# The real effects of tournament incentives: The case of firm innovation


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* We remain responsible for any errors and omission

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## Abstract

This paper examines the effects of promotion-based tournament incentives for non-CEO executives on corporate innovation. We find that firms with greater tournament incentives, which are measured as the pay gap between the CEO and other executives, are associated with a higher level of patent quantity and quality, innovation efficiency, and patent importance and novelty. An instrumental variable approach suggests that the observed relations are unlikely to be caused by endogeneity in tournament incentives. The attraction of talent and the reduction in excessive board interventions appear two plausible underlying mechanisms through which tournament incentives promote firm innovation. Our paper highlights the importance of inter-executive incentive scheme design in encouraging technological innovation.



**Keywords:** Tournament incentives, executive compensation, innovation, human capital, board monitoring

**JEL classification**: G30; G34; J31; J33; O32

## 1. Introduction

Innovation is an important driver of a nation's economic growth (Solow, 1957) and competitive advantage (Porter, 1992). Effective mechanisms that motivate innovation are of particular interest to both policy makers and firm stakeholders. Existing accounting and finance literature has studied various incentive mechanisms for motivating innovation that is captured by research and development (R&D) expenditures (e.g., Ball and MacDonald, 1995; Cardinal and Opler, 1995; Gibbs, 1995; Hemmer, 1995). Specifically, previous studies find that CEO compensation incentive has significant impact on innovation (e.g., Cheng, 2004; Holthausen et al., 1995; Rajgopal and Shevlin, 2002; Smith and Stulz, 1985; Dechow and Sloan, 1991; Cheng et al. 2012; Smith and Watts, 1992). However, most of these papers take a single-agent perspective (i.e., focus on individual executive such as the CEO) and overlook the fact that innovation requires teamwork that engages all executives. The relative levels of compensation can be more consequential to managerial behavior than absolute levels of compensation (Kale et al., 2009; Bushman et al., 2016). Therefore, it is important to take a multi-agent perspective and consider inter-executive pay disparity when designing compensation scheme that can induce optimal efforts from corporate executives and enhance the firm's innovation performance. In this paper, we explore how tournament incentives (also known as promotion-based incentives) among corporate executives affect innovation.

In a typical rank-order tournament, the executive with the best relative performance is promoted to the next level in the hierarchy, while the others are passed over. Promotion to the next level carries with it a higher pay and status and therefore provides managers with an incentive to expend a higher level of effort.[1] Gibbs (1995) suggests that in a hierarchical company, promotions provide important incentives for the managers; the reward from promotion, especially over the long term, can be substantial; and the likelihood of promotion depends on current performance ratings. Lazear and Rosen (1981), Main et al., (1993), and Kale et al., (2009)

[1] Kale et al., (2009) argue that although performance-based compensation is the only incentive for CEOs, the lower-rank executives in the management team face both performance-based equity incentives and promotion-based incentives, and the promotion-based incentives are even more dominant.

all argue that tournament provides strong promotion incentives for non-CEO executives and is positive related to firm performance. Tournament incentives are also important for motivating technological innovation, because innovation, unlike routine tasks such as marketing or mass production, is a long-term, risky, and idiosyncratic investment in intangible assets. It represents a firm's long-term growth opportunity and signals executives' abilities to pursue the long-term interest of shareholders. Existing studies (e.g., Guay, 1999; Coles et al. 2006; Kini and Williams, 2012) show that option-like payoff structure encourages firms to take more risks such as investing in technological innovation. Tournament represents an option-like incentive because being promoted to a higher level represents being in the money and the prize is the increase in monetary and non-monetary rewards (i.e., higher compensation as well as enhanced status and perks).[2] Therefore, we hypothesize that order-rank tournament incentives can motivate the management team to generate better innovation performance.

An alternative hypothesis predicts the opposite that rank-order tournament incentives could hinder firm innovation. Innovation represents long-term and risky corporate initiatives that require close collaboration and interactions among a group of highly motivated and engaged managers who work together as a team to generate ideas and convert them into new products, services, or business models. Hence, collaboration and coordination among executive team members are crucial for success in a firm's innovation activities (Henderson and Fredrickson, 2001; Siegel and Hambrick, 2005; Gnyawali et al., 2008). However, pay gaps are constructed in a way that there typically exists only one winner in the tournament. As a result, individual motivation, self-interest, and managerial hubris induced by tournament incentives could destroy the collaborative intention and synergy among executive team members, which is detrimental to firm innovation performance.

In this paper, we test the above two competing hypotheses by using patent-based metrics

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[2] In addition, precisely because innovation process is risky and idiosyncratic that may lead to extreme outcomes, the board of directors and the CEO cannot discern whether it is the executive's ability/effort or the higher project risk that results in the firm's long-run growth opportunities. Therefore, each individual executive has strong incentives to engage in innovation activities, and especially to have push for outstanding innovation performance. In equilibrium, all executives pursue better innovation performance in the presence of these tournament incentives.

to gauge a firm's innovation performance. This approach is significantly different from earlier studies that mainly use R&D expenditures to measure firm innovation. Patents capture a firm's innovation output and are superior to R&D expenditures for a number of reasons. First, R&D expenses (mainly researchers and technicians' wages as reported in Compustat) represent a particular observable innovation input whereas patent-based metrics reflect a firm's innovation output that encompasses the successful usage of both observable and unobservable innovation inputs. Hence, while the level of R&D expenditures may be a decision made by the CEO herself (and approved by the board), the execution of innovation initiative that results in different level of innovation outcome is a team effort and is more likely to be affected by the tournament incentives. Second, R&D expenditures only capture the quantity of innovation input, but patent-based metrics allow us to observe multiple dimensions of a firm's innovation output including its quantity, quality, efficiency, and fundamental nature along intensive and extensive margins. Third, R&D expenditures are sensitive to accounting norms as argued by Acharya and Subramanian (2009) and it is debatable whether it should be capitalized or expensed. Finally, about 65% of firm-years observations from Compustat have missing values of R&D expenditures.[3] However, missing R&D expenditures in financial statements do not necessarily represent that the firm is not innovative (Koh and Reeb, 2015). Simply setting the missing value as zero, a common practice in the existing literature, may introduce additional noise and significantly bias the findings. Thus, patent-based metrics are able to better reflect the productivity of R&D and therefore more realistically reflect innovation performance.[4]

Following prior studies (e.g., Kale et al, 2009; Kini and Williams, 2012), we define tournament incentives as compensation gaps between the CEO and the VPs. We also

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[3] We find that in the Compustat annual tape database for the period from 1950 to 2014, there are 65% firm-years have missing value for the R&D variable, XRD.

