

[46] This equation assumes non-negative dividends.

given by:

$$U(\vec{c},\vec{i}) = \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left((1-\tau_s)s\tilde{z}_t + (1-\tau_d)d(\pi\hat{z}_t - \hat{C}(i)\tilde{z}_t) + (1-\tau_o)\frac{o\gamma v_1}{G_\zeta}\max\{0,\mathbb{I}_{t-1}-i_{t-1}\}\tilde{z}_t - v(i_t)\tilde{z}_t\right)\right] \tag{160}$$

The first order condition with respect to i_t is given by:

$$(1-\tau_d)d\hat{C}'(i_t) + v'(i_t) = \left[(1-\tau_d)d\pi\gamma\sum_{T=1}^{\infty}\left(\frac{\beta}{G_\lambda}\right)^T + \beta(1-\tau_o)o\gamma v_1(1-2i_t)\right] \tag{161}$$

$$(1-\tau_d)d\hat{C}'(i_t) + v'(i_t) = \left[(1-\tau_d)d\pi\gamma\frac{\beta}{G_\lambda-\beta} + \beta(1-\tau_o)o\gamma v_1(1-2i_t)\right] \tag{162}$$

Notice that all the terms except i_t are time-independent. The unique solution to this equation pins down $\hat{i}$. On the left-hand side, the first term originates from the R&D cost of increasing innovation that the CEO internalizes due to his stock holdings, and the second term comes from the disutility of innovation effort. On the right-hand side, the first term is the effect of increasing the firm's productivity: Since the productivity increase is permanent, the CEO enjoys increased future dividends, but this positive impact tapers off as the average productivity in the economy grows over time and the contribution of the one-time jump to the relative productivity of the firm diminishes. The second term originates from the stock options granted to the CEO, delivering a positive payoff only when the innovation succeeds.

Next, we consider the problem of how the CEO's compensation structure is determined. As before, let $\eta \in (0,1)$ denote the weight of the CEO's preferences, and $1-\eta$ denote that of the shareholders. The compensation determination problem is written as:

$$\max_{s\geq 0, d\in[0,1], o\in[0,1]} \left\{\eta\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(c_t - v(i_t)\tilde{z}_t\right)\right] + (1-\eta)\mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t^g}{\prod_{T=1}^{t}(1+r_T)}\right]\right\} \text{ s.t.} \tag{163}$$

$$c_t = (1-\tau_s)s\tilde{z}_t + (1-\tau_d)d(\Pi(z_t,\Theta_t) - \hat{C}(i)\tilde{z}_t)$$
$$+(1-\tau_o)o\max\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\} \tag{164}$$

$$c_t^g = s\tilde{z}_t + d(\Pi(z_t,\Theta_t) - \hat{C}(i)\tilde{z}_t) + o\max\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\} \tag{165}$$

$$i_t = \hat{i}(s,d,o) \tag{166}$$

$$\underline{U} = \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t^g}{\prod_{T=1}^{t}(1+r_T)}\right] \tag{167}$$

The first term in the objective function represents the CEO's influence in the determination of his compensation structure between salary s, dividends from stocks d, and stock options o, which is increasing in η. The second term in the objective function represents the shareholders' influence, where their preferences are simply the expected value of the firm at time $t = 0$ minus the present discounted value of the expected payments to the CEO. The first set of constraints give the CEO compensation at different periods. The second set of constraints provide accounting identities which show the cost of the CEO's compensation to the firm is higher than the net compensation received by the CEO, due to the taxes τ_s, τ_d, and τ_o. The third set of constraints is to recognize that the CEO will choose the level of innovation i_t given his compensation structure. Therefore the level of innovation is equal to the policy function associated with the CEO's decision problem, $\hat{i}(s,d,o)$. The last constraint requires the present discounted value of the expected (gross) payments to the CEO to be equal to $\underline{\mathrm{U}}$ (individual rationality).

First, note that given $i_t = \hat{i}(s,d,o)$, the expected utility of the CEO can be written as

$$\begin{aligned}
& \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(c_t - v(i_t)\tilde{z}_t\right)\right] && (168)\\
= & \sum_{t=0}^{\infty}(\beta G_\zeta)^t\left[(1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1\hat{i}(1-\hat{i})}{G_\zeta} - v(\hat{i})\right]\tilde{z}_0 \\
& +(1-\tau_d)d\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left(\Pi(z_t,\Theta_t) - \hat{C}(\hat{i})\tilde{z}_t\right)\right] && (169)\\
= & \frac{1}{1-\beta G_\zeta}\left[(1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1\hat{i}(1-\hat{i})}{G_\zeta} - v(\hat{i})\right]\tilde{z}_0 + (1-\tau_d)d\left(v_1^{RN}\hat{z}_0 + v_2^{RN}(\hat{i})\tilde{z}_0\right) && (170)
\end{aligned}$$

where the arguments of $\hat{i}(s,d,o)$ are suppressed for clarity, and v_1^{RN} and $v_2^{RN}(i)$ are given by:[47]

$$v_1^{RN} = \left(1-\frac{\beta}{G_\lambda}\right)^{-1}\pi \quad (171)$$

$$v_2^{RN}(i) = (1-\beta G_\zeta)^{-1}\left(\frac{\beta i\gamma v_1}{G_\lambda} - \hat{C}(i)\right) \quad (172)$$

Next, the expected utility of the shareholders becomes

$$\begin{aligned}
& \mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t^g}{\prod_{T=1}^{t}(1+r_T)}\right] && (173)\\
= & v_1\hat{z}_0 + v_2(\hat{i}(s,d,o))\tilde{z}_0 - \underline{\mathrm{U}} && (174)
\end{aligned}$$

The first and third terms are independent of the choice of s, d or o; so they can be moved out of the maximization. Note that the real interest rate is constant in the balanced growth path equilibrium. Then:

$$\begin{aligned}
\underline{\mathrm{U}} = \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t^g}{(1+r)^t}\right] = & \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,d,o)(1-\hat{i}(s,d,o))\right]\tilde{z}_0 \\
& +d(v_1\hat{z}_0 + v_2(\hat{i}(s,d,o))\tilde{z}_0) && (175)
\end{aligned}$$

Hence, choosing two of s, d, and o completely determines the third. Thus the maximization problem has two relevant dimensions. Since the domains of o and d are compact, it makes sense to search

[47] This is obtained by replacing $\frac{1}{1+r}$ with β and following the same steps as in Theorem 2.

over the values of $(d, o) \in [0,1]^2$ which maximize the objective function. Putting all components together, the problem can be rewritten as follows:

$$\max_{(d,o)\in[0,1]^2} \quad \left\{ \frac{\eta}{1-\beta G_\zeta} \left[(1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1 \hat{i}(1-\hat{i})}{G_\zeta} - v(\hat{i}) \right] \tilde{z}_0 + \eta(1-\tau_d)d\left(v_1^{RN}\hat{z}_0 + v_2^{RN}(\hat{i})\tilde{z}_0 \right) \right.$$
$$\left. +(1-\eta)v_2(\hat{i})\tilde{z}_0 \right\}, \text{such that} \tag{176}$$
$$\underline{\mathrm{U}} = \frac{1+r}{1+r-G_\zeta}\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(1-\hat{i}) \right] \tilde{z}_0 + d(v_1\hat{z}_0 + v_2(\hat{i})\tilde{z}_0) \tag{177}$$

where the arguments of $\hat{i}(s, d, o)$ are suppressed for clarity. Note that unlike the specifications without dividends, this problem depends on the normalized productivity of the firm at time zero, $\hat{z}_0$.

A.7 Initial Consumption Level

To calculate welfare, we need to compute the initial consumption level C_0. From goods market clearing, we have:

$$Y_t = C_t + C_{m,t} + X_t + I_t \tag{178}$$

where the terms on the right-hand side are aggregates for the consumption of the representative household C_t, consumption of the managers $C_{m,t}$, R&D spending X_t, and investment in physical capital I_t respectively. In order to calculate C_t, we need expressions for $C_{m,t}$, X_t, and I_t. In a balanced growth path equilibrium, aggregate physical capital stock grows according to $K_{t+1} = G_\zeta K_t$. By definition, aggregate investment at time t is $I_t = K_{t+1} - K_t(1-\delta)$. Hence we have $I_t = K_t(G_\zeta - 1 + \delta)$. To calculate I_t, we need K_t. Recall that the first order condition with respect to capital of the firm's static profit maximization yields $k(z_t, \bar{z}_t) = \frac{\kappa}{r_t+\delta} y(z_t, \bar{z}_t)$. Hence, we have:

$$\frac{K_t}{Y_t} = \int \frac{k(z_t, \bar{z}_t)}{y(z_t, \bar{z}_t)} dZ(z) = \frac{\kappa}{r+\delta} \tag{179}$$
$$\Rightarrow I_t = \frac{K_t}{Y_t} Y_t (G_\zeta - 1 + \delta) = \frac{\kappa\pi(G_\zeta - 1 + \delta)}{\zeta(r+\delta)}\tilde{z}_t \tag{180}$$

For aggregate R&D spending, we have

$$X_t = \hat{C}(i)\tilde{z}_t \tag{181}$$

For aggregate consumption of the managers, we have:

$$C_{m,t} = \mathbb{E}[c_t] = \left(s + \frac{o\gamma v_1}{G_\zeta} i(1-i) \right) \tilde{z}_t \tag{182}$$

Hence, the initial consumption level C_0 is given by:

$$C_0 = \left[\frac{\pi}{\zeta} - \frac{\kappa\pi(G_\zeta - 1 + \delta)}{\zeta(r+\delta)} - \hat{C}(i) - \left(s + \frac{o\gamma v_1}{G_\zeta} i(1-i)\right)\right]\tilde{z}_0 \tag{183}$$

A.8 CEO's Decision Problem with Taxes

In this section, we consider the decision problem of a risk averse CEO, where each component of the compensation can be taxed at different rates. CEO compensation consists of two components: Salary s_t which is not state-contingent, and stock options o_t which have a state-contingent payoff. These two sources of CEO income are taxed at the linear rates, τ_s, and $\tau_o \in (0,1)$ respectively. CEO compensation in period t is written as:

$$c_t = (1-\tau_s)s_t\tilde{z}_t + (1-\tau_o)o_t \max\{0, V(z_t,\Theta_t) - (1+r_t)S(z_{t-1},\Theta_{t-1})\} \tag{184}$$

In this equation, s_t denotes the (normalized) salary received by the CEO, whereas o_t denotes the share options granted to the CEO as a fraction of the total shares of the firm. The second term has a positive value if the value of the firm next period exceeds the strike price this period, and is zero otherwise. Therefore, the option part of CEO compensation is convex in the future value of the firm.

Assuming the value function of the firm given a time-invariant innovation decision i is given by $V(i,z,\hat{z}) = v_1\hat{z} + v_2(i)\tilde{z}$, The lifetime utility of the CEO along a balanced growth path can be written as:

$$U(\vec{c},\vec{i}) = \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\tilde{z}_t^{1-\omega}\left(\frac{((1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1}{G_\zeta}\max\{0,\mathbb{I}_{t-1} - i_{t-1}\})^{1-\omega}}{1-\omega} - v(i_t)\right)\right] \tag{185}$$

Determination of $\vec{i}$ completely pins down the values of $\vec{c}$. In turn, the first order condition with respect to i_t is given by:

$$\begin{aligned} v'(i_t) = \beta G_\zeta^{1-\omega} \Bigg[& \frac{\left((1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1}{G_\zeta}(1-i_t)\right)^{1-\omega}}{1-\omega} - \frac{((1-\tau_s)s)^{1-\omega}}{1-\omega} \\ & - \frac{i_t(1-\tau_o)o\gamma v_1}{G_\zeta}\left((1-\tau_s)s + \frac{(1-\tau_o)o\gamma v_1}{G_\zeta}(1-i_t)\right)^{-\omega}\Bigg] \end{aligned} \tag{186}$$

Note that all terms except i_t are time-independent. The unique solution to this equation pins down $\hat{i}$. The first term is the utility from consumption at time $t+1$ conditional on successful innovation. The second term is the same for the case where innovation fails. The last term captures the fact that increasing i_t actually reduces the payout of the option conditional on success, since the payout is linear in $(1-i_t)$.

A.9 Extended Model with Short-Termism

In this section, we present the details of the extended model with short-termism introduced in Section 5. The change in the preferences given in equation (29) affects the CEO's innovation decision. Given the contract (s, o), the sequential problem of the CEO can be written as:

$$\max_{\vec{i}} \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \tilde{z}_t^{1-\omega} \left(\frac{(s + \frac{o\gamma v_1}{G_\zeta} \max\{0, \mathbb{I}_{t-1} - i_{t-1}\})^{1-\omega}}{1-\omega} - v(i_t) - \hat{\mathbb{I}}_t \xi\right)\right] \tag{187}$$

The objective is no longer guaranteed to be continuous since $\hat{\mathbb{I}}_t$ has a discrete jump at $\Pi(z_t, \epsilon_t, \bar{z}_t) - C(i_t, \bar{z}_t) - s_t = \bar{D}_t(i, z_t, \bar{z}_t, s_t)$. Call the value of i_t that solves this equation i_t^*, and suppose for now that i_t^* is independent of z_t, $\bar{z}_t$, and s_t. If there is no $i_t^* \in [0, 1]$ that can solve the equation, then there is no discontinuity, and the CEO's innovation decision can be found by using the first order condition as before. Now consider the case where $i_t^* \in [0, 1]$ exists. In the set $[0, 1] \setminus \{i_t^*\}$, there exists a single local maximum which solves the equation:

$$v'(i_t) = \beta G_\zeta^{1-\omega}\left[\frac{\left(s + \frac{o\gamma v_1}{G_\zeta}(1 - i_t)\right)^{1-\omega}}{1-\omega} - \frac{s^{1-\omega}}{1-\omega} - \frac{i_t o\gamma v_1}{G_\zeta}\left(s + \frac{o\gamma v_1}{G_\zeta}(1 - i_t)\right)^{-\omega}\right] \tag{188}$$

Call the value of i_t that solves this equation i_t^{**}. The CEO will choose either i_t^* or i_t^{**} depending on which one attains a higher value when plugged into

$$-v(i_t) - \hat{\mathbb{I}}_t \xi + \beta G_\zeta^{1-\omega}\left[i_t \frac{\left(s + \frac{o\gamma v_1}{G_\zeta}(1 - i_t)\right)^{1-\omega}}{1-\omega} + (1 - i_t)\frac{s^{1-\omega}}{1-\omega}\right] \tag{189}$$

where the first two terms are the total utility cost of choosing innovation i_t (disutility from overseeing innovation and potential punishment), and the last term is the utility gain from compensation next period. Denote the policy function of the CEO as $\hat{i}_t$. There are three economically meaningful cases: (i) $i_t^{**} < i_t^*$, so the dividend target constraint does not bind and $\hat{i}_t = i_t^{**}$, (ii) $i_t^{**} > i_t^*$ and i_t^* delivers a higher value, so the CEO chooses exactly the amount of innovation that will deliver the dividend target demanded by the investors which is $\hat{i} = i_t^*$, and (iii) $i_t^{**} > i_t^*$ but i_t^{**} delivers a higher value, in which case the CEO chooses the same innovation as he would have without the punishment, $\hat{i}_t = i_t^{**}$. The second case is the key one, where the binding dividend target constraint encourages the CEO to cut down innovation in order to avoid punishment. In cases where the CEO is already choosing a lower innovation rate compared to the shareholder-optimal one, short-termism further reduces innovation, exacerbating the loss in innovation due to agency frictions.

To close the extension to the model, we need to pick a functional form for $\bar{D}_t(i_t, z_t, \bar{z}_t, s_t)$. We pick

$$\bar{D}_t(i_t, z_t, \bar{z}_t, s_t) = \Lambda \pi \hat{z}_t - \hat{C}(i_t)(\tilde{z}_t - \hat{z}_t) - s_t \tilde{z}_t \tag{190}$$

where $\Lambda > 0$ is the scale parameter that captures how demanding the investors are. The first term is linear in the expected profits of the firm, which means the investors demand higher dividends from more profitable firms. The second term is a technical one that eliminates a mechanical advantage to the CEOs who lead larger firms.[48] This term washes out on average since $\mathbb{E}[\tilde{z}_t - \hat{z}_t] = 0$. The third term is the salary payment. Given the functional form, the equation that pins i_t^* down becomes:

$$\begin{aligned} \Pi(z_t, \epsilon_t, \bar{z}_t) - C(i_t, \bar{z}_t) - s_t\tilde{z}_t &= \bar{D}_t(i_t, z_t, \bar{z}_t, s_t) \\ \pi e^{\epsilon_t}\hat{z}_t - \hat{C}(i_t)\tilde{z}_t - s_t\tilde{z}_t &= \Lambda\pi\hat{z}_t - \hat{C}(i_t)(\tilde{z}_t - \hat{z}_t) - s_t\tilde{z}_t \\ \pi(e^{\epsilon_t} - \Lambda) &= \hat{C}(i_t) \end{aligned} \tag{191}$$

Note that the equation is independent of z_t, $\bar{z}_t$, and s_t, consistent with the assumption earlier. Since the range of the function $\hat{C}(i_t)$ is $[0, \infty)$, a solution i_t^* exists if and only if $e^{\epsilon} \geq \Lambda$. If a solution does not exist, the optimal policy is given by $\hat{i}_t = i_t^{**}$.