[4] Holthausen et al. (1995) is an exception we are aware of that uses patents as a proxy for innovation when investigating the relation between compensation and innovation. Using a divisional (or business unit) data sample of compensation and patents, they find some mixed results. Although they find modest evidence that increases in the long-term component of the divisional CEO's compensation has a positive relation with future innovation by the division, as they argue, the causal relation between compensation and patents is still unclear, and these results cannot be interpreted as that an increase in the proportion of compensation tied to long-term components should be expected to produce an increase in subsequent innovation by the firm.

decompose executive pay gaps into long-term pay gaps, which are based on long-term compensation in the form of stock and option grants, and short-term pay gaps, which are based on short-term compensation in the form of salary, bonus, and other fixed annual payments. To measure innovation, we examine seven variables that capture different aspects of a firm's innovation performance including the number of patents, the number of future citations that each patent receives, the number of patents divided by R&D expenditures (a measure of innovation efficiency), patent originality scores, patent generality scores, patent exploration intensity, and patent exploitation intensity, respectively.

Using a sample of firm-year patent and executive compensation data from 1992 to 2012, we find that tournament incentives created by pay gaps are positively associated with the number of patents, citations per patent, innovation efficiency, originality score, generality score, and exploration intensity. These results suggest that tournament incentives can dominate its potential damage on the team collaborations and motivate managers to engage in more quality innovations, consistent with the findings of the positive effects of tournament incentives on firm performance and corporate risk (Kale et al., 2009; Kini and Williams, 2012). Moreover, all these effects are attributed only to long-term pay gap that is composed of stock and option grants, and are unrelated to short-term pay gap that involves cash compensation, consistent with the notion that innovation is a long-term process and thus more likely to be motivated by the long-term incentive scheme. These results are consistent with our conjecture that tournament incentives induced by pay gaps, especially by long-term pay gaps, are beneficial to a firm's innovation performance.[5]

One important concern about the above results is that some omitted variables correlated with both executive pay gaps and corporate innovation performance may drive the observed relation, which makes a causal interpretation difficult. Following Kini and Williams (2012), we address this endogeneity concern by using the median values of tournament measures and CEO

[5] Our results are robust to the inclusion of executive PPS (Pay-for-Performance Sensitivity) dispersion which can serve as a proxy for team synergy (Bushman et al. 2016). And we find that executive PPS dispersion does not has significant effect on innovation.

incentives of firms in the same 2-digit SIC code and size quartile as instrumental variables. We then use a two-stage least square (2SLS) estimation method to mitigate the endogeneity concern. Our main results remain unchanged after we control for endogeneity in pay gaps among executive team members, which suggests that the effect of tournament incentives on firm innovation appears causal.

Next, we explore two plausible underlying economic mechanisms through which tournament incentives improve innovation performance. The first plausible mechanism we explore is the human capital channel. We argue that tournament incentives can improve corporate innovation performance by eliciting greater productivity from executives and inventors who are directly involved in the firm's innovation activities, as well as by attracting high-quality innovation talents from the labor market. We explore this mechanism at two levels. At the executive level, we show that firms with greater tournament incentives tend to have more innovative executives who personally generate patents, consistent with the notion that tournament incentives can attract talented executives who can innovate. At the individual inventor level, we also find that inventors who just join or stay at firms with greater tournament incentives are more innovative than those at firms with lower tournament incentives. We also find that firms with greater tournament incentives are more likely to attract top inventors from the labor market. We argue that overall compensation scheme is an internally consistent system in a firm, covering from top executives to floor workers. The results at the individual inventor level imply that the environment of competition for promotion generated by tournament incentives at the executive level can have a spillover effect on lower-level individual inventors, and motivate them to be productive in innovation. Though prior studies show that compensation for executives have significant economic consequences, this finding is the first one that documents the spillover effect of executive compensation on other, lower-level workers.

The second plausible mechanism we propose is the reduction in excessive interventions by boards. Due to innovation project's nature of being a type of high-risk, long-term, and unpredictable investment that might not generate immediate financial returns, managers who are under board scrutiny may be prone to invest less (in many cases sub-optimally) in such projects and put more effort in routine tasks that could offer quicker and more certain returns (He and Tian, 2013). Consistent with this view, Faleye et al., (2011) find that intense monitoring promotes managerial myopia by weakening the CEO's perception of board support, which impedes investments in risky but value-enhancing ventures such as corporate innovation. Because tournament incentive scheme is an effective corporate governance mechanism that can be used to align principal-agent interests and mitigate agency problems (such as shirking and free-riding), it can reduce the need for costly monitoring and close board scrutiny and intervention (Lazear and Rosen, 1981; Main et al., 1993; Kale et al., 2009). Therefore, tournament incentives may improve innovation performance by reducing a board's excessive monitoring and interventions. We first establish that a higher level of tournament incentives is associated with lower likelihood of having a monitoring-intensive board, suggesting that tournament incentives and board monitoring are substitute governance mechanisms. We then show that, in the subsample of firms without intensive board monitoring, tournament incentives are more likely to improve innovation performance than in the subsample of firms with intensive board monitoring. These results are consistent with the notion that tournament incentives can improve innovation, only when the board imposes little intervention.

The rest of the paper is structured as follows. Section 2 discusses the related literature and our contributions. Section 3 discusses our sample and research designs. Section 4 presents the empirical analyses. Section 5 explores possible underlying economic mechanisms through which tournament incentives affect firm innovation. Section 6 concludes.

## 2. Relation to the Existing Literature

Our paper is related to three strands of existing literature in accounting and finance, and provides several contributions. First, our findings add to the literature on the relation between compensation and innovation. One stream of accounting literature regards R&D expenditures as a means of real earnings management, and thus short-term benefits from compensation may induce the managers to reduce R&D expenditures opportunistically (e.g., Dechow and Sloan, 1991; Cheng et al., 2012). On the other hand, if the board is effective in preventing the reduction of R&D expenditure, it will increase the proportion of long-term compensation (e.g., Cheng, 2004). Another stream of literature regards investment of R&D as a risk-taking behavior, and argues that managers with more equity-based compensation, especially stock options grant, are more likely to take the risk of investing in R&D (e.g., Rajgopal and Shevlin, 2002; Smith and Stulz, 1985; Smith and Watts, 1992; Guay, 1999; Xue, 2007). In addition, Holthausen et al. (1995) find that division managers with the proportion of total compensation tied to long-term components have a positive relation with the number of future patents. Our paper contributes to this literature by showing that besides increasing the long-term and equity-based compensation for individual executives, promotion-based tournament incentive schemes for the top management team is another important design to motivate innovation, and compensation incentives can improve not only the investment in R&D (i.e., input to innovation) and the quantity of innovation output, but also many other dimensions of innovation output, including patent quality, efficiency, importance, and novelty.

Second, our paper sheds some lights on the literature of tournament incentives. Lazear and Rosen (1981) are the first to propose the rank-order tournament incentives, and suggest the gap between CEO and VP compensation as a feature of tournament incentives. Kale et al. (2009) suggest that pay gaps relate positively to firm value and performance, because if each executive has incentive to pursue the promotion prize through improving performance, then the tournament incentives motivate the whole team to improve firm value. Kini and Williams (2012) find that firms with greater tournament incentives are riskier, because the promotion incentives motivate managers to undertake risky projects.[6] Our paper is the first one to investigate the effect of tournament incentives on a firm's long-run growth opportunities, as reflected by the quantity and

[6] Kini and Williams (2012) argue that extreme outcomes will be more likely with greater project risk. Therefore, when the output of all executives is high, the risk-taking executive's output will tend to be higher than that of her competitors. The executive with the highest output will get promoted because the board of directors/CEO cannot discern whether it was the executive's ability or the higher project risk that resulted in the higher output. Given that each executive will have the same incentive to take on greater risk, a Nash equilibrium will imply that all executives take on greater risk than they would have in the absence of these tournament incentives.

quality of innovation output.

Finally, our study is related to the fast growing literature on motivating and financing corporate innovation. Holmstrom (1989) argues that innovation is inherently different from routine tasks and they may not mix well in an organization. Manso (2011) theoretically shows the importance of tolerating early failure in motivating innovation. Empirical evidence provides consistent evidence showing the importance of appropriate incentives given to firm managers when motivating innovation. Specifically, a large institutional ownership (Aghion et al. 2013), debtor friendly bankruptcy laws (Acharya and Subramanian, 2009), lower coverage of financial analysts (He and Tian, 2013), corporate venture capital (Chemmanur et al. 2014), private ownership (Lerner et al. 2011), lower union power (Bradley et al. 2016), stock options (Chang et al. 2015), and failure-tolerant investors (Tian and Wang, 2014) all promote managers and employees' incentives to undertaking innovative activities. However, existing literature has been silent on how tournament incentives among executives, a very important design on executive incentive mechanism, affect firms' innovation activities. Our paper contributes to this line of research by filling in the gap.

## 3. Sample Selection and Summary Statistics

### *3.1 Sample selection*

Our sample includes U.S. listed firms during the period of 1992-2012. We collect firm-year patent and citation information from the Google USPTO Bulk Downloads, which is available at http://www.google.com/googlebooks/uspto.html. This database provides rich information on all patents filed and granted by the USPTO between 1976 and 2014 including patent application and grant date, patent assignee name (the entity that owns the patent), the technology class of the patent, and detailed information on subsequent patents that cite the patent, etc. We obtain information on a firm's top management team and their compensation from ExecuComp, financial statement items from Compustat Industrial Annual Files, board composition and other characteristics from RiskMetrics, and institutional holdings data from

Thomson's CDA/Spectrum database (form 13F). We exclude firms that have never filed a single patent with the USPTO during our sample period. The final sample consists of 7,708 firm-year observations.

### *3.2 Variable measurement*

#### *3.2.1 Measuring innovation*

We examine seven variables that capture different aspects of a firm's innovation performance, including patent productivity, efficiency, importance, and novelty, respectively. The first two variables, *NumPat* and *CitePat*, gauge patent productivity and quality, and have been extensively examined in earlier innovation studies (e.g., He and Tian, 2013; Fang et al., 2014). We define *NumPat* as a firm's total number of patent applications filed in a given year that are eventually granted.[7] We define *CitePat* as the number of citations that each patent receives in subsequent years. Given a firm's innovation input, the number of patents captures its overall innovation productivity and the number of citations per patent captures the significance and quality of its innovation output. The third variable, *PatEff*, is measured as the total number of patents granted in a given year divided by the research and development (R&D) expenditures and captures innovation efficiency. A higher value of *PatEff* suggests a more efficient usage of innovation resources and a higher level of innovation efficiency.

The next two variables, *Originality* and *Generality*, capture the fundamental importance and impact of innovation (Lerner et al., 2011; Hsu et al., 2014). As proposed by Hall et al., (2001), patents that cite a wider array of technology classes of patents are considered as having greater originality. In a similar spirit, patents that are being cited by a wider array of technology classes of patents are viewed as having greater generality.[8]

The last two innovation variables that we examine pertain to the type of innovation activities and the novelty of innovation output. The management literature has identified two

[7] The reason for using a patent's application year rather than its grant year is that previous studies (such as Griliches et al., 1988) have shown that the former is superior in capturing the actual time of innovation.

[8] Similar to citations, we set patent generality and originality variables as missing when a firm has no patent in a year, since we can measure patent generality and originality only if we have information regarding patent citations.

generic types of innovation activity: *exploratory* innovation and *exploitative* innovation (Levinthal and March, 1993; McGrath, 2001; Benner and Tushman, 2002). Exploration involves departure from existing knowledge and experiment with new technologies or approaches. In contrast, exploitation pertains to "the refinement and extension of existing technologies and paradigms" (March, 1991).[9] We define exploratory and exploitative patents according to the extent to which a firm's new patents use current versus new knowledge. A firm's existing knowledge consists of its previous patent portfolio and the set of patents that have been cited by the firm's patents filed over the past five years. A patent is categorized as exploitative if at least 60% of its citations are based on current knowledge, and a patent is categorized as exploratory if at least 60% of its citations are based on new knowledge (i.e., citations not in the firm's existing knowledge base). We then calculate the intensity of exploratory patents for a given firm-year (*Explore60)* as the number of exploratory patents filed in a given year divided by the number of all patents filed by the firm in the same year. We define the intensity of exploitative patents for a given firm year (*Exploit60)* as the number of exploitative patents filed in a given year divided by the number of all patents filed by the firm in the same year.

Following the existing innovation literature, to account for the long-term nature of innovation process, our empirical tests relate firm characteristics in the current year to patent-related variables three years ahead.[10] A first look at the distribution of the number of patents in the sample shows that the distribution is right skewed, that is, a significant number of firm-year observations have zero patents. To mitigate the right skewness problem, we use the natural logarithm of patent counts *Ln(PatNum),* the natural logarithm of citations per patent *Ln(CitePat),* and the natural logarithm of innovation efficiency *Ln(PatEff)*. To avoid losing firm-year observations with zero patents, we add one to the actual values when calculating the natural logarithm.

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[9] Since the seminal work of March (1991), innovation strategy and the conceptual distinction between exploration and exploitation have been studied in a wide range of management research areas, including strategic management (e.g., Winter and Szulanski 2001), organization theory (e.g., Holmqvist 2004; He and Wong, 2004), and managerial economics (e.g., Ghemawat and Ricart i Costa 1993).

[10] *PatEff* is calculated based on R&D expenditure in a given year and the number of patents three years ahead.

*3.2.2 Measuring tournament incentives*

Following prior compensation studies (e.g., Kale et al., 2009; Kini and Williams, 2012; Bognanno, 2001), our main measure of tournament incentives is the compensation gap between the CEO and the VPs. An executive's compensation is composed of two parts: *short-term* compensation in the form of salary, bonus, and other fixed annual payments, and *long-term* compensation in the form of stock and option grants. We therefore construct three pay gap variables: *Ln(TotalGap)*, which is defined as the natural logarithm of the difference between CEO's total compensation (i.e., sum of short-term and long-term compensation) and the median value of total compensation of all VPs in a given firm-year; *Ln(ST Gap)*, which is calculated in a similar manner but only using short-term compensation; and *Ln(LT Gap)*, which is calculated using only long-term compensation.