The new innovation policy $\hat{i}$ is now a function of s, o, and ϵ_t. Denote the cumulative distribution function of ϵ_t as $P(\epsilon_t)$. By definition of ϵ_t, $P(\epsilon_t) = P(\epsilon_{t-1}) \equiv P(\epsilon), \forall t$. Given the new innovation function, the expected lifetime utility of the CEO takes the form:

$$\mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\omega}}{1-\omega} - v(i_t)\tilde{z}_t^{1-\omega}\right)\right] \tag{192}$$

$$\begin{aligned} = \; & \sum_{t=0}^{\infty} (\beta G_\zeta^{1-\omega})^t \Bigg[\int \left(\frac{\hat{i}(s,o,\epsilon_{t-1})}{1-\omega} \left(s + \frac{o\gamma v_1(1-\hat{i}(s,o,\epsilon_{t-1}))}{G_\zeta} \right)^{1-\omega} + \frac{(1-\hat{i}(s,o,\epsilon_{t-1}))s^{1-\omega}}{1-\omega} \right) dP(\epsilon_{t-1}) \\ & - \int \left(v(\hat{i}(s,o,\epsilon_t)) - \hat{\mathbb{I}}_t(\hat{i}(s,o,\epsilon_t), \epsilon_t)\xi \right) dP(\epsilon_t) \Bigg] \tilde{z}_0^{1-\omega} \end{aligned} \tag{193}$$

$$\begin{aligned} = \; & \frac{\tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}} \int \Bigg[\left(\frac{\hat{i}(s,o,\epsilon)}{1-\omega} \left(s + \frac{o\gamma v_1(1-\hat{i}(s,o,\epsilon))}{G_\zeta} \right)^{1-\omega} + \frac{(1-\hat{i}(s,o,\epsilon))s^{1-\omega}}{1-\omega} \right) \\ & - \left(v(\hat{i}(s,o,\epsilon)) - \hat{\mathbb{I}}_t(\hat{i}(s,o,\epsilon), \epsilon)\xi \right) \Bigg] dP(\epsilon) \end{aligned} \tag{194}$$

Next, we need to rederive the value function of the firm given a time-invariant innovation decision which is a function of the realization of the temporary productivity shock ϵ. We use i to refer to the function itself, and $i(\epsilon)$ for the value of the function at ϵ. The value function of the firm can be written recursively as:

$$V(i, z, \bar{z}) = \int \left[\Pi(z, \epsilon, \bar{z}) - C(i(\epsilon), \bar{z}) + \frac{i(\epsilon)}{1+r} V(i, z + \gamma\bar{z}, \bar{z}') + \frac{1-i(\epsilon)}{1+r} V(i, z, \bar{z}') \right] dP(\epsilon) \tag{195}$$

[48] Consider the scenario where we do not have the second term, and $D_t(i_t, z_t, \bar{z}_t, s_t) = \Lambda\pi\hat{z}_t - s_t\tilde{z}_t$. Then reorganizing $\Pi(z_t, \epsilon_t, \bar{z}_t) - C(i_t, \bar{z}_t) - s_t\tilde{z}_t = \bar{D}_t(i_t, z_t, \bar{z}_t, s_t)$ leads to $\pi(e^{\epsilon_t} - \Lambda)\hat{z} = \hat{C}(i_t)$, which means the cutoff at which the dividend constraint binds, i_t^*, is higher for firms with higher $\hat{z}$. We eliminate this advantage by adding the second term, which also allows closed-form solutions.

Guess a solution of the form $V(i,z,\bar{z}) = v_1\hat{z} + v_2(i)\tilde{z}$. To verify:

$$\begin{aligned} v_1\hat{z} + v_2(i)\tilde{z} &= \Bigg[\pi e^{\epsilon}\hat{z} - \hat{C}(i(\epsilon))\tilde{z} + \frac{i(\epsilon)}{1+r}\left[\frac{v_1}{G_\lambda}\hat{z} + \frac{v_1\gamma}{G_\lambda}\tilde{z} + v_2(i)G_\zeta\tilde{z}\right] \\ &\quad + \frac{1-i(\epsilon)}{1+r}\left[\frac{v_1}{G_\lambda}\hat{z} + v_2(i)G_\zeta\tilde{z}\right]\Bigg] dP(\epsilon) & (196) \\ v_1\hat{z} + v_2(i)\tilde{z} &= \left[\pi + \frac{v_1}{(1+r)G_\lambda}\right]\hat{z} + \left[\int\left(-\hat{C}(i(\epsilon)) + \frac{i(\epsilon)v_1\gamma}{(1+r)G_\lambda}\right)dP(\epsilon) + \frac{v_2(i)G_\zeta}{1+r}\right]\tilde{z} & (197) \end{aligned}$$

Hence:

$$\begin{aligned} v_1 &= \left(1 - \frac{1}{(1+r)G_\lambda}\right)^{-1}\pi & (198) \\ v_2(i) &= \left(1 - \frac{G_\zeta}{1+r}\right)^{-1}\int\left(\frac{i(\epsilon)\gamma v_1}{(1+r)G_\lambda} - \hat{C}(i(\epsilon))\right)dP(\epsilon) & (199) \end{aligned}$$

Given the value function of the firm, the expected utility of the shareholders becomes

$$\begin{aligned} & \mathbb{E}\left[V(z_0,\Theta_0) - \sum_{t=0}^{\infty}\frac{c_t}{\prod_{T=1}^{t}(1+r_T)}\right] & (200) \\ =\; & v_1\hat{z}_0 + v_2(i)\tilde{z}_0 - \underline{\mathrm{U}} & (201) \end{aligned}$$

The first and third terms are independent of the choice of s or o; so they can be moved out of the maximization. Note that the real interest rate is constant in the balanced growth path equilibrium. Then:

$$\underline{\mathrm{U}} = \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{(1+r)^t}\right] = \frac{(1+r)\tilde{z}_0}{1+r-G_\zeta}\int\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o,\epsilon)(1-\hat{i}(s,o,\epsilon))\right]dP(\epsilon) \quad (202)$$

Putting all components together, the problem can be rewritten as follows:

$$\begin{aligned} \max_{o\in[0,1]} \quad & \Bigg\{\frac{\eta\tilde{z}_0^{1-\omega}}{1-\beta G_\zeta^{1-\omega}}\int\Bigg[\frac{\hat{i}(s,o,\epsilon)}{1-\omega}\left(s + \frac{o\gamma v_1(1-\hat{i}(s,o,\epsilon))}{G_\zeta}\right)^{1-\omega} + \frac{(1-\hat{i}(s,o,\epsilon))s^{1-\omega}}{1-\omega} \\ & -v(\hat{i}(s,o,\epsilon)) - \hat{\mathbb{I}}_t(\hat{i}(s,o,\epsilon),\epsilon)\xi\Bigg]dP(\epsilon) + (1-\eta)v_2(\hat{i}(s,o))\tilde{z}_0\Bigg\}, \text{such that} & (203) \\ \underline{\mathrm{U}} = \; & \mathbb{E}\left[\sum_{t=0}^{\infty}\frac{c_t}{(1+r)^t}\right] = \frac{(1+r)\tilde{z}_0}{1+r-G_\zeta}\int\left[s + \frac{o\gamma v_1}{G_\zeta}\hat{i}(s,o,\epsilon)(1-\hat{i}(s,o,\epsilon))\right]dP(\epsilon) & (204) \end{aligned}$$

A.10 Microfoundations of the Board Objective Function

In Section 2, CEO influence in the determination of the compensation structure is modeled in a way similar to Page (2018), where the objective function assigns a weight $\eta \in [0,1]$ to the CEO's utility and $(1-\eta)$ to the shareholders' utility (the expected value of the firm minus compensation). To link the CEO influence parameter η to the empirical results, we assume that η is decreasing in institutional ownership. In this section, we offer microfoundations that provide a rationale for these modeling assumptions.

What is the process through which CEO compensation is determined? A CEO's compensation is ordinarily the result of bargaining and negotiations between the CEO and the board of directors. In an ideal world, the board of directors would adopt the preferences of the shareholders and make decisions accordingly. In practice, a CEO can have significant influence over the board members (see Bertrand and Mullainathan (2001), Bebchuk and Fried (2003), Hwang and Kim (2009) among others). Therefore, the composition of the board can affect CEO influence, where a board stacked with dependent directors might put more weight on the CEO's preferences compared to those of the shareholders.

The next logical step is to consider how board members are appointed. In a world with perfect information, the shareholders would not agree to appoint a candidate to the board if the candidate is not independent. The more likely scenario is one where the shareholders are imperfectly informed whether a candidate is dependent or independent. In such a setting, better-informed shareholders – such as institutional investors – can help improve the composition of the board members by increasing the likelihood of election of independent board members. In the following section, we explicitly model this game in detail and establish an inverse relationship between institutional ownership and CEO influence under very mild assumptions.

A.10.1 Model

There are $N \in \mathbb{Z}^{++}$ shareholders of the firm, denoted by $i \in \{1, ..., N\}$. The shareholders vote upon the appointment of a new director to the board. The candidate in question can have two types, $x \in \{I, D\}$ where I stands for an independent candidate, and D stands for a dependent candidate. An independent candidate assigns zero weight to the CEO's preferences and acts as a perfect mediator of shareholder preferences. A dependent candidate assigns some nonzero weight $\eta_{ub} > 0$ to the CEO's utility and $1 - \eta_{ub}$ to the shareholders' utility. All shareholders share the same preferences as they all want to maximize the value of the firm. They would prefer to appoint an independent candidate over a dependent candidate, as the appointment of dependent candidates to the board increases CEO influence which leads to a reduction in firm value as discussed in Section 2. If they do not appoint a candidate, there is a small loss, as the spot on the board remains vacant and must be filled eventually, and the problem is deferred but not resolved.

Table A1 presents the payoff matrix of the shareholders. The value from appointing an independent candidate is normalized to zero. Appointing a dependent candidate results in a value loss of θ. Not appointing any candidate yields the deferral cost of δ. We assume $0 < \delta < \theta$, i.e. the cost of deferring the problem is smaller than the cost of appointing a dependent candidate.

Given the payoff structure, shareholders must decide to appoint or reject the candidate through a majority vote. The type of the candidate, $x \in \{I, D\}$ is not perfectly observable. The shareholders

TABLE A1: PAYOFF MATRIX

	Independent Candidate ($x = I$)	Dependent Candidate ($x = D$)
Candidate is appointed	0	$-\theta$
Candidate is rejected	$-\delta$	$-\delta$

receive a private and noisy signal regarding the true type of the candidate, and the quality of the private signals are heterogeneous across shareholders. Given this information structure which is public information, each shareholder i can vote in favor of or against the candidate, or abstain, denoted by $v_i \in \{Y, N, 0\}$ respectively. In the case of a tie, a fair coin toss determines the final outcome.

The game we have described thus far is new in the context of corporate governance. However, similar games have been extensively studied in the context of voting and voter turnout in public elections. Our assumption of homogeneity in shareholder preferences places our game in the *common value elections* branch of this literature. Some recent work includes Feddersen and Pesendorfer (1996, 1999) and Krishna and Morgan (2011). The closest paper to our setting is McMurray (2013) where the electorate must decide between two electoral outcomes where each voter receives a private signal on which outcome is optimal, but the quality of the private signal is heterogeneous across voters. The voters can vote for either policy or abstain. The ability of the voters to abstain is crucial. While private signals are always informative, voters with worse signal quality might rationally choose not to vote. This is because of the "swing voter's curse" proposed in Feddersen and Pesendorfer (1996): a citizen's vote is most likely to be pivotal when he or she mistakenly votes for the inferior outcome. In the context of our game, this means less informed shareholders might choose to abstain in order not to overturn the votes of better-informed shareholders – such as institutional investors – as they are more likely to be correct. In the rest of this section, we apply the model in McMurray (2013) to our setting, discuss how institutional investors would differ from other shareholders, and link the outcomes to our model in Section 2.

Without loss of generality, let the ex-ante probabilities of both types of candidates to be equal, $Pr(x = I) = Pr(x = D) = 0.5$. Each shareholder i has private signal quality $q_i \in [0.5, 1]$, where higher values correspond to more informative signals. This signal quality is drawn from a common distribution $F(q)$ and the draws are i.i.d. across shareholders. The associated probability distribution function $f(q)$ is assumed to be smooth and strictly positive on $(0.5, 1)$. The private signal of shareholder i is denoted by $s_i \in \{i, d\}$ where receiving signal $s_i = i$ is more likely when the true type of the candidate is $x = I$, and signal $s_i = d$ is more likely when the true type is $x = D$. F is common knowledge, but the realizations of q_i and s_i are private to shareholder i. Once the signal is observed, shareholder i's belief is given by Bayesian updating:

$$Pr(i|q_i, x = I) = Pr(d|q_i, x = D) = \frac{0.5q_i}{0.5q_i + 0.5(1 - q_i)} = q_i \tag{205}$$

This means shareholder i assigns probability q_i to her signal s_i being correct. Therefore shareholders with better signal quality are more confident. For instance, $q_i = 1$ implies the shareholder is certain that the signal is correct, and $q_i = 0.5$ implies the shareholder learned nothing new from the signal. Let $\sigma : [0.5, 1] \times \{i, d\} \to \{Y, N, 0\}$ denote a strategy which maps signal quality q_i and observed private signal s_i to voting decision v_i. The strategy σ_i^* is a best response to opponent strategies if it maximizes expected payoff. We consider the Bayesian Nash equilibrium of this game where the strategy of each shareholder is a best response to other shareholders' strategies. For convenience, the number of shareholders N is assumed to be drawn from a Poisson distribution with mean n, which makes the equilibrium necessarily symmetric (Myerson (1998, 2000)). Therefore, the equilibrium strategy profile is denoted as σ^*.

Definition 1. *For any quality threshold $T \in [0.5, 1]$, σ_T is defined as a quality threshold strategy as follows:*

$$\sigma^T(q, s) = \begin{cases} Y \textit{ if } s = I \textit{ and } q \geq T \\ N \textit{ if } s = D \textit{ and } q \geq T \\ 0 \textit{ otherwise} \end{cases} \tag{206}$$

The quality threshold strategy is a very intuitive one. It specifies the shareholder to vote in line with the private signal she receives, but this is done only if the shareholder's signal quality q_i lies above a certain quality threshold $T \in [0.5, 1]$. As a consequence of this strategy, shareholders with signal quality worse than T choose to abstain, allowing more informed shareholders to vote (truthfully) according to their own private signals. $T > 0.5$ is the rational response to the "swing voter's curse" discussed earlier. Using this definition, we can characterize the set of Bayesian Nash equilibria of the game:

Theorem 4. *There exists a quality threshold $T^* \in (0.5, 1)$ such that σ^{T^*} is a Bayesian Nash equilibrium. Furthermore, if σ^* is a Bayesian Nash equilibrium, then it is a quality threshold strategy.*

It can further be shown that the equilibrium is unique for well-behaved signal quality distributions F. For the main result we are interested in, we assume the probability density function f to be log-concave.[49] Let T_n^* denote the equilibrium participation threshold for a game where the mean of the population distribution is n.

Theorem 5. *Assume f is log-concave. Then there exists a unique limit point T_∞^* such that for any sequence of equilibrium participation thresholds, $T_n^* \to T_\infty^*$.*

[49] Examples of log-concave distributions are the normal distribution, exponential distribution, uniform distribution over a convex set, logistic distribution, and extreme value distribution.

This result means that in large elections, F precisely determines the level of voter turnout $\tau = 1 - F(T^*_\infty)$, where shareholders with signal quality $q_i < T^*_\infty$ choose to abstain. Abstention is still non-trivial (a positive mass) even as the population goes to infinity. Finally, define the margin of victory as a fraction of those who did not abstain as $\mu = 2\mathbb{E}[q_i | q_i \geq T^*_\infty] - 1$.

Now we are ready to consider the effects of improved information on the equilibrium outcome. Proposition 1 outlines two particular cases where the results are unambiguous.

Proposition 1. *Let F and G be two distributions with log-concave probability density functions f and g. Suppose G first-order stochastically dominates F. Then:*

1. *If $g(q) = f(q), \forall q \geq T^*_{\infty,F}$, then $T^*_{\infty,G} = T^*_{\infty,F}$, $\tau_G = \tau_F$, and $\mu_G = \mu_F$.*
2. *If $G(T^*_{\infty,F}) = F(T^*_{\infty,F})$, then $T^*_{\infty,G} > T^*_{\infty,F}$, $\tau_G < \tau_F$, and $\mu_G > \mu_F$.*

Proposition 1 considers the effects of improving signal quality where the new signal quality distribution first-order stochastically dominates the old distribution. In particular, it highlights that information is only useful if it improves the information of those who were already voting.

In the first case, only the signal quality of the former abstainers is improved. In this case, the threshold T^*_∞ does not change, therefore the turnout, the margin of victory, and the probability of following the superior policy (the probability of approval when the candidate is independent, and the probability of refusal when the candidate is dependent) all remain the same. Additional information does not change the realized election outcome, and provides no benefits.

In the second case, only the signal quality of former voters is improved. This time, the threshold T^*_∞ increases, which means more low signal quality shareholders choose to abstain. Consequently, the turnout goes down, but the margin of victory improves, as well as the probability of following the superior policy. As a result of better-informed shareholders at the right tail of the distribution, the signal quality of the shareholders that vote improves not only due to the exogenous change in F, but also as a result of less informed shareholders rationally choosing not to vote, in effect, deferring to the judgment of shareholders that are better-informed. Since this is a common value election, this improves the expected utility of all shareholders by increasing the probability of accepting independent board member candidates, and decreasing the same probability for dependent board member candidates. This leads to a board less stacked with dependent board members.

A.10.2 Interpretation

As Proposition 1 demonstrates, better information can improve board independence and thereby reduce CEO influence precisely when signal quality is improved among the voting shareholders. This allows less informed shareholders to abstain and benefit from the expertise of their better-informed counterparts. We argue that institutional investors precisely fulfill this role. In particular, we posit that institutional investors are better informed than shareholders that have a smaller stake in the firm on average.

The informational advantage of institutional investors can owe to many different reasons. First, the firm might provide institutional investors with more information than what they provide to individual shareholders. Institutional investors enjoy a degree of influence over the firm, not only because they are large stakeholders, but also because other investors closely monitor the portfolio allocation decisions of institutional investors. Second, institutional investors can have a better information acquisition technology thanks to their specialization, or they might be familiar with the board members in question from their activities in other firms where they served as a board member, owing to the widespread portfolios of institutional investors. Third, in the context of costly information acquisition, large stakeholders such as institutional investors would optimally allocate more resources into information acquisition compared to individual shareholders with small or transient investment in the firm. This is because the cost per share is lower for large investors.

All of these scenarios would link higher institutional ownership to a more independent board and less CEO influence.[50] In our model in the main text, we only require CEO influence to be decreasing in institutional ownership. The board member appointment model under information frictions we propose in this appendix provides one channel through which the inverse relationship between the two can be justified. Capturing the specifics of shareholder voting in more detail such as costly voting, costly information acquisition, and sharing information across shareholders might be good avenues for further research.

A.10.3 Proofs

The proofs for Theorem 4, Theorem 5, and Proposition 1 can be constructed through minor modifications of Theorems 1, 2, and 4, and Proposition 3 in McMurray (2013). The primary difference is in the payoff matrix. In McMurray (2013), the voters must choose between two policies A and B. Policy A is the superior policy if the true state of nature is α and the inferior policy otherwise. The payoff when the superior policy is chosen is 1, and it is 0 otherwise. Choosing the parameters of our model as $\delta = 1$ and $\theta = 2$ would make the incentives identical. However, it is simple to show that the more general form with $0 < \delta < \theta$ would also work as the pivotal voters would still strictly favor voting in the same direction regardless of the absolute values of δ and θ.

A.11 Comparative Statics

In this section, we examine the innovation decisions of the firms, the compensation structure, output growth rate, and social welfare provided that the firms and managers had different fundamental characteristics other than those implied by the parameter estimates from Table 1. This is summarized in Figure A1. For each panel in each figure, we solve and simulate the model 20 times, each simulation corresponding to a different value of the parameter in question. For each of these 20 simulations, we calculate the relevant moments. The first two rows of Figure A1 show the comparative statics of the impact of changing the parameter that governs CEO influence, η. We find

[50] There is a positive correlation between institutional ownership and proxies of board independence. See Whidbee (1997) and Arthur (2001) among others.

that an increase in CEO influence reduces the fraction of stock options in the CEO compensation and increases the fraction of state-noncontingent pay, salary, in the CEO compensation. CEO influence has a negative impact on the firm's innovation, which leads to a lower aggregate output growth rate and consumption-equivalent welfare. We also plot the optimal innovation level of the shareholder by the dashed red line in the innovation panel. The red line captures the firm's optimal innovation choice without agency frictions conditional on other firms in the economy still being subject to agency frictions. When other firms suffer from the more severe distortion caused by increased agency frictions, it becomes more attractive for the firm to carry out more innovation since the firm can capture a larger market share and profit by increasing its productivity.

The third and fourth rows of Figure A1 show the comparative statics of the impact of changing the parameter that governs the firm's R&D cost, χ. We find that with higher R&D cost, the firm chooses a contract that results in a lower innovation level. We plot the optimal innovation level of the shareholders by the dashed red line in the innovation panel as well. The distance between the dashed red line and the solid blue line represents the deviation of innovation from the shareholder-optimal level. We find that the distortion caused by agency frictions is more severe for more innovative firms (firms with lower R&D cost). If a firm is less efficient in innovation, it needs less innovation effort from the CEO and, therefore, it would adopt a less incentivized compensation contract, featuring a lower fraction of stock options and a higher fraction of salary. The equilibrium output growth rate and social welfare decrease since the firm carries out less innovation.

The last two rows of Figure A1 show the comparative statics of the impact of changing the parameter that governs CEO innovation disutility, ν. When it becomes costlier for the CEO to oversee innovation, the firm needs to adopt a more incentivized compensation contract to motivate the manager to exert the same effort. Hence, the option ratio increases and the salary ratio decreases in the CEO compensation. We also plot the CEO's optimal innovation decision in the innovation panel. The red dashed line captures the innovation the firm would choose if it were not subject to the agency frictions while all other firms in the economy were subject to the agency frictions. When it becomes costlier for all other firms' managers to oversee innovation, the benefit for innovation increases since the firm can capture a larger market share by increasing its relative productivity. Hence the optimal innovation decision is upward sloping. Also, the gap between the optimal innovation rate and innovation rate chosen by the CEO is smaller if it is less costly for the CEO to oversee the innovation. In other words, the agency friction is less severe if the CEO is more innovative. The equilibrium output growth rate and social welfare decrease in ν since the firms carry out less innovation.

A.12 Exogenous vs. Endogenous Productivity Growth

In the benchmark model, productivity growth along a balanced growth path equilibrium is completely driven by the endogenous innovation strategies of the firms in the economy. The implicit assumption is that there are no other mechanisms at play that might change total factor productivity between the two time periods. If there are other sources of TFP growth, such as a reduction in unmodeled sources of inefficiency, this would mean that we would be attributing

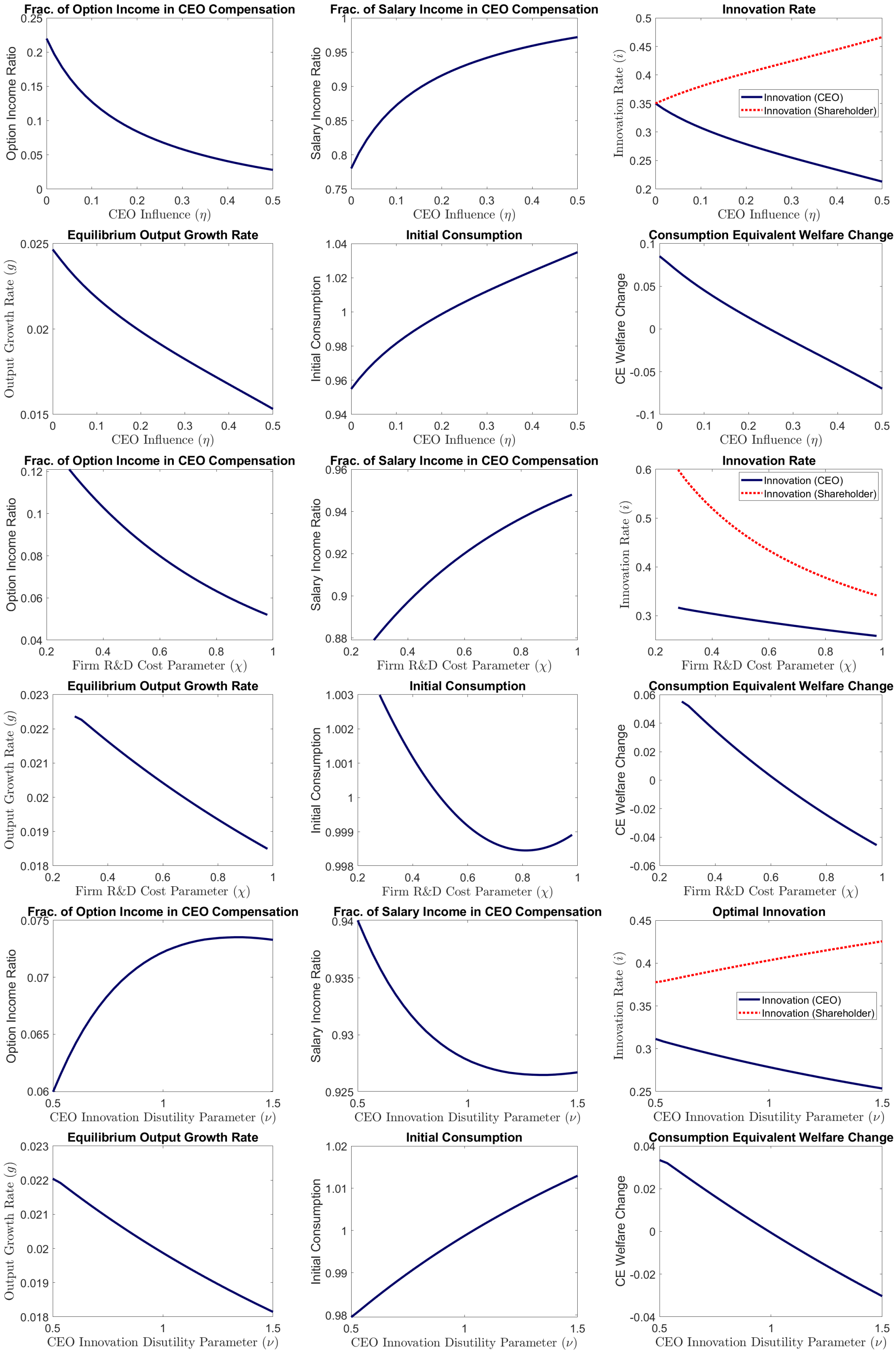

FIGURE A1: COMPARATIVE STATICS

too much importance to the role of innovation in the determination of economic growth. To see how much our quantitative results would change if we attribute a smaller role to innovation, we introduce exogenous productivity growth to the model. To do so, we change the law of motion that governs a firm's productivity z_t. In the modified model, if the firm is successful in innovation, its new productivity becomes $z_{t+1} = z_t + \iota\bar{z}_t + \gamma\bar{z}_t$, where $\iota > 0$ is a parameter that determines the free exogenous productivity increase. Therefore, even when the firm fails in innovation, its new productivity becomes $z_{t+1} = z_t + \iota\bar{z}_t$ instead of remaining the same as in the baseline. One could also think about this term as the productivity increase due to incremental innovations that do not require CEO supervision.

Most of the model solution remains similar to the baseline. There are two main changes. First, the value of $v_2(i)$ in equation (34) changes to

$$v_2(i) \quad = \quad \left(1 - \frac{G_\zeta}{1+r}\right)^{-1} \left(\frac{i\gamma v_1}{(1+r)G_\lambda} + \frac{\iota v_1}{(1+r)G_\lambda} - \hat{C}(i)\right) \tag{207}$$

Second, the growth rate of aggregate productivity changes to $g_z = \hat{i}\gamma\bar{z} + \iota\bar{z}$.

To estimate this modified model, we require 50% of aggregate productivity growth to be due to the ι term. We choose its value to deliver exactly 1% output growth in the absence of firm innovation. Then we re-estimate all the remaining parameters as before. The results of this estimation exercise are presented in Table C3. Using this re-estimated model, we repeat the agency friction shut-down experiment in Section 4.7. The results can be found in Table C5. As expected, both aggregate productivity growth and social welfare become less connected to agency frictions. The welfare impact of agency frictions goes down from its baseline value of 7.3% to 3.5%, which is approximately half of the initial value. The welfare change numbers in other experiments are likewise halved when we attribute half of the aggregate productivity growth to exogenous growth.

A.13 Derivation of the Option Exercise Value

In this section, we derive the option exercise value in our model. To simplify notation for the present discounted values, assert the equilibrium result that $r_t = r, \forall t$ in a BGP, which is due to the Euler equation of the consumer's optimization problem. Define $\tilde{V}(z_t, \Theta_t)$ as the firm value without CEO cash compensation at time t. Then:

$$\tilde{V}(z_t, \Theta_t) = V(z_t, \Theta_t) - s_t - \sum_{T=1}^{\infty} \frac{s_{t+T}}{(1+r)^T} \tag{208}$$

The first term on the RHS is the firm value function at time t which is the expected present discounted value of all static profits minus R&D expenses from time t onwards. The second term is the salary payment to the manager at time t. The third term is the present discounted value of all salary payments to the manager from time $t+1$ onwards, which is deterministic. We can also write down the firm value function at time t explicitly as follows:

$$V(z_t,\Theta_t) = [\Pi(z_t,\Theta_t) - C(i_t,\bar{z}_t)] + \mathbb{E}_t\left[\sum_{T=1}^{\infty}\frac{\Pi(z_{t+T},\Theta_{t+T}) - C(i_{t+T},\bar{z}_{t+T})}{(1+r)^T}\right] \tag{209}$$

The first term is the static profits minus R&D expenses at time t. The second term is the expected present discounted value of all static profits minus R&D expenses from time $t+1$ onwards.

Next, we write down the strike price (with salary payments explicitly shown) at time t as:

$$\tilde{S}(z_t,\Theta_t) = \tilde{V}(z_t,\Theta_t) - [\Pi(z_t,\Theta_t) - C(i_t,\bar{z}_t) - s_t] \tag{210}$$

where the first term is the firm value without CEO cash compensation at time t, and the second term is the cash flow to the shareholders at time t, which is equal to static profits minus R&D expenses and salary payment to the manager at time t. Plugging equation (208) into equation (210), we get:

$$\begin{aligned}\tilde{S}(z_t,\Theta_t) &= V(z_t,\Theta_t) - s_t - \sum_{T=1}^{\infty}\frac{s_{t+T}}{(1+r)^T} - [\Pi(z_t,\Theta_t) - C(i_t,\bar{z}_t) - s_t] \\ &= V(z_t,\Theta_t) - \sum_{T=1}^{\infty}\frac{s_{t+T}}{(1+r)^T} - [\Pi(z_t,\Theta_t) - C(i_t,\bar{z}_t)]\end{aligned} \tag{211}$$

where the positive and negative s_t terms cancel each other out. Now, we can write down the value from exercising a stock option (granted at time $t-1$ and exercised at time t) with salary payments explicitly shown as follows:

$$\begin{aligned}&\tilde{V}(z_t,\Theta_t) - (1+r)\tilde{S}(z_{t-1},\Theta_{t-1}) \\ =\ &\left(V(z_t,\Theta_t) - s_t - \sum_{T=1}^{\infty}\frac{s_{t+T}}{(1+r)^T}\right) \\ &-(1+r)\left(V(z_{t-1},\Theta_{t-1}) - \sum_{T=1}^{\infty}\frac{s_{t-1+T}}{(1+r)^T} - [\Pi(z_{t-1},\Theta_{t-1}) - C(i_{t-1},\bar{z}_{t-1})]\right) \\ =\ &[V(z_t,\Theta_t) - (1+r)\left(V(z_{t-1},\Theta_{t-1}) - [\Pi(z_{t-1},\Theta_{t-1}) - C(i_{t-1},\bar{z}_{t-1})]\right)] \\ &+\left[-s_t - \sum_{T=1}^{\infty}\frac{s_{t+T}}{(1+r)^T} + (1+r)\sum_{T=1}^{\infty}\frac{s_{t-1+T}}{(1+r)^T}\right]\end{aligned} \tag{212}$$

where the last identity collects non-salary and salary terms in two separate groups. Note that the salary terms cancel each other out:

$$\begin{aligned}
& \left[-s_t - \sum_{T=1}^{\infty} \frac{s_{t+T}}{(1+r)^T} + (1+r) \sum_{T=1}^{\infty} \frac{s_{t-1+T}}{(1+r)^T}\right] \\
= & \left[-s_t - \sum_{T=1}^{\infty} \frac{s_{t+T}}{(1+r)^T} + (1+r) \frac{s_t}{(1+r)} + (1+r) \sum_{T=2}^{\infty} \frac{s_{t-1+T}}{(1+r)^T}\right] \\
= & \left[-s_t - \sum_{T=1}^{\infty} \frac{s_{t+T}}{(1+r)^T} + s_t + \sum_{T=1}^{\infty} \frac{s_{t+T}}{(1+r)^T}\right] \\
= & \ 0
\end{aligned}$$

Therefore, we obtain the exercise value of an option in our model as:

$$\begin{aligned}
& V(z_t, \Theta_t) - (1+r)\left(V(z_{t-1}, \Theta_{t-1}) - [\Pi(z_{t-1}, \Theta_{t-1}) - C(i_{t-1}, \bar{z}_{t-1})]\right) \\
= & \ V(z_t, \Theta_t) - (1+r) S(z_{t-1}, \Theta_{t-1})
\end{aligned} \tag{213}$$

which concludes the derivation.