There are instances in which a CEO's compensation is less than the median VP's compensation, which results in negative values of pay gaps. We follow prior studies (e.g., Kale et al., 2009; Hartman, 1984; Slemrod, 1990) and transform all observations by adding a constant equal to the absolute value of the minimum gap to each observation.[11]

*3.2.3 Measuring control variables*

Following the innovation literature, we control for a vector of firm and industry characteristics that may affect a firm's innovation activities. We provide detailed variable definitions in Appendix 1. We compute all variables for firm *i* over its fiscal year *t*. In the baseline regressions, our control variables include firm size (measured by the natural logarithm of total sales), profitability (measured by the return-on-assets ratio), leverage (measured by the total debt to total assets ratio), capital expenditures scaled by total assets, investments in research and development (measured by R&D expenditures over total assets), asset tangibility (measured by net property, plants, and equipment scaled by total assets), industry concentration (measured by the Herfindahl index based on annual sales), growth opportunities (measured by Tobin's *q*),

[11] Following Kale et al. (2009), prior to the logarithm transform, we add $271,000, $1,040,000, and $810,000 to all observations for *ST Gap*, *LT Gap*, and *TotalGap*, respectively.

and institutional ownership (measured by the percentage of institutional holdings). To control for nonlinear effects of product market competition on innovation output documented by Aghion et al. (2005), we include the Herfindahl index and its squared term.

Following Kini and Williams (2012), we also include several variables that capture executives' alignment incentives that may affect their behavior. Specifically, we include *CEO Delta*, which is calculate as the CEO's total portfolio delta, computed as her dollar increase in wealth for a 1% increase in stock price in a given year; *CEO Vega*, which is calculated as the CEO's total portfolio vega, computed as her dollar increase in wealth for a 1% standard deviation increase in the firm's return volatility in a given year.[12] In addition, we include the standard deviation of VPs' total compensation, *Std VP*, to capture the possibility of a tournament among VPs (e.g., Milgrom and Roberts, 1992; Gibbs, 1994), and finally the natural logarithm of CEO age *CEO Age*.

*3.3 Summary statistics*

To minimize the effect of outliers, we winsorize all continuous independent variables at the 1st and 99th percentiles. Panel A of Table 1 provides summary statistics. Among dependent variables, the average value of *Ln(NumPat)*, *Ln(CitePat)* and *Ln(PatEff)* is 1.475, 0.226, and 0.270, respectively. An average firm has an originality score of 0.363, a generality score of 0.667, an exploratory intensity of 0.686, and an exploitative ratio of 0.176. As for managerial compensation, tournament and alignment measures, the average value of *Ln(Total Gap), Ln(LT Gap),* and *Ln(ST Gap)* is 7.896, 7.641 and 6.868, respectively. Average *CEO delta* and *CEO vega* are 0.631 and 0.024, respectively. Regarding control variables, an average firm has a natural logarithm of sales of 7.2, leverage ratio of 18.6%, R&D intensity of 2.6%, capital expenditure ratio of 4.2%, PPE-to-assets ratio of 21.6%, and Tobin's *q* of 1.7.

Panel B reports the sample distribution by industry in which industry classifications are

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[12] The parameters used to compute option delta are no longer available in ExecuComp for years after 2006. So, following the Appendix A in Kini and Williams (2012), we estimate those parameters first and then compute option delta based on Core and Guay (2002).

based on 2-digit SIC codes. The largest sector in our sample is Chemical & Allied Products (SIC code 28), followed by Electronic & Other Electric Equipment (SIC code 36) and Industrial Machinery & Equipment (SIC code 35). Firms in those industries tend to be more active in innovation than those in other industries.

## 4. Baseline Empirical Results

### *4.1 Tournament incentives and innovation*

To assess how tournament incentives affect a firm's innovation performance, we estimate the following models:

$$Innovation_{i,t+3}=\alpha+\beta Ln(Total\ Gap)_{i,t}+\lambda' Control_{i,t}+Year_t+Firm_i+\varepsilon_{i,t} \qquad (1)$$

$$Innovation_{i,t+3}=\alpha+\beta_1 Ln(LT\ Gap)_{i,t}+\beta_2 Ln(ST\ Gap)_{i,t}+\lambda' Control_{i,t}+Year_t+Firm_i+\varepsilon_{i,t} \qquad (2)$$

where *i* indexes firm and *t* indexes time. The dependent variable, *Innovation*, is one of the seven innovation-related variables described in Section 3.2.1. The main variable of interest is the natural logarithm of total pay gaps, *Ln(Total Gap)*, in equation (1), and the natural logarithm of long-term pay gaps, *Ln(LT Gap)*, and the natural logarithm of short-term pay gaps, *Log(ST Gap)*, in equation (2). *Control* is a vector of firm characteristics that could affect a firm's innovation performance as discussed in Section 3.2.3.[13] *Year* and *Firm* capture year and firm fixed effects, respectively. We include firm fixed effects in the baseline regressions for two reasons. First, firm fixed effects allow us to directly answer the question by exploring how the variation of pay gaps within a firm explains its subsequent variation in innovation output. Put differently, we can interpret the coefficient estimate of pay gaps as the effect of a firm's change in pay gaps among executives on its subsequent change in innovation performance. Second, like most studies in corporate finance, the baseline OLS framework is subject to endogeneity concerns. Firm fixed effects absorb time-invariant firm unobservable heterogeneity and hence help mitigate endogeneity concerns. We cluster standard errors at the firm level.

Table 2 Panel A presents the results using total pay gaps as the tournament measure. The

[13] Except for *PatEff* where R&D intensity is excluded from control variables because *PatEff* is already deflated by the R&D expenditure.

coefficient estimates of the key variable of interest, *Ln(Total Gap)*, is positive and significant in columns (1) - (6) in which the dependent variable is the number of patents, citations per patents, patent efficiency, originality score, generality score, and exploration intensity, respectively. However, the coefficient estimate of total pay gaps is not statistically significant when exploitation intensity is the dependent variable in column (7). Taken together, these findings are consistent with our conjecture that tournament incentives created by pay gaps encourage executives to spend more efforts and become more productive in innovation activities. Control variables exhibit signs that are consistent with previous studies. For example, larger firms and firms with higher Tobin's *q* generally produce more patents.

In Table 2 Panel B, we separate total pay gaps into long-term and short-term gaps which allow us to examine their potentially differential effects on innovation performance. Different from prior studies such as Kale et al., (2009) who find both long-term and short-term gaps have a significantly positive impact on firm performance, we find only long-term pay gaps are positively associated with innovation performance, evidenced by the positive and signification coefficient estimates of *Ln(LT Gap)*. In contrast, short-term pay gaps, which contain cash and bonus, does not seem to have an impact on innovation that is characterized by high uncertainty and is long term in nature except in column (1) where the dependent variable is number of patents.