A.14 SMM estimation

The productivity increase parameter conditional on successful innovation γ, the CEO disutility parameter ν, the R&D cost parameter χ, the upper bound for the distribution of CEO influence across firm types η_{ub}, and the present discounted value of CEO compensation, $\underline{\text{U}}$. All of these parameters are jointly estimated to match the following 7 moments: correlation between innovation and option ratio, correlation between innovation and institutional ownership, correlation between institutional ownership and option ratio, firm R&D intensity, CEO compensation to firm market capitalization ratio, long-run output growth, and mean option ratio using simulated methods of moments (SMM), which minimizes a distance criterion between key moments from actual data. SMM proceeds in the following way: For an arbitrary value of parameter vector $\theta = \{\gamma, \nu, \chi, \eta_{ub}, \underline{\text{U}}\}$, the dynamic problem is solved and the policy functions are generated. Then we use the policy functions to simulate a data panel of $(KN, T+100)$, where K is a strictly positive integer denoting the number of simulated panel data sets, N is the number of firms in the actual data, and T is the time dimension of the simulated data. The first 100 periods are discarded so as to start from the ergodic distribution.

Let x_{it} be the actual data vector, $i \in \{1, ..., N\}$, $t \in \{1, ..., T\}$, and let $y_{itk}(b)$ be the simulated vector from simulation k, $i \in \{1, ..., N\}$, $t \in \{1, ..., T\}$, and $k \in \{1, ..., K\}$. The simulated data vector, $y_{itk}(\theta)$, depends on a vector of structural parameters, θ. Define the moment conditions as:

$$\frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} \left[h(x_{it}) - \frac{1}{K} \sum_{k=1}^{K} h(y_{itk}(\theta))\right] \equiv \Psi^A - \Psi^S(\theta) \tag{214}$$

where $h(y_{itk}(\theta))$ is a vector of simulated moments and $h(x_{it})$ is the actual data moments. $\Psi^A =$

$\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}h(x_{it})$, $\Psi^S(\theta)=\frac{1}{NTK}\sum_{i=1}^{N}\sum_{t=1}^{T}\sum_{k=1}^{K}h(y_{itk}(\theta))$

The simulated moments estimator is defined as the solution to the minimization of:

$$\hat{\theta} = \arg\min_{\theta} \left[\Psi^A - \Psi^S(\theta)\right]' \hat{W} \left[\Psi^A - \Psi^S(\theta)\right] \tag{215}$$

in which $\hat{W}$ is a positive definite matrix that converges in probability to a deterministic positive definite matrix W. It is constructed by calculating the inverse of the variance-covariance matrix of the data moments.[51] Define Ω as the variance-covariance matrix of the data moments Ψ^A. Lee and Ingram (2010) show that under the estimating null, the variance-covariance of the simulated moments $\Psi^S(\theta)$ is equal to $\frac{1}{K}\Omega$. Since $\Psi^A$and $\Psi^S(\theta)$ are independent by construction, $\hat{W} = \left[(1+\frac{1}{K})\Omega\right]^{-1}$. Ω is calculated using influence function method following Erickson and Whited (2002).

We use a simulated annealing algorithm for minimizing the objective function. This starts with a predefined first and second guess. For the third guess onward, it takes the best prior guess and randomizes from this to generate a new set of parameter guesses. That is, it takes the best-fit parameters and randomly "jumps off" from this point for its next guess. Over time the algorithm "cools", so that the variance of the parameter jumps falls, allowing the estimator to fine-tune its parameter estimates around the global best fit. We restart the program with different initial conditions to ensure the estimator converges to the global minimum. The simulated annealing algorithm is extremely slow, which restricts the size of the parameter space that can be estimated. Nevertheless, we use this because it is robust to the presence of local minima and discontinuities in the objective function across the parameter space.

The simulated moments are asymptotically normal for fixed K. Denote $g(\theta) \equiv \Psi^A - \Psi^S(\theta)$. The asymptotic distribution of θ is given by:

$$\sqrt{n}(\theta - \hat{\theta}) \xrightarrow{d} N(0, avar(\hat{\theta})) \tag{216}$$

in which

$$avar(\hat{\theta}) = (1+\frac{1}{K}) \left[\frac{\partial g}{\partial \theta} W \frac{\partial g}{\partial \theta'}\right]^{-1} \left[\frac{\partial g}{\partial \theta} W \Omega W \frac{\partial g}{\partial \theta'}\right] \left[\frac{\partial g}{\partial \theta} W \frac{\partial g}{\partial \theta'}\right]^{-1} \tag{217}$$

in which Ω is the probability limit of a consistent estimator of the covariance matrix. We calculate the estimate of this covariance matrix using influence function of the moment vector clustered at firm level following Erickson and Whited (2002).

[51]Note that in our estimation exercise, we target an aggregate long-run output growth rate of 2%, and an aggregate R&D expenditures to GDP ratio of 2.91%, which are macro moments rather than moments directly taken from our firm sample. Average firm growth rate and firm-level R&D intensity – the natural counterparts of these two macro moments – are higher in our sample which consists of public firms from Compustat that are more innovative than the average firm in the economy. Therefore, to compute the variance-covariance matrix, we first normalize the firm-level values for the firm growth rate and R&D intensity such that the averages across all firms for the two moments equal the previously-mentioned macro values via dividing all values by the same constant scalar. This normalization preserves the shape of the distribution.

B Empirical Appendix

In this section, we present some empirical evidence which motivates our model and disciplines the structural estimation. In particular, we are interested in the relationship between institutional ownership, managerial compensation structure, and innovation. This information is used to discipline the same elasticities in our model through indirect inference. We combine information from USPTO Utility Patents Grant Data, Compustat North American Fundamentals, Execucomp, and Thomson-Reuters Institutional Holdings database to construct our sample.

B.1 Data Sources

USPTO Utility Patents Grant Data: The patent grant data are obtained from the NBER Patent Database Project and contain data for all 3,279,509 utility patents the USPTO granted between 1976 and 2006. This dataset includes extensive information on each granted patent, including the unique patent number, a unique identifier for the assignee, the nationality of the assignee, the technology class, and backward and forward citations in the sample up to 2006. Following a dynamic assignment procedure, we link this dataset to the Compustat dataset.

Compustat North American Fundamentals: We draw our main sample from Compustat for publicly traded firms in North America. This dataset contains balance sheets reported annually by companies between 1974 and 2006. It comprises 29,378 different companies, and 390,467 firm$\times$year observations. The main variables of interest are net sales, employment, firm age (defined as the time since entry into the Compustat sample), SIC code, R&D expenditures, total liabilities, net income, and plant property and equipment as a proxy for physical capital.

Executive Compensation Data (Execucomp): Standard and Poor's Execucomp provides detailed information for all components of CEO compensation from 1992 forward. This information is used to construct our CEO compensation measures.

Thomson-Reuters Institutional Holdings (13F) database: We obtain institutional ownership information from the Thomson-Reuters Institutional Holdings (13F) database. This dataset compiles Securities and Exchange Commission (SEC) Form 13-F filings of institutional holdings. It provides institutional common stock holdings and transactions, as reported on Form 13F filed with the SEC. Under rule 13(f), all institutional investors managing more than $100 million in equity are required to report all equity holdings greater than 10,000 shares or $200,000 in market value to the SEC on a quarterly basis.

B.2 Variable Construction

Average Patent Citations: Our first measure of disruptive innovations is the number of citations a patent received as of 2006. We use the truncation correction weights devised by Hall, Jaffe, and Trajtenberg (2001) to correct for systematic citation differences across different technology classes and for the fact that earlier patents have more years during which they can receive citations (truncation bias). The average patent citations of a firm in a year are computed as the average number of citations received by the patents for which the firm applied in that year. This is a scale-free variable.

Tail Innovations: The tail innovation index is defined as the fraction of a firm's patents that are in the top p% of all the patents according to number of citations received among all patents applied for in that year as in Acemoglu, Akcigit, and Celik (2022). Specifically, let $s_{ft}(p)$ denote the fraction of a firm's patents that are above the p^{th} percentile of the year t distribution according to citations. Our baseline tail innovation index, $\text{Tail}_{ft}(p)$, is simply $s_{ft}(0.90)/s_{ft}(0)$, and thus measures the fraction of patents by firm f at time t with citations above the $90th$ percentile. The variable is multiplied by 100 for ease of inspection.

Average Originality: We use the originality index devised by Hall, Jaffe, and Trajtenberg (2001). Let $i \in I$ denote a technology class and $s_{ij} \in [0,1]$ denote the share of citations that patent j makes to patents in technology class i (with $\sum_{i \in I} s_{ij} = 1$). Then for a patent j that makes positive citations, we define: $\text{Originality}_j = 1 - \sum_{i \in I} s_{ij}^2$. This index thus measures the dispersion of the citations made by a patent in terms of the technology classes of cited patents. Greater dispersion of citations is interpreted as a sign of greater originality, since the patented innovation combines information from a diverse range of technological fields. The patent classes used in the baseline analysis are the 36 two-digit technological subcategories defined in Hall, Jaffe, and Trajtenberg (2001). For robustness, the same measures are recalculated using the three-digit International Patent Classification categories, and the US Patent Class categories assigned internally by the USPTO. The average originality of a firm's innovation in a given year is the average originality of all the patents for which the firm applied in that year. The variable is multiplied by 100 for ease of inspection.

CEO Compensation Measures: We define the empirical measures of the compensation components to be consistent with the model as follows. Equity compensation is defined as the value of equity awarded to the manager as reported in Execucomp. For option compensation, we use the CEO's granted options value calculated using the Black-Scholes formula. Finally, salary compensation is defined following Dittmann and Maug (2007) as the sum of salary and bonus. Thus, the option/income ratio is the income from options divided by total compensation, the share/income ratio is the value of shares awarded divided by total compensation, and the deferred ratio is the sum of the two. Table C6 reports the summary statistics for the final sample we use.

Institutional Ownership: We obtain institutional ownership information from the Thomson-Reuters Institutional Holdings (13F) database. This dataset compiles Securities and Exchange Commission (SEC) Form 13-F filings of institutional holdings. It provides institutional common stock holdings and transactions, as reported on Form 13F filed with the SEC. Under rule 13(f), all institutional investors managing more than $100 million in equity are required to report all equity holdings greater than 10,000 shares or $200,000 in market value to the SEC on a quarterly basis. Institutional ownership is defined as the fraction of shares owned by institutional investors.

B.3 Institutional Ownership, Managerial Compensation, and Disruptive Innovations

The main estimating equations are:

$$\text{innovation}_{it+1} = \boldsymbol{\alpha}\ \text{inst ownership}_{it} + \boldsymbol{X}_{it}'\,\boldsymbol{\beta} + \delta_s + v_t + \varepsilon_{it+1} \tag{218}$$

$$\text{pay structure}_{it+1} = \boldsymbol{\gamma}\ \text{inst ownership}_{it} + \boldsymbol{X}_{it}'\,\boldsymbol{\beta} + \delta_s + v_t + \varepsilon_{it+1} \tag{219}$$

$$\text{innovation}_{it+1} = \boldsymbol{\theta}\ \text{pay structure}_{it+1} + \boldsymbol{X}_{it}'\,\boldsymbol{\beta} + \delta_s + v_t + \varepsilon_{it+1} \tag{220}$$

where innovation_{it}, $\text{inst ownership}_{it}$, and $\text{pay structure}_{it}$ are the measures of disruptive innovations, institutional ownership fraction, and CEO compensation structure respectively for firm i in year t; $\boldsymbol{X}_{it}$ is a vector of control variables including firm size, firm age,[52] R&D stock,[53] stock price volatility,[54] and leverage; δ_s denotes a full set of four-digit main SIC fixed effects, so that the comparisons are always across firms within a narrowly defined industry; v_t denotes a full set of year fixed effects. Finally, ϵ_{it+1} denotes the error term.

The results are presented in Tables B1 through B4. Table B1 reports the results of the first estimating equation. The three columns of Table B1 correspond to three different measures of disruptive innovation: tail innovations, average patent quality, and average originality. In all three cases, firms with higher institutional ownership tend to carry out more disruptive innovations. All else equal, when institutional ownership increases by one percentage point (pp), tail innovation increases by 0.0314 pp, average citations of patents increase by 2.927 pp, and average patent originality index increases by 0.0529 pp. In economic terms, one standard deviation increase in institutional ownership is associated with a 21.7% increase in tail innovations compared to its mean; and this number is 17.9% and 13.9% for average patent quality and average originality respectively. These results are consistent with earlier findings in Aghion, Van Reenen, and Zingales (2013) who use total patent citations as their measure of innovation, a scale-dependent measure.

Table B2 reports the results of the second estimating equation. Firms with high institutional ownership tend to adopt more incentivized managerial compensation contracts, featuring a higher fraction of deferred income, which is defined as the fraction of stock and options in the CEO's total compensation. This is consistent with earlier findings between institutional ownership and pay-for-performance sensitivity in Hartzell and Starks (2003). Ceteris paribus, a one percentage point increase in the institutional ownership fraction is associated with a 0.258 pp increase in deferred ratio, a 0.232 pp increase in the option/income ratio, and a 0.026 pp increase in the share/income ratio. The decomposition of deferred income into option and stock income reveals that the positive association is largely driven by the positive association between institutional ownership and option/income ratio. This is a recurring pattern in the remainder of the empirical analysis, and this is the primary reason underlying our choice in picking stock options (as opposed to stocks) as the state-contingent component of manager compensation in our quantitative model.

We report the relationship between managerial compensation structure and innovation in Table B3. We find that a higher deferred ratio is positively associated with disruptive innovation as

[52]The firm age is calculated as the difference between the current year and the year in which the firm first entered the Compustat sample. The results are unchanged if one uses the initial public offering year instead.

[53]This is a discounted sum of past R&D expenditures as in Aghion, Van Reenen, and Zingales (2013).

[54]Stock price volatility (CV price) is the coefficient of variation of the daily stock price, obtained from the CRSP database.

TABLE B1: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION

	Tail Innov	Avg. citations	Avg. originality
institutional ownership	3.142	2.927	5.290
	(0.387)***	(0.361)***	(0.554)***
size	0.269	0.388	0.740
	(0.061)***	(0.057)***	(0.098)***
log(R&D stock)	0.897	0.944	2.646
	(0.067)***	(0.066)***	(0.109)***
leverage	-1.897	-2.141	-3.296
	(0.403)***	(0.397)***	(0.541)***
age	-0.048	-0.030	0.018
	(0.007)***	(0.007)***	(0.014)
CV price	-0.516	-0.315	0.237
	(0.452)	(0.387)	(0.562)
R^2	0.11	0.16	0.30
N	55,013	55,013	55,013

Notes: Robust standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1.

TABLE B2: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION STRUCTURE

	deferred ratio	option/income ratio	share/income ratio
institutional ownership	0.258	0.232	0.026
	(0.019)***	(0.018)***	(0.008)***
size	0.028	0.019	0.009
	(0.004)***	(0.004)***	(0.002)***
log(R&D stock)	0.016	0.017	-0.001
	(0.002)***	(0.002)***	(0.001)
leverage	-0.020	-0.037	0.016
	(0.022)	(0.021)*	(0.009)*
age	-0.001	-0.002	0.000
	(0.000)***	(0.000)***	(0.000)***
CV price	0.100	0.115	-0.014
	(0.026)***	(0.026)***	(0.010)
R^2	0.22	0.22	0.13
N	16,425	16,425	16,425

Notes: Robust standard errors in parentheses are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1.

measured by tail innovations, average patent quality, and average originality. Columns 1, 4, and 7 of Table B3 present fixed effect panel regressions of disruptive innovation on the deferred ratio. When deferred ratio increases by one percentage point, tail innovations increase by 1.256 pp, average patent citations increase by 1.156 pp, and average patent originality increases by 1.521 pp.[55] Columns 2, 5, and 8 of this table repeat the specification in columns 1, 4, and 7, further controlling for institutional ownership. We find that the positive relationship between deferred ratio and innovation is still positive and statistically significant after controlling for institutional ownership, which itself is positive but statistically insignificant at 10%. We further decompose the deferred ratio into the option/income ratio and share/income ratio in columns 3, 6, and 9. We find that the positive correlation between the deferred ratio and innovation is mainly driven by the option/income ratio.

These findings are consistent with previous studies in the literature such as Coles, Daniel, and Naveen (2006) and Panousi and Papanikolaou (2012), which find that CEO compensation contracts with higher pay-for-performance components, and especially stock options, tend to encourage the CEOs to take more risk. This is also consistent with Mao and Zhang (2018) who find that dampened managerial risk-taking incentive leads to a significant reduction in innovation. We want to highlight that these regressions suggest institutional ownership's positive association with innovation is largely realized through its effect on managerial compensation structure – the coefficients of deferred ratio and option/income ratio are always statistically significant, but institutional ownership itself is not. For economic significance, we can compare the standardized coefficients (betas). In column 2, these are 2.555% vs. 0.542% for deferred ratio and institutional ownership. In column 3, these are 2.642% vs. 0.539% for option/income ratio and institutional ownership. The dominance pattern is similar for the remaining columns. In our model, institutional ownership affects innovation through its impact on managerial compensation structure, consistent with these results.[56]

Lending credence to our claims in the introduction and the model regarding the effects of corporate governance and innovation on firm value and profitability, we find that institutional ownership is positively associated with firm value, and firms with more disruptive innovations tend to have a higher market-to-book ratio. The results are shown in Table C7.

B.4 Robustness and Instrumental Variable Regressions

The coefficient of institutional ownership may be biased if large institutional shareholders select firms in which to invest on the basis of characteristics that are observable to them, but not to the econometrician. For example, large institutions might invest in firms when they anticipate an increase in their innovation. One can also theorize that firms might adopt more incentivized CEO contracts in order to attract institutional investors. To mitigate such concerns, Hartzell and

[55] Note that we multiply tail innovations and originality by 100 for ease of inspection.

[56] In an extended model with a direct effect of institutional ownership on innovation (i.e., through mechanisms other than managerial compensation), the parameter that governs the strength of this new mechanism is estimated to be small to remain consistent with the insignificance result obtained here. Therefore, we abstract from a direct effect in our baseline model to keep the model as tractable as possible.

Starks (2003) use share turnover[57] as an instrument for institutional ownership. Share turnover is argued to be a reasonable instrument since it is correlated with institutional ownership, but unlikely to affect the managerial compensation structure directly. To mitigate similar concerns, Aghion, Van Reenen, and Zingales (2013) use inclusion in the S&P 500 index as an instrument for institutional ownership's effect on innovation. They argue that S&P 500 inclusion can serve as a reasonable instrument for institutional ownership, since an S&P 500 firm is more likely to attract institutional investors. One major reason is that fund managers are typically benchmarked against the S&P 500, which creates an incentive for them to weight their portfolio toward S&P 500 firms. S&P inclusion, however, is less likely to be correlated with disruptive innovations. Standard and Poor's explicitly states that the decision of whether or not to include a firm in the S&P 500 or not is not an opinion on that company's investment potential. It mainly depends on whether the firm can represent a certain sector well. Hence, Aghion, Van Reenen, and Zingales (2013) argue that the exclusion restriction is likely to be satisfied. If we use the IVs proposed by Hartzell and Starks (2003) and Aghion, Van Reenen, and Zingales (2013), the associations remain positive and statistically significant. The results are shown in Table B4. While we make no claims regarding the validity of these instruments,[58] the fact that the relationships are robust to using these proposed IVs is reassuring.

We do a sanity check for our model's hypothesized direction of causality between institutional ownership and managerial compensation structure in Table C8 and Table C9. In column 1 of Table C8, we regress the deferred ratio on lagged institutional ownership. In column 2, we regress institutional ownership on the lagged deferred ratio. In both regressions, we control for the lagged dependent variable, other covariates, and year and industry dummies as in the baseline regressions.

All estimated coefficients are standardized (betas) so their magnitudes are comparable. We find that lagged institutional ownership has a much stronger association with the deferred ratio than vice versa, consistent with what our model would imply. We perform similar tests for the correlation between the option/income ratio and institutional ownership in Table C9 and obtain similar results.

To mitigate the concern that the correlation between institutional ownership is driven by certain special industries, such as high-tech industries or pharmaceuticals, we test the baseline results by dividing the whole sample into subsamples of high-tech and low-tech firms.[59] The same exercise is repeated for pharmaceutical and non-pharmaceutical firms. The results are shown in Section C. The results are quite similar for the high-tech and low-tech subsamples, and the same is true for the non-pharmaceutical subsample.

[57] Share turnover is defined as the average daily volume of traded shares, normalized by the number of common shares outstanding. This information is obtained from the CRSP database.

[58] We direct the readers to the original papers for the full argumentation regarding validity.

[59] High-tech firms are those in SIC 35 and 36, which include industrial and commercial machinery and equipment and computer equipment, and electronic and other electrical equipment and components. Low-tech firms constitute the rest.

TABLE B3: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION

	Tail Innov.			Avg. Citations			Avg. Originality		
deferred ratio	1.256	1.263		1.156	1.055		1.521	1.406	
	(0.518)**	(0.524)**		(0.562)**	(0.571)*		(0.556)***	(0.555)**	
size	0.412	0.398	0.401	0.495	0.452	0.451	1.158	1.133	1.136
	(0.160)**	(0.161)**	(0.161)**	(0.150)***	(0.151)***	(0.150)***	(0.243)***	(0.247)***	(0.247)***
log(R&D stock)	0.804	0.805	0.803	0.840	0.851	0.852	2.145	2.147	2.145
	(0.121)***	(0.121)***	(0.122)***	(0.119)***	(0.119)***	(0.119)***	(0.203)***	(0.204)***	(0.204)***
leverage	-2.759	-2.778	-2.768	-3.893	-3.916	-3.918	-4.266	-4.248	-4.239
	(1.019)***	(1.019)***	(1.018)***	(1.225)***	(1.244)***	(1.241)***	(1.339)***	(1.357)***	(1.356)***
age	-0.047	-0.047	-0.047	-0.031	-0.031	-0.031	0.029	0.030	0.030
	(0.013)***	(0.013)***	(0.013)***	(0.012)***	(0.012)***	(0.012)***	(0.023)	(0.023)	(0.023)
CV price	0.755	0.771	0.757	1.578	1.708	1.711	2.234	2.564	2.551
	(1.259)	(1.292)	(1.293)	(1.158)	(1.175)	(1.175)	(1.423)	(1.458)*	(1.458)*
inst ownership		0.410	0.408		1.387	1.387		0.744	0.742
		(0.935)	(0.935)		(0.903)	(0.903)		(1.206)	(1.206)
option/income ratio			1.329			1.038			1.466
			(0.565)**			(0.620)*			(0.592)**
share/income ratio			0.784			1.179			0.970
			(0.767)			(0.759)			(1.318)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.40	0.40	0.40
N	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371

Notes: Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See Section B.2 for detailed variable definitions.
*** p<0.01, ** p<0.05, * p<0.1.

We further probe the robustness of our baseline results by replacing the four-digit SIC dummies in our baseline specification with two-digit or three-digit SIC dummies, and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. The results are shown in Section C. The estimates are once again very close to those in our baseline regressions, although significance is somewhat reduced in the case of firm fixed effects regressions for specifications where the number of observations is low. The signs, however, are maintained. This result is not unexpected, as most of the variation in explanatory variables is driven by cross-sectional differences.

TABLE B4: INSTRUMENTING INSTITUTIONAL OWNERSHIP WITH S&P 500 INCLUSION AND SHARE TURNOVER

	deferred ratio	Tail Innov	Avg. citations	Avg. originality
institutional ownership	0.978	35.320	30.663	58.580
	(0.108)***	(11.268)***	(10.365)***	(17.786)***
size	-0.004	-2.029	-1.593	-3.066
	(0.007)	(0.808)**	(0.740)**	(1.278)**
log(R&D stock)	0.022	1.220	1.222	3.181
	(0.003)***	(0.142)***	(0.127)***	(0.215)***
leverage	0.007	2.222	1.409	3.527
	(0.026)	(1.534)	(1.410)	(2.381)
age	-0.001	-0.126	-0.097	-0.112
	(0.000)***	(0.029)***	(0.027)***	(0.045)**
CV price	0.235	2.845	2.583	5.804
	(0.038)***	(1.287)**	(1.164)**	(2.033)***
N	16,425	55,013	55,013	55,013
instrument	share turnover	S&P 500	S&P 500	S&P 500
first stage	5.249	0.048	0.048	0.048
	(0.515)***	(0.012)***	(0.012)***	(0.012)***

We are also interested in whether the decision to include certain firms or firm-year observations influences the results. One can think of three different specifications: (i) including all observations, (ii) focusing only on firms that have patents, and (iii) focusing only on firm-year observations which have a non-zero number of patents. Our results go through with all three different specifications, where our baseline results correspond to the first case. The results for the latter two specifications are included in Section C. The results are very similar, suggesting that the relationships we find hold regardless of whether one considers the intensive or the extensive margin in generating disruptive innovations.

Finally, we further check the robustness of the baseline results by adding additional control variables: log employment, log sales, log physical capital, asset maturity, S&P rating, investment grade, total compensation, profitability, g-index, self-citation fraction, the stock of unvested stock options, and Tobin's Q. We also test the correlation between institutional ownership and alternative dependent variables: total market value of patents from Kogan, Papanikolaou, Seru, and Stoffman (2017), total tail innovations, total citations, total patents weighted by their originality, citations within 5 years, originality based on USPC and 3-digit IPC technological subcategories, different cut-offs for tail innovations, citations weighted by total patent count in a year, and citations excluding self-citations. The baseline results still hold with additional control variables, with alternative dependent variables, and alternative corporate governance measures such as proxies of board independence, and institutional ownership excluding (as well as only including) quasi-indexers.

B.5 Option Vesting and Innovation

There is a concern that CEOs might reduce investment in R&D in order to boost the current stock price in quarters in which their options or equity vest (for instance, see Edmans, Fang, and Lewellen (2017).) This raises a question as to whether our results regarding the positive correlation between innovation and option-to-income ratio still hold when CEOs have this short-term concern regarding the current stock price. In order to check if our results are robust to this concern, we control for both the number and the value of options the CEOs exercise in the current year. The results are presented in Tables C51 and C52, respectively. In both tables, we find that the coefficients of the number and value of exercised options are insignificant, and our main results go through unchanged. This finding is not surprising, in that Edmans, Fang, and Lewellen (2017) already find the short-term effect on investment in R&D to disappear and reverse within the next three quarters. Therefore, at the annual level, the insignificance is to be expected.

B.6 Controlling for Additional Financial Constraint Proxies and Distance-to-Default

In the baseline empirical results, we already control for leverage to account for financial frictions the firm faces. To further check the robustness of our results, we first use the Whited-Wu Index developed in Whited and Wu (2006). The results are displayed in Table C53. The coefficient of the index is positive for tail innovation and average citations, and negative for originality. In all cases, they remain statistically insignificant, whereas the coefficient of the leverage is still significant and negative. Our main results still hold with slightly different magnitudes, but the same degree of significance.

An additional concern is that the CEOs of firms that are close to bankruptcy might overinvest in risky projects. To establish the robustness of our results to this concern, we first create the distance-to-default and the implied default probabilities following Merton (1974) and Gilchrist and Zakrajsek (2012). Based on the implied default probabilities, we create an indicator variable that denotes whether a firm is close to default or not.[60] We repeat our baseline regressions controlling for this variable, the results of which are displayed in Table C54. We find the coefficient to be negative but insignificant in all specifications. This tells us that the direct effect of being close to default manifests as a reduction in the quality of innovation. Our main results remain robust to this additional concern.

C Additional Tables and Figures

[60] We pick the mean of the implied default probability in the sample as our threshold.

TABLE C1: SHORT-TERMISM MODEL PARAMETERS AND TARGET MOMENTS

A. Parameter estimates

Parameter	*Value*	*Description*	*Identification*
		External Estimation	
δ	0.069	capital depreciation rate	US NIPA
ς	0.150	productivity share in production	Corrado, Hulten, and Sichel (2009)
κ	0.250	capital share in production	Corrado, Hulten, and Sichel (2009)
λ	0.600	labor share in production	Corrado, Hulten, and Sichel (2009)
ω	2.000	CRRA parameter	Kaplow (2005)
β	0.982	discount factor	risk-free rate
σ_ϵ	0.1916	std. of temporary productivity shock	std. of profitability
		Internal Estimation	
γ	0.524	innovation productivity increase	output growth rate
ν	310.39	CEO disutility	$\beta(innovation, option\ ratio)$
χ	1.443	R&D cost scale parameter	R&D intensity
η_{ub}	0.0014	upper bound of CEO influence	$\beta(innovation, inst\ own), \beta(option\ ratio, inst\ own)$
$\underline{U}$	0.339	PDV of CEO compensation	mean option ratio, CEO pay/market cap
ξ	261.678	cost of missing EPS target	compensation loss
Λ	0.619	short-term pressure	fraction of binding firms

B. Moments

Target Moments	Data	Model
$\beta(innovation, inst\ own)$	0.048	0.028
$\beta(innovation, option\ ratio)$	0.025	0.030
$\beta(option\ ratio, inst\ own)$	0.029	0.032
R&D intensity	2.91%	2.76%
CEO pay/market cap	0.31%	0.32%
Output growth rate	2.00%	2.00%
Mean option ratio	36.16%	35.48%
Compensation loss	8.63%	8.54%
Fraction of binding firms	40.70%	40.00%

Notes: The estimation is done with the simulated method of moments, which chooses model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A reports the estimated parameters. Panel B reports the simulated and actual moments. All correlations are standardized correlation coefficients (betas), i.e. the variables are standardized by subtracting their mean and dividing by their standard deviation, both in the model and the data. See Section 4.1 for details.

Table C2: Model Parameters and Target Moments: Early and Late Subsamples

A. Parameter estimates

Parameter	*Early Subsample*	*Late Subsample*	*Description*	*Identification*
			Internal Estimation	
γ	0.449 (0.0110)	0.339 (0.0031)	innovation productivity increase	output growth rate
ν	207.14 (4.0681)	212.99 (5.9735)	CEO disutility	$\beta(innovation, option\, ratio)$
χ	0.626 (0.0250)	1.090 (0.0036)	R&D cost scale parameter	R&D intensity
η_{ub}	0.0013 (0.00004)	0.0013 (0.0001)	upper bound of CEO influence	$\beta(innovation, inst\, own), \beta(option\, ratio, inst\, own)$
$\underline{U}$	0.190 (0.0041)	0.517 (0.0151)	PDV of CEO compensation	mean option ratio, CEO pay/market cap

B. Moments

	Early Subsample		Late Subsample	
Target Moments	Data	Model	Data	Model
$\beta(innovation, inst\, own)$	0.056	0.057	0.043	0.033
$\beta(innovation, option\, ratio)$	0.029	0.058	0.048	0.033
$\beta(option\, ratio, inst\, own)$	0.024	0.033	0.028	0.033
R&D intensity	2.91%	3.04%	2.91%	2.87%
CEO pay/market cap	0.24%	0.24%	0.36%	0.37%
Output growth rate	2.54%	2.53%	1.54%	1.54%
Mean option ratio	30.14%	31.39%	40.56%	40.29%

Notes: The estimation is done with the simulated method of moments, which chooses model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A reports the estimated parameters. Panel B reports the simulated and actual moments. All correlations are standardized correlation coefficients (betas), i.e. the variables are standardized by subtracting their mean and dividing by their standard deviation, both in the model and the data. See Section 4.1 for details.