Overall, our baseline results are consistent with the conjecture that pay gap-induced tournament incentives are beneficial to a firm's innovation performance. When decomposing total pay gaps into long-term and short-term gaps, we find that only pay gaps that involve long-term compensation, such as stock and options, are effective in encouraging investment in risky projects.

*4.2 Instrumental variables estimation*

A reasonable concern of our baseline results is that omitted variables correlated with both executive pay gaps and corporate innovation performance may bias the results. As discussed before, the inclusion of firm fixed effects in the baseline tests alleviates such a concern to certain extent by controlling time-invariant factors. In this section, we further address the endogeneity concern by using the 2SLS approach to correct for the potential bias in our baseline regressions. Because both tournament and alignment incentives measures are related to managerial compensation, all three tournament variables (i.e., *Ln(Total Gap), Ln(LT Gap), Ln(ST Gap))* and two incentive variables (i.e., *CEO Delta and CEO Vega)* could be endogenous.

To implement the instrumental variable estimation, ideal instruments should help to capture the variation in tournament and incentive variables but are exogenous to firms' innovation performance. Murphy (1999) documents that the level and structure of managerial compensation vary by industry and firm size. Kale et al., (2009) examine the determinants of executive pay gaps and find that median industry values for pay gaps are significant determinants of the size of the tournament prize. Following Kini and Williams (2012), we use the median values of tournament measures of firms in the same 2-digit SIC code and size quartile, *Ln(Median Ind_Total Gap), Ln(Median Ind_LT Gap),* and *Ln(Median Ind_ST Gap),* as the instruments for the firm's tournament variables. Similarly, we use the median values of incentive measures of firms in the same 2-digit SIC code and size quartile, *Median Ind_CEO Delta* and *Median Ind_CEO Vega,* as the instruments for the firm's incentive variables.

Table 3 presents the results from the 2SLS estimation that uses total gaps as the measure of tournament incentives. Columns (1)-(3) report the results from the first-stage regression of the 2SLS approach for the three endogeneous variables, and present all the test statistics that are related to endogeneity and instrumental variable selection in the bottom panel of the table. We include the same set of control variables as that in the baseline regression Equation (1). We also include year and firm fixed effects, and cluster standard errors at the firm level.

In column (1) in which the dependent variable is *Ln(Total Gap),* the coefficient estimate of the industry-median level of total gaps *Ln(Median Ind_TotalGap)* is positive and significant at the 1% level, which is consistent with the finding of Kale et al., (2009) that median industry values for pay gaps are significant determinants of the size of the tournament prize. In column (2) and (3) in which the dependent variable is *CEO Delta* and *CEO Vega*, respectively, the coefficient estimates on the corresponding instrumental variables are positive and significant at the 1% level. These findings suggest that our instruments are highly correlated with the instrumented endogenous variables. The Shea partial $R^2$ values and the significant *F*-statistic provide support for the joint relevance of our instruments in the first stage. Further, the Anderson–Rubin *F*-statistic rejects the null hypothesis that the instruments are not relevant. We also compare the *F*-statistics with the critical values of Stock and Yogo (2005) for the weak instrument test and are able to reject the null hypothesis that our instruments are weak.

Columns (4)-(10) of Table 3 report the results from the second-stage regressions estimating Equation (1) with the main tournament variable *Ln(Total Gap)* replaced by its fitted value from the first-stage regression. The two incentive variables *CEO delta* and *CEO Vega* are also replaced by their fitted value from the first-stage regression. The coefficient estimate on *Ln(Total Gap)* continues to be positive and significant in regressions in which the dependent variable is the number of patents, citations per patent, patent efficiency, originality and generality, and exploration intensity. The coefficient estimates of *Ln(Total Gap)*, however, is not significant in column (10) where the dependent variable is exploitation intensity, suggesting that tournament incentives measured by total pay gaps do not encourage exploitative innovation activities.

Comparing results obtained from the OLS regressions (Table 2 Panel A) with those obtained from the 2SLS regressions (Table 3), we observe that the magnitudes of the 2SLS coefficient estimates are larger than those of the OLS estimates, even though the coefficient estimates from both approaches are positive and significant (except for exploitive patent intensity). This observation suggests that OLS regressions bias the coefficient estimates downward because of endogeneity in pay gaps. One plausible reason is that the omitted variables simultaneously reduce pay gaps among executives and enhance innovation. Corporate culture could be an example of such an omitted variable. For example, collaborative-orientated corporate culture facilitates cooperation among executives and positively affects firm innovation. Meanwhile, because of collaborative-oriented culture that resides in the firm, tournament-induced pay gaps may not be needed to the extent if the corporate culture was absent to motivate innovation. This observation does not necessarily reflect a causal consequence of pay gaps on innovation output because of the endogeneity problem inherent in the optimal pay gap design. However, the negative correlation caused by the omitted variable could be the main driving force that biases the coefficient estimates of pay gaps downward. Using the instruments to clean up the correlation between pay gaps and the residuals in Equation (1), the endogeneity problem is mitigated and the coefficient estimates increase, i.e., become more positive.

In Table 4, we use *Ln(LT Gap)* and *Ln(ST Gap)* as tournament measures and industry-median level of long-term pay gaps *Ln(Median Ind_LT Gap)* and industry-median level of short-term pay gaps *Ln(Median Ind_ST Gap)* to instrument for these two tournament measures, respectively. In columns (1) – (4), we report the results from the first-stage regressions. The coefficient estimates of the instruments are highly significant in their corresponding regressions. The Shea partial $R^2$ values, Anderson-Rubin $F$-statistic and Stock and Yogo (2005) all suggest that the instruments satisfy the relevance condition and are not weak.

In columns (5) – (11), we report the results from the second-stage regressions with instrumented *Ln(LT Gap)* and *Ln(ST Gap)*. The coefficient estimates of instrumented *Ln(LT Gap)* are positive and significant in regressions in which the dependent variable is the number of patents, patent citations, patent efficiency, patent originality, and exploration. In contrast, the coefficient estimates of instrumented *Ln(ST Gap)* are insignificant.

Taken together, the 2SLS analyses suggest that tournament incentives, especially long-term gaps among executives, have positive effects on a firm's innovation performance in terms of quantity, quality, efficiency, fundamental nature, and exploration intensity. In particular, only long-term pay gaps among executives appear to induce the kind of tournament incentives that successfully promote innovation. However, tournament incentives appear to discourage a firm's exploitive innovation that mainly relies on existing knowledge.