Table C3: Model Parameters and Target Moments (Exogenous Growth (50%))

A. Parameter estimates

Parameter	*Value*	*Description*	*Identification*
		External Estimation	
δ	0.069	capital depreciation rate	US NIPA
ς	0.150	productivity share in production	Corrado, Hulten, and Sichel (2009)
κ	0.250	capital share in production	Corrado, Hulten, and Sichel (2009)
λ	0.600	labor share in production	Corrado, Hulten, and Sichel (2009)
ω	2.000	CRRA parameter	Kaplow (2005)
β	0.982	discount factor	risk-free rate
		Internal Estimation	
γ	0.223	innovation productivity increase	output growth rate
ν	206.36	CEO disutility	$\beta(innovation, option\ ratio)$
χ	0.609	R&D cost scale parameter	R&D intensity
η_{ub}	0.0008	upper bound of CEO influence	$\beta(innovation, inst\ own), \beta(option\ ratio, inst\ own)$
$\underline{U}$	0.360	PDV of CEO compensation	mean option ratio, CEO pay/market cap

B. Moments

Target Moments	Data	Model
$\beta(innovation, inst\ own)$	0.048	0.042
$\beta(innovation, option\ ratio)$	0.025	0.043
$\beta(option\ ratio, inst\ own)$	0.029	0.033
R&D intensity	2.91%	1.66%
CEO pay/market cap	0.31%	0.31%
Output growth rate	2.00%	2.00%
Mean option ratio	36.16%	31.83%

Notes: The estimation is done with the simulated method of moments, which chooses model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A reports the estimated parameters. Panel B reports the simulated and actual moments. All correlations are standardized correlation coefficients (betas), i.e. the variables are standardized by subtracting their mean and dividing by their standard deviation, both in the model and the data. See Section 4.1 for details.

TABLE C4: IDENTIFICATION: JACOBIAN MATRIX

	ν	χ	η_u	$\bar{U}$	γ
$\beta(innov, \eta)$	0.5396	-0.9018	-0.9931	0.4638	-0.0955
$\beta(innov, option)$	0.1984	-0.9039	-0.9112	0.4610	-0.0612
$\beta(option, \eta)$	0.2878	-0.0033	-0.0270	0.0088	-0.0172
R&D Intensity	-0.4498	0.4062	-0.8878	-0.0687	-0.0487
CEO pay/market cap	-0.2423	-0.2338	-0.5529	0.8953	1.0631
Output growth rate	-0.1780	-0.2424	-0.3421	-0.0521	0.9164
Mean option ratio	0.4211	-0.4631	-0.7044	0.7059	0.2875

Notes: This table shows the Jacobian matrix associated with the estimation of the baseline model. Each entry of the matrix reports the percentage change in each moment given one percent increase in each parameter.

TABLE C5: COUNTERFACTUAL EXPERIMENT: THE IMPACT OF REDUCED AGENCY FRICTIONS IN THE BASELINE MODEL (EXOGENOUS GROWTH (50%))

	Baseline	Reduced CEO Influence (25%)	Reduced CEO Influence (50%)	Reduced CEO Influence (100%)
Output growth rate	2.00%	2.05%	2.10%	2.24%
R&D intensity	1.66%	1.81%	2.00%	2.64%
Mean option ratio	31.83%	34.74%	38.24%	47.14%
Mean innovation probability	23.33%	24.42%	25.71%	29.21%
Consumption/output	0.80	0.80	0.80	0.79
Welfare change	-	0.7%	1.5%	3.5%

TABLE C6: SUMMARY STATISTICS

Variable	Number of Observations	Mean	Std. Dev.
tail innovation	55,013	3.78	14.21
average patent quality	55,013	4.29	12.79
average patent originality	55,013	9.86	18.57
log(1+total patent count)	55,013	0.58	1.19
institutional ownership	55,013	0.34	0.26
deferred ratio	16,425	0.41	0.31
option/income ratio	16,425	0.36	0.30
share/income ratio	16,425	0.05	0.13
market-to-book ratio	54,698	2.17	2.25
log(firm assets)	55,013	5.21	2.07
log(R&D stock)	55,013	1.85	2.20
leverage	55,013	0.22	0.21
firm age	55,013	14.58	12.59
stock price volatility (CV price)	55,013	0.22	0.16
share turnover	55,013	0.01	0.01
S&P 500 inclusion	55,013	0.11	0.31

Notes: This table reports the summary statistics of variables used in the empirical analysis. The average patent citations of a firm in a year are computed as the average number of citations received by the patents the firm applied for in that year. Tail innovation is defined as the fraction of a firm's patents that are in the top 10% of all the patents according to number of citations received among all patents applied for in that year as in Acemoglu, Akcigit, and Celik (2022). The average originality of a firm's innovation in a given year is the average originality of all the patents the firm applied for in that year. Equity compensation is defined as the value of equity awarded to the manager as reported in Execucomp. For option compensation, we use the CEO's granted options value calculated using the Black-Scholes formula. Thus, the option/income ratio is the income from options divided by total compensation, the share/income ratio is the value of shares awarded divided by total compensation, and the deferred ratio is the sum of the two. See Section B.2 for more details.

TABLE C7: INSTITUTIONAL OWNERSHIP, INNOVATION, AND FIRM VALUE

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.640				
	(0.066)***				
size	-0.244	-0.189	-0.192	-0.187	-0.200
	(0.018)***	(0.012)***	(0.012)***	(0.012)***	(0.012)***
log(R&D stock)	0.157	0.113	0.108	0.109	0.073
	(0.013)***	(0.010)***	(0.010)***	(0.010)***	(0.011)***
leverage	-0.366	-0.524	-0.516	-0.537	-0.530
	(0.096)***	(0.063)***	(0.063)***	(0.063)***	(0.063)***
age	-0.009	-0.007	-0.007	-0.008	-0.008
	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***
CV price	0.086	0.343	0.339	0.353	0.347
	(0.085)	(0.068)***	(0.068)***	(0.068)***	(0.068)***
tail innovation		0.008			
		(0.001)***			
avg patent quality			0.012		
			(0.001)***		
avg originality				0.006	
				(0.001)***	
log patcount					0.148
					(0.015)***
R^2	0.17	0.18	0.18	0.18	0.18
N	54,698	97,531	97,531	97,531	97,531

Notes: Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C8: INSTITUTIONAL OWNERSHIP AND DEFERRED RATIO – CURRENT AND LAGGED

	Deferred Ratio	Inst. Ownership
institutional ownership	0.211	0.788
	(0.015)***	(0.007)***
deferred ratio	0.228	0.000
	(0.010)***	(0.003)
R^2	0.26	0.74
N	14,540	14,842

Notes: Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. Both regressions control for year dummies and a full set of four-digit SIC industry dummies and other covariates in the baseline regressions. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C9: INSTITUTIONAL OWNERSHIP AND OPTION/INCOME RATIO – CURRENT AND LAGGED

	Option/Income Ratio	Inst. Ownership
institutional ownership	0.185	0.788
	(0.014)***	(0.006)***
option/income ratio	0.241	-0.001
	(0.010)***	(0.003)
R^2	0.27	0.74
N	14,540	14,842

Notes: Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. Both regressions control for year dummies and a full set of four-digit SIC industry dummies and other covariates in the baseline regressions. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C10: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION – PATENTING FIRMS

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	4.946	4.702	6.597
	(0.704)***	(0.642)***	(0.885)***
size	0.262	0.390	1.283
	(0.126)**	(0.114)***	(0.178)***
log(R&D stock)	0.691	0.757	1.913
	(0.104)***	(0.099)***	(0.158)***
leverage	-2.965	-3.127	-5.279
	(0.854)***	(0.786)***	(1.032)***
age	-0.097	-0.078	-0.077
	(0.012)***	(0.011)***	(0.020)***
CV price	-1.010	-0.619	0.791
	(0.926)	(0.774)	(1.056)
R^2	0.09	0.15	0.19
N	28,945	28,945	28,945

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C11: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION STRUCTURE – PATENTING FIRMS

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.254	0.231	0.022
	(0.024)***	(0.024)***	(0.010)**
size	0.029	0.021	0.008
	(0.005)***	(0.005)***	(0.002)***
log(R&D stock)	0.013	0.014	-0.001
	(0.003)***	(0.003)***	(0.001)
leverage	-0.046	-0.067	0.021
	(0.029)	(0.028)**	(0.013)
age	-0.001	-0.002	0.000
	(0.000)***	(0.000)***	(0.000)**
CV price	0.108	0.132	-0.025
	(0.032)***	(0.032)***	(0.010)**
R^2	0.24	0.25	0.14
N	11,004	11,004	11,004

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C12: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: TAIL INNOVATION – PATENTING FIRMS

	Tail Innov.	Tail Innov.	Tail Innov.
Deferred Ratio	2.081	2.067	
	(0.792)***	(0.799)***	
size	0.171	0.142	0.147
	(0.241)	(0.239)	(0.238)
log(R&D stock)	0.643	0.644	0.641
	(0.155)***	(0.156)***	(0.156)***
leverage	-2.414	-2.430	-2.400
	(1.550)	(1.533)	(1.532)
age	-0.078	-0.077	-0.076
	(0.018)***	(0.018)***	(0.018)***
CV price	-0.054	0.051	0.010
	(1.812)	(1.832)	(1.835)
Inst. Ownership		0.949	0.941
		(1.447)	(1.447)
Option/Income Ratio			2.200
			(0.857)**
Share/Income Ratio			1.098
			(1.153)
R^2	0.16	0.16	0.16
N	11,013	10,980	10,980

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C13: Managerial Compensation Structure and Firm Innovation: Average Patent Quality – Patenting Firms

	Avg. Citations	Avg. Citations	Avg. Citations
Deferred Ratio	2.035	1.923	
	(0.868)**	(0.879)**	
size	0.221	0.170	0.171
	(0.225)	(0.222)	(0.221)
log(R&D stock)	0.690	0.703	0.702
	(0.143)***	(0.143)***	(0.142)***
leverage	-3.059	-3.083	-3.076
	(1.739)*	(1.749)*	(1.743)*
age	-0.058	-0.058	-0.058
	(0.015)***	(0.015)***	(0.015)***
CV price	1.260	1.443	1.433
	(1.635)	(1.635)	(1.633)
Inst. Ownership		1.695	1.693
		(1.388)	(1.389)
Option/Income Ratio			1.954
			(0.950)**
Share/Income Ratio			1.700
			(1.119)
R^2	0.24	0.24	0.24
N	11,013	10,980	10,980

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C14: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE ORIGINALITY – PATENTING FIRMS

	Avg. Originality	Avg. Originality	Avg. Originality
Deferred Ratio	1.849	1.641	
	(0.777)**	(0.779)**	
size	1.344	1.309	1.308
	(0.331)***	(0.337)***	(0.337)***
log(R&D stock)	1.565	1.567	1.568
	(0.249)***	(0.251)***	(0.250)***
leverage	-3.710	-3.689	-3.698
	(1.895)*	(1.907)*	(1.904)*
age	-0.030	-0.030	-0.030
	(0.029)	(0.029)	(0.029)
CV price	1.688	2.106	2.118
	(1.937)	(1.965)	(1.967)
Inst. Ownership		1.369	1.372
		(1.683)	(1.684)
Option/Income Ratio			1.603
			(0.824)*
Share/Income Ratio			1.923
			(1.834)
R^2	0.28	0.28	0.28
N	11,013	10,980	10,980

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C15: INSTITUTIONAL OWNERSHIP, INNOVATION, AND FIRM VALUE – PATENTING FIRMS

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.449				
	(0.102)***				
size	-0.308	-0.268	-0.270	-0.266	-0.301
	(0.029)***	(0.022)***	(0.022)***	(0.022)***	(0.023)***
log(R&D stock)	0.183	0.145	0.141	0.145	0.093
	(0.018)***	(0.014)***	(0.014)***	(0.014)***	(0.014)***
leverage	-0.526	-0.718	-0.708	-0.742	-0.706
	(0.161)***	(0.105)***	(0.105)***	(0.105)***	(0.105)***
age	-0.009	-0.008	-0.008	-0.009	-0.010
	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***
CV price	0.094	0.398	0.390	0.412	0.396
	(0.135)	(0.106)***	(0.106)***	(0.107)***	(0.106)***
tail innovation		0.006			
		(0.001)***			
avg patent quality			0.009		
			(0.001)***		
avg originality				0.004	
				(0.001)***	
log patcount					0.177
					(0.017)***
R^2	0.20	0.23	0.23	0.23	0.23
N	28,821	51,480	51,480	51,480	51,480

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C16: Instrumenting Institutional Ownership with S&P 500 Inclusion and Share Turnover – Patenting Firms

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.051	40.537	35.180	58.278
	(0.147)***	(12.222)***	(11.011)***	(16.741)***
size	-0.006	-2.099	-1.632	-2.145
	(0.008)	(0.839)**	(0.752)**	(1.148)*
log(R&D stock)	0.019	1.092	1.101	2.495
	(0.004)***	(0.185)***	(0.161)***	(0.259)***
leverage	-0.026	1.776	0.933	1.606
	(0.033)	(1.923)	(1.714)	(2.515)
age	-0.001	-0.193	-0.160	-0.216
	(0.000)**	(0.037)***	(0.033)***	(0.050)***
CV price	0.228	2.588	2.461	6.016
	(0.045)***	(1.592)	(1.384)*	(2.129)***
N	11,004	28,945	28,945	28,945
Instrument	share turnover	S&P 500	S&P 500	S&P 500
first stage	4.429	0.062	0.062	0.062
	(0.542)***	(0.015)***	(0.015)***	(0.015)***

Notes: These regression results are based on a restricted subsample of firm-year observations requiring the firms to receive at least one patent within the period 1976-2004. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 for all columns except column 1 which starts at 1992. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C17: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION – POSITIVE PATENT YEARS

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	4.006	3.135	1.902
	(1.076)***	(0.926)***	(0.935)**
size	-0.633	-0.421	-0.083
	(0.228)***	(0.179)**	(0.192)
log(R&D stock)	0.139	0.036	-0.314
	(0.185)	(0.153)	(0.159)**
leverage	-1.747	-1.191	-3.652
	(1.500)	(1.200)	(1.269)***
age	-0.095	-0.073	0.006
	(0.020)***	(0.016)***	(0.020)
CV price	-1.280	-0.597	2.226
	(1.729)	(1.314)	(1.276)*
R^2	0.14	0.26	0.14
N	15,769	15,769	15,769

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C18: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION STRUCTURE – POSITIVE PATENT YEARS

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.245	0.232	0.013
	(0.031)***	(0.031)***	(0.012)
size	0.023	0.015	0.009
	(0.006)***	(0.006)***	(0.003)***
log(R&D stock)	0.012	0.014	-0.002
	(0.003)***	(0.003)***	(0.002)
leverage	-0.085	-0.106	0.021
	(0.034)**	(0.034)***	(0.015)
age	-0.001	-0.001	0.001
	(0.000)*	(0.000)***	(0.000)**
CV price	0.107	0.119	-0.013
	(0.041)***	(0.040)***	(0.013)
R^2	0.25	0.27	0.16
N	7,108	7,108	7,108

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C19: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: TAIL INNOVATION – POSITIVE PATENT YEARS

	Tail Innov.	Tail Innov.	Tail Innov.
Deferred Ratio	2.913	2.907	
	(1.092)***	(1.096)***	
size	-0.551	-0.577	-0.577
	(0.353)	(0.349)*	(0.348)*
log(R&D stock)	0.105	0.098	0.098
	(0.243)	(0.244)	(0.244)
leverage	-1.584	-1.532	-1.530
	(2.160)	(2.146)	(2.151)
age	-0.081	-0.080	-0.080
	(0.026)***	(0.026)***	(0.026)***
CV price	-2.352	-2.169	-2.170
	(2.463)	(2.478)	(2.480)
Inst. Ownership		1.448	1.447
		(2.051)	(2.052)
Option/Income Ratio			2.914
			(1.169)**
Share/Income Ratio			2.857
			(1.601)*
R^2	0.21	0.21	0.21
N	7,111	7,096	7,096

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C20: Managerial Compensation Structure and Firm Innovation: Average Patent Quality – Positive Patent Years

	Avg. Citations	Avg. Citations	Avg. Citations
Deferred Ratio	2.784	2.757	
	(1.211)**	(1.230)**	
size	-0.360	-0.374	-0.376
	(0.283)	(0.282)	(0.282)
log(R&D stock)	0.004	-0.003	-0.002
	(0.213)	(0.215)	(0.215)
leverage	-0.945	-0.848	-0.861
	(1.955)	(1.965)	(1.959)
age	-0.068	-0.068	-0.068
	(0.021)***	(0.021)***	(0.021)***
CV price	-0.689	-0.615	-0.604
	(1.974)	(1.969)	(1.968)
Inst. Ownership		0.952	0.959
		(1.864)	(1.867)
Option/Income Ratio			2.707
			(1.313)**
Share/Income Ratio			3.148
			(1.464)**
R^2	0.33	0.33	0.33
N	7,111	7,096	7,096

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C21: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE ORIGINALITY – POSITIVE PATENT YEARS