### *4.3 Robustness tests*

We conduct a rich set of additional tests to ensure the robustness of our results:

First, we use an alternative measure to capture tournament incentives. Instead of using the median of VP compensation to calculate pay gaps, we use the compensation of the *highest* paid VP and define *Total Gap (Max VP Comp)* as the difference between the CEO's total compensation and the highest paid VP's total compensation for a given firm-year observation. We define long-term and short-term gaps in a similar fashion. We obtain qualitatively similar results. For example, using the 2SLS approach, the coefficient estimate on *Ln(Total Gap Max VP Comp)* is 0.044 (*p*-value = 0.021) for regression in which the dependent variable is *NumPat*; 0.039 (*p*-value = 0.063), 0.016 (*p*-value = 0.033), 0.019 (*p*-value = 0.027), 0.011 (*p*-value = 0.030), 0.031 (*p*-value = 0.018), and -0.013 (*p*-value = 0.220) in regression in which the dependent variable is *CitePat*, *PatEff*, *Originality*, *Generality*, *Explore60*, and *Exploit60*, respectively.

Second, we an alternative measure for innovation efficiency based on the number of future citations a patent receives, i.e., the number of future citations divided by R&D expenditures. In the 2SLS analysis, the coefficient estimate on *Ln(Total Gap)* is 0.044 (*p*-value = 0.008). The coefficient estimate on *Ln(LT Gap)* and *Ln(ST Gap)* is 0.072 (*p*-value = 0.005) and 0.001 (*p*-value = 0.973), respectively.

Third, we use alternative definitions of exploratory and exploitative patent and re-conduct the regression analyses. Specifically, we define a patent as exploratory (exploitative) if at least 80% of its citations are based on new (current) knowledge. In an un-tabulated analysis, we find that our results continue to hold. For example, under the 2SLS approach where the dependent variable is *Explore80*, the coefficient estimate on *Ln(Total Gap)*, *Ln(LT Gap)*, and *Ln(ST Gap)* is 0.064 (*p*-value = 0.015), 0.057 (*p*-value = 0.021), and 0.037 (*p*-value = 0.260), respectively.

Fourth, since several dependent variables are bounded between 0 and 1 (including *Originality*, *Generality*, *Explore60*, and *Exploit60*), we use a Tobit model instead of the OLS model in the baseline analyses. We find that our results continue to hold.

Finally, since several dependent variables, *NumPat* and *CitePat*, are right skewed, we adopt the quantile regression model and find that our baseline results continue to hold.

## 5. Possible Economic Mechanisms

Our current results are consistent with the conjecture that tournament incentives induced by pay gaps are beneficial to a firm's innovation performance. In this section, we explore two plausible underlying economic mechanisms through which this occurs. The first mechanism we examine is the human capital channel. Because innovation is an exploration of untested approaches and the innovation process is long, risky, and idiosyncratic, innovation requires a significantly higher level of effort, persistence, and motivation on the part of executives and employees. Pay gaps provide strong, tournament-like incentives that promote competition and elicit strong efforts from executives and employees who engage in innovation activities. We explore this mechanism at two levels in Section 5.1: the executive level and the individual inventor level.

The second mechanism is reduced excessive interventions by boards. Faleye et al. (2011) finds that intensive board monitoring leads to managerial myopia and is detrimental to innovation. To the extent that tournament incentives motivate executives to work hard and take more risks, which reduce the need for intensive monitoring by boards, we posit that reduced excessive interventions by boards is a plausible underlying mechanism through which pay gaps improve corporate innovation. Section 5.2 tests this mechanism.

### *5.1 Human capital mechanism*

One possible mechanism leading to better innovation performance is an increase in inventor productivity and the attraction of innovation talents that is induced by the tournament incentives. As discussed before, because innovation is an exploration of untested approaches and the innovation process is long, risky, and idiosyncratic, innovation requires a significantly higher level of effort, persistence, and motivation on the part of employees. Competition for pay and promotion is a means to elicit strong efforts from agents who are otherwise prone to shirking and free riding (Gibbons and Murphy, 1990; Jensen and Meckling, 1976). It is therefore expected that employees at firms with larger pay gaps are more productive in innovation activities.

To test this conjecture, we explore this mechanism in two levels. We first examine the innovation productivity of individual executives who personally engage in the firm's innovation activities and own patents. We collect individual inventor data from the Harvard Business School (HBS) patent and inventor database available at http://dvn.iq.harvard.edu/dvn/dv/patent. The HBS patent and inventor database provides information for both inventors (the individuals who receive credit for producing the patent) and assignees (the entity that owns the patents, which could be a government, a firm, or an individual). It provides a unique identifier for each inventor so that we are able to track the productivity and mobility of individual inventors.[14] To identify executive inventors, we match firm, year, and inventor name between the HBS patent and inventor database and ExecuComp that provides the names and titles of executives at each firm.[15] We retain only those inventors who are also corporate executives (i.e., those appear in ExecuComp database).

Table 5 presents the second-stage results of 2SLS regressions that examine the effect of pay gaps on individual executives′ own innovation productivity. The dependent variable, *Ln(1+AverageExecutiveInventorProductivity)*, is the natural logarithm of one plus average executive inventor productivity, where executive inventor productivity is measured by the number of patents obtained by an executive in a given year. We include the same set of control variables as in the baseline analysis but their coefficients are suppressed for brevity. We include year and firm fixed effects. As shown in column (1), the coefficient estimate on *Ln(Total Gap)* is 0.066 and significant at the 1% level, suggesting that a larger pay gap helps to stimulate competition among members of the top management team and intensifies individual efforts in

[14] See Lai et al., (2013) for details about the HBS patent and inventor database.

[15] We tried several ways to match inventor name between HBS patent and inventor database and ExecuComp: (1) we require the inventors' first and last names to be exactly the same in both databases; (2) we require inventor last names to be exactly the same in the two databases, and conduct a fuzzy match on first names; (3) We conduct a fuzzy match on both last names and first names. Untabulated results show that all three approaches result in qualitatively similar results. In the main test, we report the results based on exact matching on both first name and last name.

their respective areas. As a result, executives who engage in innovation activities at firms with high pay gaps are personally more productive than executives at firms with low pay gaps. When examining long-term gaps and short-term gaps separately, we find that the coefficient estimate on long-term gaps is positively and significant at the 5% level, but the coefficient estimate on short-term gaps is insignificant.

As an additional test, we examine whether pay gap-induced tournament incentives affect the presence of top executive inventors in a firm. Table 6 presents the results of probit regressions with the instrumental variables we proposed before. We define a top executive inventor if an executive is in the top 5 percentile distribution of innovation productivity among all executive inventors in a given year. In model (1), we use total pay as the measure of tournament incentives and the coefficient estimate on the key variable of interest *Ln(Total Gap)* is 0.116 and significant at the 5% level. This result suggests that larger pay gaps increase the likelihood of having highly-productive executives. In model (2), we examine the effect of long-term and short-term pay gaps separately, and find that only long-term pay gaps have a positive and significant effect on the likelihood of having top innovative executives.