	Avg. Originality	Avg. Originality	Avg. Originality
Deferred Ratio	0.298	0.129	
	(0.708)	(0.711)	
size	0.484	0.443	0.431
	(0.289)*	(0.290)	(0.290)
log(R&D stock)	-0.610	-0.596	-0.589
	(0.206)***	(0.207)***	(0.207)***
leverage	-4.739	-4.718	-4.776
	(1.731)***	(1.756)***	(1.758)***
age	-0.001	-0.001	-0.002
	(0.026)	(0.026)	(0.026)
CV price	-1.233	-1.013	-0.967
	(1.854)	(1.872)	(1.870)
Inst. Ownership		1.338	1.368
		(1.485)	(1.484)
Option/Income Ratio			-0.082
			(0.748)
Share/Income Ratio			1.782
			(1.579)
R^2	0.20	0.20	0.20
N	7,111	7,096	7,096

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C22: MANAGERIAL COMPENSATION, INNOVATION, FIRM VALUE – POSITIVE PATENT YEARS

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.324				
	(0.136)**				
size	-0.358	-0.289	-0.291	-0.288	-0.346
	(0.040)***	(0.030)***	(0.030)***	(0.030)***	(0.032)***
log(R&D stock)	0.202	0.141	0.139	0.143	0.079
	(0.024)***	(0.018)***	(0.018)***	(0.018)***	(0.017)***
leverage	-0.478	-0.766	-0.759	-0.800	-0.739
	(0.232)**	(0.153)***	(0.153)***	(0.153)***	(0.152)***
age	-0.005	-0.004	-0.004	-0.004	-0.005
	(0.003)*	(0.002)*	(0.002)*	(0.002)**	(0.002)**
CV price	0.229	0.497	0.485	0.521	0.481
	(0.182)	(0.144)***	(0.144)***	(0.145)***	(0.144)***
tail innovation		0.006			
		(0.001)***			
avg patent quality			0.009		
			(0.001)***		
avg originality				0.002	
				(0.001)**	
log patcount					0.203
					(0.022)***
R^2	0.22	0.26	0.26	0.26	0.26
N	15,719	27,218	27,218	27,218	27,218

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C23: INSTRUMENTING INSTITUTIONAL OWNERSHIP WITH S&P 500 INCLUSION AND SHARE TURNOVER – POSITIVE PATENT YEARS

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.035	32.367	28.206	18.298
	(0.180)***	(9.579)***	(8.278)***	(7.190)**
size	-0.006	-2.205	-1.810	-0.992
	(0.009)	(0.614)***	(0.524)***	(0.461)**
log(R&D stock)	0.019	0.596	0.441	-0.050
	(0.004)***	(0.246)**	(0.196)**	(0.204)
leverage	-0.078	1.595	1.763	-1.720
	(0.037)**	(2.026)	(1.665)	(1.584)
age	-0.001	-0.208	-0.173	-0.059
	(0.001)*	(0.045)***	(0.038)***	(0.036)*
CV price	0.219	1.123	1.527	3.615
	(0.056)***	(1.966)	(1.520)	(1.445)**
N	7,108	15,769	15,769	15,769
instrument	share turnover	S&P 500	S&P 500	S&P 500
first stage	4.239	0.101	0.101	0.101
	(0.582)***	(0.018)***	(0.018)***	(0.018)***

Notes: These regression results are based on a restricted subsample of firm-year observations where the firm applied for at least one patent. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 for all columns except column 1 which starts at 1992. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C24: Institutional Ownership and Firm Innovation

A. High Tech Firms

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	9.003	7.900	10.739
	(1.323)***	(1.258)***	(1.789)***
R^2	0.11	0.18	0.22
N	8,714	8,714	8,714

B. Low Tech Firms

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.911	1.853	4.180
	(0.378)***	(0.346)***	(0.561)***
R^2	0.09	0.13	0.28
N	46,299	46,299	46,299

Notes: We divide the baseline sample into two subsamples: high-tech firms and low-tech firms. High-tech firms are those in SIC 35 and 36, which include industrial and commercial machinery and equipment and computer equipment; and electronic and other electrical equipment and components, and low-tech firms are the rest. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C25: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION STRUCTURE

A. High Tech Firms

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.224	0.210	0.013
	(0.044)***	(0.044)***	(0.016)
R^2	0.23	0.25	0.15
N	2,686	2,686	2,686

B. Low Tech Firms

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.266	0.238	0.029
	(0.021)***	(0.020)***	(0.009)***
R^2	0.21	0.21	0.12
N	13,739	13,739	13,739

Notes: We divide the baseline sample into two subsamples: high-tech firms and low-tech firms. High-tech firms are those in SIC 35 and 36, which include industrial and commercial machinery and equipment and computer equipment; and electronic and other electrical equipment and components, and low-tech firms are the rest. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C26: Institutional Ownership, Innovation, and Firm Value

A. High Tech Firms

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	1.031				
	(0.172)***				
tail innovation		0.007			
		(0.001)***			
avg patent quality			0.010		
			(0.002)***		
avg originality				0.007	
				(0.002)***	
log patcount					0.249
					(0.031)***
R^2	0.12	0.14	0.14	0.14	0.15
N	8,669	15,678	15,678	15,678	15,678

B. Low Tech Firms

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.567				
	(0.072)***				
tail innovation		0.008			
		(0.001)***			
avg patent quality			0.012		
			(0.001)***		
avg originality				0.006	
				(0.001)***	
log patcount					0.125
					(0.018)***
R^2	0.18	0.19	0.19	0.19	0.19
N	46,029	81,853	81,853	81,853	81,853

Notes: We divide the baseline sample into two subsamples: high-tech firms and low-tech firms. High-tech firms are those in SIC 35 and 36, which include industrial and commercial machinery and equipment and computer equipment; and electronic and other electrical equipment and components, and low-tech firms are the rest. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C27: INSTRUMENTING INSTITUTIONAL OWNERSHIP WITH S&P 500 INCLUSION AND SHARE TURNOVER

A. High Tech Firms

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.303	30.506	14.974	1.520
	(0.313)***	(31.928)	(25.955)	(39.622)
N	2,686	8,714	8,714	8,714
instrument	share turnover	S&P 500	S&P 500	S&P 500

B. Low Tech Firms

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	0.889	36.299	34.310	67.899
	(0.109)***	(11.890)***	(11.389)***	(20.629)***
N	13,739	46,299	46,299	46,299
instrument	share turnover	S&P 500	S&P 500	S&P 500

Notes: We divide the baseline sample into two subsamples: high-tech firms and low-tech firms. High-tech firms are those in SIC 35 and 36, which include industrial and commercial machinery and equipment and computer equipment; and electronic and other electrical equipment and components, and low-tech firms are the rest. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 for all columns except column 1 which starts at 1992. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C28: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION (EXCLUDING PHARMACEUTICAL FIRMS)

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	3.162	2.921	4.988
	(0.400)***	(0.375)***	(0.565)***
R^2	0.11	0.16	0.31
N	51,317	51,317	51,317

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C29: Institutional Ownership and Managerial Compensation Structure (Excluding Pharmaceutical Firms)

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.260	0.234	0.025
	(0.019)***	(0.019)***	(0.008)***
R^2	0.21	0.22	0.13
N	15,633	15,633	15,633

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C30: Managerial Compensation Structure and Firm Innovation: Tail Innovation (Excluding Pharmaceutical Firms)

	Tail Innov.	Tail Innov.	Tail Innov.
Deferred Ratio	1.258	1.253	
	(0.530)**	(0.537)**	
Inst. Ownership		0.588	0.584
		(0.985)	(0.985)
Option/Income Ratio			1.331
			(0.581)**
Share/Income Ratio			0.703
			(0.782)
R^2	0.18	0.18	0.18
N	15,645	15,583	15,583

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C31: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE PATENT QUALITY (EXCLUDING PHARMACEUTICAL FIRMS)

	Avg. Citations	Avg. Citations	Avg. Citations
Deferred Ratio	1.176	1.056	
	(0.579)**	(0.589)*	
Inst. Ownership		1.616	1.616
		(0.948)*	(0.949)*
Option/Income Ratio			1.044
			(0.642)
Share/Income Ratio			1.143
			(0.774)
R^2	0.24	0.24	0.24
N	15,645	15,583	15,583

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C32: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE ORIGINALITY (EXCLUDING PHARMACEUTICAL FIRMS)

	Avg. Originality	Avg. Originality	Avg. Originality
Deferred Ratio	1.305	1.190	
	(0.558)**	(0.558)**	
Inst. Ownership		0.934	0.930
		(1.216)	(1.217)
Option/Income Ratio			1.282
			(0.597)**
Share/Income Ratio			0.545
			(1.307)
R^2	0.41	0.41	0.41
N	15,645	15,583	15,583

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C33: INSTITUTIONAL OWNERSHIP, INNOVATION, AND FIRM VALUE (EXCLUDING PHARMACEUTICAL FIRMS)

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.609				
	(0.065)***				
tail innovation		0.007			
		(0.001)***			
avg patent quality			0.012		
			(0.001)***		
avg originality				0.006	
				(0.001)***	
log patcount					0.142
					(0.015)***
R^2	0.13	0.15	0.15	0.15	0.15
N	51,009	92,552	92,552	92,552	92,552

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 at annual frequency. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C34: INSTRUMENTING INSTITUTIONAL OWNERSHIP WITH S&P 500 INCLUSION AND SHARE TURNOVER (EXCLUDING PHARMACEUTICAL FIRMS)

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.048	35.113	29.702	58.695
	(0.121)***	(11.350)***	(10.359)***	(17.925)***
N	15,633	51,317	51,317	51,317
instrument	share turnover	S&P 500	S&P 500	S&P 500

Notes: The estimation results are based on the baseline sample excluding all pharmaceutical firms. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1990 to 2004 for all columns except column 1 which starts at 1992. All specifications control for the same set of explanatory variables, year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C35: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION (SIC-2)

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	3.512	3.299	5.749
	(0.391)***	(0.367)***	(0.580)***
R^2	0.08	0.13	0.26
N	55,013	55,013	55,013

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C36: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION STRUCTURE (SIC-2)

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.270	0.253	0.017
	(0.019)***	(0.018)***	(0.008)**
R^2	0.17	0.16	0.08
N	16,425	16,425	16,425

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C37: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION (SIC-2)

	Tail Innov.	Tail Innov.	Tail Innov.
Deferred Ratio	1.971	1.965	
	(0.526)***	(0.528)***	
Inst. Ownership		0.372	0.347
		(0.913)	(0.913)
Option/Income Ratio			2.210
			(0.567)***
Share/Income Ratio			0.074
			(0.818)
R^2	0.12	0.12	0.13
N	16,438	16,371	16,371

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C38: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE PATENT QUALITY (SIC-2)

	Avg. Citations	Avg. Citations	Avg. Citations
Deferred Ratio	1.709	1.588	
	(0.537)***	(0.539)***	
Inst. Ownership		1.317	1.303
		(0.879)	(0.879)
Option/Income Ratio			1.720
			(0.580)***
Share/Income Ratio			0.574
			(0.811)
R^2	0.19	0.19	0.19
N	16,438	16,371	16,371

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C39: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE ORIGINALITY (SIC-2)

	Avg. Originality	Avg. Originality	Avg. Originality
Deferred Ratio	1.337	1.188	
	(0.593)**	(0.600)**	
Inst. Ownership		0.911	0.900
		(1.248)	(1.249)
Option/Income Ratio			1.295
			(0.634)**
Share/Income Ratio			0.361
			(1.424)
R^2	0.34	0.34	0.34
N	16,438	16,371	16,371

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C40: Institutional Ownership, Innovation, and Firm Value (SIC-2)

	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio	MTB Ratio
institutional ownership	0.686				
	(0.066)***				
tail innovation		0.009			
		(0.001)***			
avg patent quality			0.013		
			(0.001)***		
avg originality				0.007	
				(0.001)***	
log patcount					0.139
					(0.015)***
R^2	0.13	0.15	0.15	0.15	0.15
N	54,698	97,531	97,531	97,531	97,531

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C41: Instrumenting Institutional Ownership with S&P 500 Inclusion and Share Turnover (SIC-2)

	Deferred Ratio	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	1.126	33.334	28.665	43.973
	(0.104)***	(8.986)***	(8.185)***	(12.839)***
N	16,425	55,013	55,013	55,013
instrument	share turnover	S&P 500	S&P 500	S&P 500

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and a full set of two-digit SIC industry dummies. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C42: Institutional Ownership and Firm Innovation (Firm Fixed Effects)

	Tail Innov.	Avg. Citations	Avg. Originality
institutional ownership	3.433	3.673	6.786
	(0.550)***	(0.549)***	(0.809)***
R^2	0.13	0.21	0.34
N	31,317	31,317	31,317

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C43: INSTITUTIONAL OWNERSHIP AND MANAGERIAL COMPENSATION (FIRM FIXED EFFECTS)

	Deferred Ratio	Option/Income Ratio	Share/Income Ratio
institutional ownership	0.199	0.184	0.015
	(0.024)***	(0.023)***	(0.010)
size	0.025	0.023	0.002
	(0.007)***	(0.007)***	(0.003)
log(R&D stock)	0.009	0.018	-0.009
	(0.007)	(0.006)***	(0.003)***
leverage	-0.112	-0.106	-0.006
	(0.027)***	(0.026)***	(0.011)
age	0.011	0.003	0.008
	(0.001)***	(0.001)**	(0.001)***
CV price	-0.010	-0.005	-0.005
	(0.026)	(0.026)	(0.010)
R^2	0.43	0.44	0.36
N	16,427	16,427	16,427

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C44: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: TAIL INNOVATION (FIRM FIXED EFFECTS)

	Tail Innov.	Tail Innov.	Tail Innov.
Deferred Ratio	1.672	1.469	
	(0.637)***	(0.641)**	
Inst. Ownership		2.272	2.250
		(1.135)**	(1.135)**
Option/Income Ratio			1.840
			(0.706)***
Share/Income Ratio			-0.874
			(0.866)
R^2	0.14	0.14	0.14
N	11,825	11,776	11,776

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C45: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE PATENT QUALITY (FIRM FIXED EFFECTS)

	Avg. Citations	Avg. Citations	Avg. Citations
Deferred Ratio	1.564	1.280	
	(0.600)***	(0.585)**	
Inst. Ownership		2.952	2.943
		(1.124)***	(1.124)***
Option/Income Ratio			1.435
			(0.648)**
Share/Income Ratio			0.295
			(0.884)
R^2	0.23	0.23	0.23
N	11,825	11,776	11,776

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C46: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION: AVERAGE ORIGINALITY (FIRM FIXED EFFECTS)

	Avg. Originality	Avg. Originality	Avg. Originality
Deferred Ratio	1.506	1.099	
	(0.723)**	(0.725)	
Inst. Ownership		3.522	3.520
		(1.561)**	(1.561)**
Option/Income Ratio			1.144
			(0.781)
Share/Income Ratio			0.810
			(1.505)
R^2	0.38	0.38	0.38
N	11,825	11,776	11,776

Notes: This table reports the regression results using the baseline sample controlling for the same set of explanatory variables, year dummies and Blundell, Griffith, and Van Reenen (1999) firm fixed effects. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C47: Managerial Compensation Structure and Firm Innovation (Total Compensation)

	Tail Innov.			Avg. Citations			Avg. Originality		
total compensation	-0.085	-0.103	-0.103	0.043	0.014	0.014	0.368	0.360	0.360
	(0.181)	(0.184)	(0.184)	(0.167)	(0.172)	(0.172)	(0.186)**	(0.186)*	(0.186)*
Deferred Ratio	1.268	1.280		1.048	0.976		1.369	1.291	
	(0.510)**	(0.511)**		(0.488)**	(0.487)**		(0.562)**	(0.564)**	
size	0.446	0.435	0.437	0.455	0.429	0.426	1.071	1.062	1.065
	(0.176)**	(0.176)**	(0.176)**	(0.161)***	(0.161)***	(0.161)***	(0.266)***	(0.269)***	(0.269)***
log(R&D stock)	0.817	0.819	0.818	0.840	0.852	0.854	2.118	2.117	2.116
	(0.124)***	(0.125)***	(0.125)***	(0.122)***	(0.122)***	(0.122)***	(0.208)***	(0.209)***	(0.209)***
leverage	-2.529	-2.557	-2.550	-3.389	-3.426	-3.437	-4.140	-4.135	-4.125
	(1.052)**	(1.050)**	(1.049)**	(1.119)***	(1.134)***	(1.132)***	(1.434)***	(1.455)***	(1.454)***
age	-0.044	-0.043	-0.043	-0.028	-0.028	-0.028	0.036	0.037	0.037
	(0.013)***	(0.013)***	(0.013)***	(0.012)**	(0.012)**	(0.012)**	(0.024)	(0.024)	(0.024)
CV price	0.933	1.010	1.002	1.796	1.945	1.957	3.121	3.413	3.402
	(1.321)	(1.357)	(1.358)	(1.247)	(1.260)	(1.260)	(1.517)**	(1.553)**	(1.554)**
Inst. Ownership		0.546	0.546		1.287	1.288		0.328	0.327
		(0.947)	(0.947)		(0.907)	(0.907)		(1.302)	(1.302)
Option/Income Ratio			1.320			0.916			1.349
			(0.552)**			(0.533)*			(0.603)**
Share/Income Ratio			0.994			1.407			0.877
			(0.804)			(0.771)*			(1.362)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.41	0.41	0.41
N	14,564	14,500	14,500	14,564	14,500	14,500	14,564	14,500	14,500