Next we examine the innovation productivity of individual inventors who are at lower levels but directly contribute to a firm's innovation performance. We argue that the overall compensation scheme in a firm is an internally consistent system that covers from top executives to floor workers. The environment of competition for promotion generated by tournament incentives at the executive level may have a spillover effect on lower-level individual inventors. For example, strong tournament incentives could attract high-quality innovation talents to join the firm as they seek better job prospects and promotion opportunities. Competition for promotion may also encourage executives to exert greater efforts in team building and supervising their subordinates (i.e., lower-level inventors) to work hard as well.

To test this conjecture, following prior studies (e.g., Bradley et al., 2016; Gu et al., 2015), we define three groups of inventors. "Stayers" are inventors who produce at least one patent for the current firm both in the last three years and in the next three years; "New Hires" are inventors who produced at least one patent in a different firm in the last three years, but produces at least one patent for the current firm in the next three years; "Leavers" are inventors who produced at least one patent for the current firm in the last three years, but produced at least one patent in a different firm in the next three years.

Table 7 panel A presents summary statistics of productivity of each type of inventors (i.e., stayers, new hires, leavers), where we measure inventor productivity by the number of patents that an inventor receives credit for in a given year. The average annual productivity of newly hired innovation employees, new hires, is 0.78, which is substantially higher than the productivity of stayers and leavers (0.11 and 0.36, respectively). This result suggests that new hires appear to be more productive than current employees.

Panel B of Table 7 presents the 2SLS results on the relation between pay gaps and inventor productivity. For each type of inventors, we aggregate individual inventor productivity to construct a firm-level measure *Ln(1+AverageInventorProductivity)* which is calculated as the natural logarithm of one plus the average productivity for all inventors of the same type. We include the same set of control variables as in the baseline analyses in Equation (1) but suppress their coefficients for brevity. We also include year and firm fixed effects. Models (1), (3), and (5) use *Ln(Total Gap)* as the measure of tournament incentives. We find that total pay gaps have a significant and positive effect on the productivity of stayers and new hires. However, we do not find pay gaps to affect the productivity of leavers. Taken together, these results suggest that tournament incentives elicit stronger efforts from employees who wish to stay in the firm and compete for pay and promotion. Employees who have intentions to leave in the near future are not motivated by pay-gap induced tournament incentives. We further decompose total pay gaps into long-term gaps and short-term gaps in models (2), (4), and (6), and find that long-term pay gaps appear to be able to motivate individual inventors (new hires and stayers) to produce more and higher quality innovation output, which is consistent with our previous results. Short-term pay gaps, however, do not appear to have an effect on individual inventor's innovation output.

We also explore the turnover of individual inventors. Strong tournament incentives provided by the firm could attract high-quality innovation talents to join the firm as they seek better job prospects and promotion opportunities. The ability to attract top innovation talents from the labor market will in turn enhance the firm's innovation performance. To test this conjecture, among the new hires we define before, we first use the HBS patent and inventor database to identify top new hires. For comparison purpose, we also examine whether pay gaps affect the departure of top inventors. We define a top new hire if she is in the top 5 percentile distribution of innovation productivity in the next three years after she joins the firm among all new hires in that year. Similarly, we define a top new leaver if she is in the top 5 percentile distribution of innovation productivity in the last three year before she leaves the firm among all leavers in that year.

Table 8 presents the probit regressions with the instrumental variables we propose before that examine the effect of pay gaps on the probability of attracting top inventors and the probability of top inventors leave the firm. The dependent variable in models (1) and (2) is a dummy variable that equals one if a firm has at least one top new hire in a given year. In model (1), the coefficient estimate on *Ln(Total Gap)* is positive and significant at the 1% level, suggesting that larger pay gaps increase a firm′s likelihood of attracting top inventors from the labor market. The presence of these highly productive inventors helps enhance the firm′s innovation performance. In model (2), we examine the effect of pay gaps on attraction of top inventors for long-term and short-term pay gaps separately. The coefficient estimate on long-term pay gaps, *Ln(LT Gap)*, is significant at the 5% level. In contrast, the coefficient estimate on short-term pay gaps is negative although insignificant. Taken together, these findings suggest that only pay differential on long-term compensation including stock and option are effective in attracting top innovation talents. In model (3) and (4), we examine whether pay gaps affect the departure of top innovation employees. In both models, the coefficient estimates on pay gaps are insignificant, suggesting that pay gaps do not affect the likelihood of departure of top innovators.

*5.2 Reduced excessive board interventions*

Innovation projects are characterized by high risk of failure and the time to return is substantially longer than routine investment projects such as capital expenditures and mergers and acquisitions (M&As). Given managers are closely monitored by the board of directors and are under performance pressure, they may exhibit managerial myopia and under-invest in innovation projects if they do not receive support from the board when investing in such projects. Faleye et al. (2011) argue that excessive board monitoring weakens management's perception of board support and risk tolerance, causing the top management team to focus more on routine projects with relatively safe outcomes rather than on high-risk innovation. Consistent with this conjecture, they find that firms with monitoring-intensive boards are associated with lower R&D investments and lower patent citations. Tournament theory suggests that larger pay gaps reduce the need for intense board monitoring and provide strong incentives that better align principal-agent interests. Following this line of argument, we posit that a second plausible economic mechanism through which pay gaps enhance corporate innovation is the reduction in excessive monitoring by boards.

We provide two pieces of evidence on this mechanism. In Table 9 Panel A, we first examine whether pay gaps are indeed a surrogate governance mechanism that reduces the need for intense board monitoring. We define monitoring-intensive board, *Monitoring_Intensive_Board***,** as a dummy variable that equals one if more than half of independent directors are monitoring intensive, and zero otherwise. Following Faleye et al. (2011), we define monitoring intensive directors as the independent directors who serve on at least two principal monitoring committees (audit, compensation, nominating, and governance). Model (1) presents the results from a probit regression that examines the effect of pay gaps on the likelihood of having a monitoring intensive board. In addition to firm and executive characteristics, we control for several board characteristics that may affect its monitoring intensity, including board size, average director age, and average director tenure. The coefficient estimate on *Ln(Total Gap)* is -0.300 and significant at the 5% level, suggesting that larger pay gaps are associated with a lower likelihood of having a monitoring-intensive board. In model (2), we decompose total pay gaps into long-term and short-term pay gaps, and find that only long-term pay gaps serve as a surrogate governance mechanism for intensive monitoring boards.