Notes: This table adds total compensation as a control variable to the baseline specification. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C48: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION – ALTERNATIVE MEASURES

	Patent Value (KPSS)	Tail Innov. (total)	Citations (total)	Originality (total)
inst ownership	0.398	0.055	0.217	0.343
	(0.066)***	(0.075)	(0.072)***	(0.084)***
size	0.190	0.179	0.193	0.218
	(0.012)***	(0.013)***	(0.013)***	(0.015)***
log(R&D stock)	0.418	0.389	0.437	0.566
	(0.016)***	(0.016)***	(0.016)***	(0.018)***
leverage	-0.195	-0.225	-0.328	-0.355
	(0.059)***	(0.062)***	(0.063)***	(0.075)***
age	0.013	0.003	0.006	0.008
	(0.002)***	(0.002)**	(0.002)***	(0.002)***
CV price	0.037	-0.047	-0.093	-0.060
	(0.048)	(0.056)	(0.056)*	(0.068)
R^2	0.52	0.38	0.49	0.51
N	55,013	55,013	55,013	55,013

Notes: In this table we use alternative dependent variables: (1) Total market value of patents obtained from Kogan, Papanikolaou, Seru, and Stoffman (2017), (2) total tail innovations (instead of the fraction of tail innovations), (3) total citations (instead of average), and (4) total patents weighted by their originality (instead of average). Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C49: INSTITUTIONAL OWNERSHIP AND FIRM INNOVATION – ALTERNATIVE MEASURES (INSTRUMENTAL VARIABLE REGRESSION)

	Patent Value (KPSS)	Tail Innov. (total)	Citations (total)	Originality (total)
inst ownership	26.709	15.942	13.163	14.794
	(6.696)***	(4.497)***	(3.756)***	(4.211)***
size	-1.689	-0.955	-0.732	-0.814
	(0.487)***	(0.328)***	(0.274)***	(0.307)***
log(R&D stock)	0.682	0.548	0.567	0.711
	(0.080)***	(0.054)***	(0.045)***	(0.050)***
leverage	3.173	1.809	1.329	1.495
	(0.907)***	(0.603)***	(0.502)***	(0.562)***
age	-0.051	-0.035	-0.025	-0.027
	(0.017)***	(0.011)***	(0.009)***	(0.010)***
CV price	2.786	1.613	1.260	1.450
	(0.757)***	(0.506)***	(0.422)***	(0.475)***
N	55,013	55,013	55,013	55,013
instrument	S&P 500	S&P 500	S&P 500	S&P 500

Notes: In this table we use alternative dependent variables: (1) Total market value of patents obtained from Kogan, Papanikolaou, Seru, and Stoffman (2017), (2) total tail innovations (instead of the fraction of tail innovations), (3) total citations (instead of average), and (4) total patents weighted by their originality (instead of average). Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C50: Managerial Compensation and Firm Innovation – Alternative Measures

	Patent Value (KPSS)			Tail Innov. (total)			Citations (total)			Originality (total)		
Deferred Ratio	0.264	0.263		0.096	0.121		0.139	0.139		0.176	0.182	
	(0.068)***	(0.067)***		(0.074)	(0.073)*		(0.069)**	(0.068)**		(0.079)**	(0.078)**	
size	0.517	0.518	0.520	0.407	0.414	0.416	0.376	0.376	0.377	0.404	0.407	0.408
	(0.034)***	(0.036)***	(0.036)***	(0.032)***	(0.032)***	(0.032)***	(0.029)***	(0.030)***	(0.029)***	(0.034)***	(0.035)***	(0.035)***
log(R&D stock)	0.503	0.504	0.503	0.471	0.469	0.468	0.476	0.476	0.476	0.582	0.581	0.581
	(0.028)***	(0.028)***	(0.028)***	(0.027)***	(0.027)***	(0.027)***	(0.026)***	(0.026)***	(0.026)***	(0.031)***	(0.031)***	(0.031)***
leverage	-0.771	-0.781	-0.777	-0.612	-0.616	-0.611	-0.750	-0.760	-0.757	-0.681	-0.687	-0.683
	(0.181)***	(0.185)***	(0.184)***	(0.174)***	(0.175)***	(0.174)***	(0.165)***	(0.167)***	(0.167)***	(0.199)***	(0.202)***	(0.202)***
age	0.003	0.003	0.003	-0.004	-0.004	-0.004	0.002	0.002	0.002	0.005	0.005	0.005
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
CV price	0.218	0.221	0.216	0.121	0.053	0.047	0.266	0.250	0.246	0.350	0.336	0.330
	(0.160)	(0.160)	(0.160)	(0.183)	(0.186)	(0.186)	(0.167)	(0.169)	(0.169)	(0.190)*	(0.193)*	(0.193)*
inst ownership		-0.027	-0.027		-0.223	-0.224		0.009	0.009		-0.099	-0.100
		(0.157)	(0.157)		(0.157)	(0.157)		(0.151)	(0.151)		(0.178)	(0.178)
Option/Income Ratio			0.290			0.151			0.159			0.210
			(0.072)***			(0.078)*			(0.073)**			(0.083)**
Share/Income Ratio			0.070			-0.096			-0.006			-0.018
			(0.162)			(0.159)			(0.147)			(0.175)
R^2	0.63	0.63	0.63	0.51	0.51	0.51	0.61	0.61	0.61	0.63	0.63	0.63
N	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371

Notes: In this table we use alternative dependent variables: (1) Total market value of patents obtained from Kogan, Papanikolaou, Seru, and Stoffman (2017), (2) total tail innovations (instead of the fraction of tail innovations), (3) total citations (instead of average), and (4) total patents weighted by their originality (instead of average). Robust asymptotic standard errors reported in parentheses are clustered at the firm level. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

TABLE C51: MANAGERIAL COMPENSATION STRUCTURE AND FIRM INNOVATION (NB. OF EXERCISED OPTIONS)

	Tail Innov.			Avg. Citations			Avg. Originality		
nb. of exercised options	-0.001	-0.013	-0.016	-0.069	-0.070	-0.069	0.116	0.125	0.122
	(0.172)	(0.171)	(0.171)	(0.153)	(0.152)	(0.152)	(0.290)	(0.291)	(0.291)
Deferred Ratio	1.256	1.264		1.160	1.059		1.514	1.398	
	(0.519)**	(0.524)**		(0.564)**	(0.572)*		(0.556)***	(0.556)**	
size	0.412	0.398	0.402	0.497	0.455	0.454	1.154	1.128	1.131
	(0.161)**	(0.161)**	(0.161)**	(0.150)***	(0.151)***	(0.150)***	(0.244)***	(0.248)***	(0.248)***
log(R&D stock)	0.804	0.805	0.803	0.840	0.851	0.852	2.146	2.147	2.145
	(0.121)***	(0.121)***	(0.122)***	(0.119)***	(0.119)***	(0.119)***	(0.203)***	(0.204)***	(0.204)***
leverage	-2.759	-2.779	-2.769	-3.899	-3.922	-3.924	-4.256	-4.238	-4.228
	(1.021)***	(1.020)***	(1.019)***	(1.227)***	(1.245)***	(1.242)***	(1.339)***	(1.357)***	(1.357)***
age	-0.047	-0.047	-0.047	-0.031	-0.031	-0.031	0.029	0.030	0.030
	(0.013)***	(0.013)***	(0.013)***	(0.012)***	(0.012)***	(0.012)***	(0.023)	(0.023)	(0.023)
CV price	0.755	0.772	0.759	1.586	1.716	1.720	2.220	2.548	2.536
	(1.259)	(1.293)	(1.294)	(1.160)	(1.177)	(1.176)	(1.423)	(1.457)*	(1.458)*
inst ownership		0.410	0.408		1.386	1.386		0.746	0.744
		(0.935)	(0.935)		(0.903)	(0.903)		(1.206)	(1.207)
Option/Income Ratio			1.330			1.042			1.458
			(0.566)**			(0.622)*			(0.592)**
Share/Income Ratio			0.783			1.178			0.971
			(0.767)			(0.759)			(1.318)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.40	0.40	0.40
N	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371

Notes: This table adds the number of exercised options as a control variable to the baseline specification. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C52: Managerial Compensation Structure and Firm Innovation (Value of Exercised Options)

	Tail Innov.			Avg. Citations			Avg. Originality		
value of exercised options	0.007	0.007	0.007	0.004	0.003	0.004	0.015	0.015	0.015
	(0.011)	(0.011)	(0.011)	(0.010)	(0.010)	(0.010)	(0.017)	(0.017)	(0.017)
Deferred Ratio	1.247	1.254		1.151	1.050		1.502	1.387	
	(0.519)**	(0.525)**		(0.564)**	(0.572)*		(0.556)***	(0.555)**	
size	0.404	0.390	0.394	0.491	0.449	0.448	1.143	1.118	1.121
	(0.161)**	(0.162)**	(0.162)**	(0.150)***	(0.151)***	(0.150)***	(0.244)***	(0.248)***	(0.248)***
log(R&D stock)	0.804	0.804	0.803	0.840	0.851	0.852	2.144	2.146	2.144
	(0.121)***	(0.121)***	(0.122)***	(0.119)***	(0.119)***	(0.119)***	(0.203)***	(0.204)***	(0.204)***
leverage	-2.737	-2.756	-2.747	-3.881	-3.905	-3.908	-4.220	-4.202	-4.193
	(1.022)***	(1.021)***	(1.020)***	(1.228)***	(1.247)***	(1.244)***	(1.339)***	(1.356)***	(1.356)***
age	-0.047	-0.047	-0.046	-0.031	-0.031	-0.031	0.029	0.030	0.030
	(0.013)***	(0.013)***	(0.013)***	(0.012)***	(0.012)**	(0.012)**	(0.023)	(0.023)	(0.023)
CV price	0.744	0.759	0.746	1.572	1.702	1.706	2.211	2.539	2.527
	(1.259)	(1.292)	(1.294)	(1.159)	(1.176)	(1.175)	(1.422)	(1.456)*	(1.457)*
inst ownership		0.409	0.407		1.386	1.387		0.741	0.740
		(0.935)	(0.935)		(0.903)	(0.903)		(1.206)	(1.207)
Option/Income Ratio			1.319			1.033			1.444
			(0.566)**			(0.621)*			(0.591)**
Share/Income Ratio			0.786			1.180			0.974
			(0.767)			(0.759)			(1.318)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.40	0.40	0.40
N	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371

Notes: This table adds the value of exercised options as a control variable to the baseline specification. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C53: Managerial Compensation Structure and Firm Innovation (Whited-Wu Index)

	Tail Innov.			Avg. Citations			Avg. Originality		
Whited-Wu index	1.947	1.886	1.812	0.586	0.823	0.840	-5.944	-5.511	-5.583
	(5.291)	(5.279)	(5.277)	(5.369)	(5.376)	(5.375)	(6.944)	(6.965)	(6.967)
Deferred Ratio	1.334	1.344		1.222	1.127		1.632	1.525	
	(0.520)**	(0.527)**		(0.566)**	(0.575)*		(0.557)***	(0.556)***	
size	0.483	0.467	0.466	0.514	0.485	0.485	0.838	0.837	0.837
	(0.300)	(0.302)	(0.302)	(0.298)*	(0.303)	(0.303)	(0.418)**	(0.421)**	(0.421)**
log(R&D stock)	0.814	0.814	0.813	0.850	0.860	0.861	2.171	2.171	2.170
	(0.121)***	(0.121)***	(0.121)***	(0.118)***	(0.119)***	(0.118)***	(0.203)***	(0.205)***	(0.205)***
leverage	-2.721	-2.734	-2.720	-3.775	-3.809	-3.812	-3.879	-3.876	-3.862
	(1.045)***	(1.049)***	(1.048)***	(1.223)***	(1.240)***	(1.235)***	(1.401)***	(1.417)***	(1.416)***
age	-0.047	-0.047	-0.047	-0.032	-0.032	-0.032	0.026	0.027	0.027
	(0.013)***	(0.013)***	(0.013)***	(0.012)***	(0.012)**	(0.012)***	(0.023)	(0.024)	(0.024)
CV price	0.550	0.557	0.546	1.406	1.509	1.512	2.533	2.819	2.808
	(1.268)	(1.303)	(1.304)	(1.143)	(1.164)	(1.164)	(1.424)*	(1.459)*	(1.460)*
inst ownership		0.397	0.395		1.340	1.340		0.726	0.724
		(0.937)	(0.937)		(0.900)	(0.900)		(1.204)	(1.204)
Option/Income Ratio			1.409			1.112			1.588
			(0.568)**			(0.625)*			(0.593)***
Share/Income Ratio			0.874			1.233			1.070
			(0.767)			(0.760)			(1.320)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.40	0.40	0.40
N	16,350	16,284	16,284	16,350	16,284	16,284	16,350	16,284	16,284

Notes: This table adds the degree of financial constraint (measured by the Whited-Wu Index developed inWhited and Wu (2006)) as a control variable to the baseline specification. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.

Table C54: Managerial Compensation Structure and Firm Innovation (High Default Risk)

	Tail Innov.			Avg. Citations			Avg. Originality		
high default risk	-0.533	-0.536	-0.531	-0.329	-0.218	-0.219	-0.241	-0.079	-0.075
	(0.455)	(0.468)	(0.469)	(0.379)	(0.388)	(0.389)	(0.598)	(0.620)	(0.619)
Deferred Ratio	1.236	1.251		1.143	1.050		1.512	1.404	
	(0.520)**	(0.525)**		(0.564)**	(0.572)*		(0.556)***	(0.556)**	
size	0.410	0.399	0.402	0.494	0.453	0.452	1.157	1.133	1.136
	(0.160)**	(0.161)**	(0.161)**	(0.150)***	(0.151)***	(0.150)***	(0.243)***	(0.247)***	(0.247)***
log(R&D stock)	0.805	0.805	0.803	0.841	0.852	0.852	2.146	2.147	2.145
	(0.121)***	(0.121)***	(0.122)***	(0.119)***	(0.119)***	(0.119)***	(0.203)***	(0.204)***	(0.204)***
leverage	-2.627	-2.650	-2.640	-3.811	-3.863	-3.866	-4.206	-4.229	-4.221
	(1.018)***	(1.020)***	(1.019)***	(1.236)***	(1.252)***	(1.249)***	(1.350)***	(1.366)***	(1.366)***
age	-0.047	-0.047	-0.047	-0.031	-0.031	-0.031	0.029	0.030	0.030
	(0.013)***	(0.013)***	(0.013)***	(0.012)***	(0.012)***	(0.012)***	(0.023)	(0.023)	(0.023)
CV price	1.068	1.063	1.047	1.771	1.827	1.831	2.375	2.607	2.592
	(1.316)	(1.343)	(1.344)	(1.226)	(1.241)	(1.240)	(1.438)*	(1.468)*	(1.468)*
inst ownership		0.345	0.344		1.360	1.361		0.734	0.733
		(0.943)	(0.943)		(0.909)	(0.909)		(1.216)	(1.216)
Option/Income Ratio			1.316			1.032			1.464
			(0.566)**			(0.621)*			(0.592)**
Share/Income Ratio			0.781			1.178			0.970
			(0.766)			(0.759)			(1.318)
R^2	0.18	0.18	0.18	0.24	0.24	0.24	0.40	0.40	0.40
N	16,438	16,371	16,371	16,438	16,371	16,371	16,438	16,371	16,371

Notes: This table adds an indicator variable denoting high default risk as a control variable to the baseline specification. To construct this indicator, we first calculate the distance-to-default and the associated probability of default following Merton (1974) and Gilchrist and Zakrajsek (2012). The value of the indicator is set to one if the probability of default is higher than its average value in the sample. Robust asymptotic standard errors reported in parentheses are clustered at the firm level. The sample period is from 1992 to 2004 at annual frequency. All specifications control for year dummies and a full set of four-digit SIC industry dummies unless mentioned otherwise. See the text and notes to Table C6 and Section B.2 for detailed variable definitions. $***p < 0.01, **p < 0.05, *p < 0.1$.