To the extent that pay gaps and board monitoring are substitute governance mechanisms, we expect pay gaps to have a greater (less) effect on innovation when firms' boards are less (more) monitoring-intensive. In Table 9 Panel B, we split the sample firms into two groups by board monitoring intensity (i.e., whether *Monitoring_Intensive_Board*=1) and conduct the 2SLS analysis separately for each subsample. We include the same set of control variables as in the baseline analysis as well as year and firm fixed effect. In the subsample of firms with monitoring intensive board (i.e., *Monitoring_Intensive_Board*=1), the coefficient estimate on *Ln(Total Gap)* is insignificant in most regressions except for *CitePat*. In contrast, in the subsample of firms with less monitoring intensive board (i.e., *Monitoring_Intensive_Board*=0), the coefficient estimate on *Ln(Total Gap)* is significant in all regressions and is generally consistent with the baseline results. To further test whether the differences in the coefficient estimates between the two groups are statistically significant, we conduct a Wald test with the null hypothesis that the coefficient estimates on *Ln(Total Gap)* are equal between two groups. The $\chi^2$ statistics are significant in all regressions, rejecting the null hypothesis.

In Table 9 Panel C, we conduct the 2SLS analysis for each subsample using long-term and short-term pay gaps as the main measure for tournament incentives. The results on long-term pay gaps are qualitatively similar to those reported in Panel B, which are consistent with our conjecture that pay gaps appear to have a larger impact on innovation for firms with lower board monitoring intensity. The $\chi^2$ statistics suggest that the coefficient estimates on *Ln(ST Gap)* are significantly different across the two subsamples. Consistent with our earlier findings, we do not find short-term pay gaps affect a firm's innovation output, and this finding does not vary with the intensity of board monitoring.

Overall, our findings in this section suggest that human capital and the reduction of excessive board monitoring appear to be two plausible underlying economic mechanisms through which tournament incentives encourage firm innovation.

## 6. Conclusion

In this paper, we examine the effect of tournament incentives on corporate innovation performance. Using a sample of U.S. firms over the period of 1992-2012, we find that firms with higher executive pay gaps, especially long-term pay gaps generate more patents, patents with higher subsequent citations, and are more efficient in innovation activities. These patents also have higher originality and generality scores, and are more exploratory in nature. Our findings are robust to an array of robustness tests, including alternative measures of tournament incentives and innovation variables, and alternative model specifications. To establish causality, we use an instrumental variable approach and the results suggest a causal effect of tournament incentives on firm innovation performance. We further show that better human capital and the reduction in excessive interventions appear two possible underlying mechanisms through which pay gap-induced tournament incentives foster corporate innovation.

Taken together, our findings suggest that tournament incentives have a positive effect on corporate innovation performance. However, we need to bear in mind one important caveat when interpreting or generalizing our results: Our results reflect only the net effect of tournament incentives on firm innovation. Tournament incentives could have a negative effect on firm innovation by, for example, destroying collaboration and coordination among executives. Other studies argue and indeed find evidence that large pay disparity among executives can lead to undesirable managerial behavior that is ultimately detrimental to firm performance and value (e.g., Shi et al., 2015). Therefore, companies must fully consider the merits and downsides of large executive pay gaps when making compensation design for the top management team.

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**Table 1 Sample Distribution and Summary Statistics**

This table reports the sample distribution and summary statistics for variables used in the baseline analyses based on the sample of U.S. public firms from 1992 to 2012. All variables are defined in Appendix A.

**Panel A: Variable summary statistics**

| Variable | Median | Mean | S.D. | N |
|---|---|---|---|---|
| *NumPat* | 1.475 | 1.994 | 2.092 | 7,708 |
| *CitePat* | 0.226 | 1.408 | 1.705 | 7,708 |
| *PatEff* | 0.270 | 0.367 | 0.341 | 4,486 |
| *Originality* | 0.363 | 0.361 | 0.359 | 4,131 |
| *Generality* | 0.667 | 0.583 | 0.275 | 3,248 |
| *Explore60* | 0.686 | 0.664 | 0.305 | 4,543 |
| *Exploit60* | 0.176 | 0.244 | 0.266 | 4,543 |
| *Ln(Total Gap)* | 7.896 | 7.998 | 0.800 | 7,708 |
| *Ln(LT Gap)* | 7.641 | 7.788 | 0.775 | 7,708 |
| *Ln(ST Gap)* | 6.868 | 6.916 | 0.680 | 7,708 |
| *CEO Delta* | 0.196 | 0.631 | 1.442 | 7,708 |
| *CEO Vega* | 0.004 | 0.024 | 0.049 | 7,708 |
| *Std VP* | 6.005 | 6.031 | 1.170 | 7,708 |
| *CEO Age* | 4.190 | 4.182 | 0.007 | 7,708 |
| *Sales* | 7.249 | 7.313 | 1.572 | 7,708 |
| *ROA* | 0.165 | 0.144 | 0.096 | 7,708 |
| *Leverage* | 0.186 | 0.197 | 0.168 | 7,708 |
| *Capex* | 0.042 | 0.053 | 0.042 | 7,708 |
| *R&DAssets* | 0.026 | 0.049 | 0.062 | 7,708 |
| *PPEAssets* | 0.216 | 0.257 | 0.176 | 7,708 |
| *HHI* | 0.181 | 0.237 | 0.190 | 7,708 |
| *TobinQ* | 1.734 | 2.188 | 1.398 | 7,708 |
| *InstOwn* | 0.742 | 0.715 | 0.196 | 7,708 |

**Panel B: Sample distribution by industry**

| SIC Code | Industry | No. of Obs. | Percentage | Cum. Pct. |
|---|---|---|---|---|
| 28 | Chemical & Allied Products | 1,062 | 13.78% | 13.78% |
| 36 | Electronic & Other Electric Equipment | 1,037 | 13.45% | 27.23% |
| 35 | Industrial Machinery & Equipment | 840 | 10.90% | 38.13% |
| 38 | Instruments & Related Products | 718 | 9.31% | 47.44% |
| 73 | Business Services | 670 | 8.69% | 56.14% |
| 37 | Transportation Equipment | 470 | 6.10% | 62.23% |
| 56 | Apparel And Accessory Stores | 220 | 2.85% | 65.09% |
| 34 | Fabricated Metal Products | 188 | 2.44% | 67.53% |
| 26 | Paper And Allied Products | 170 | 2.21% | 69.73% |
| 58 | Eating and Drinking Places | 170 | 2.21% | 71.94% |
| | Others | 2,163 | 28.06% | 100.00% |
| Total | - | 7,708 | 100% | 100.00% |

**Table 2 Effects of Pay Gap on Innovation - Baseline Regressions**

This table reports the OLS regressions of innovation output on pay gaps. Panel A reports results on total pay gaps (*Total Gap*). Panel B reports results on long-term gap (*LT Gap*) and short-term gap (*ST Gap*). Patent variables are in year *t+3*. All variables are defined in Appendix A. Year and firm fixed effects are included. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

**Panel A: Total Gap**

| Dep Var = | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| ***Ln(Total Gap)*** | **0.044**** | **0.052**** | **0.012**** | **0.009*** | **0.014**** | **0.018**** | **-0.009** |
| | (0.021) | (0.025) | (0.006) | (0.005) | (0.007) | (0.008) | (0.007) |
| *CEO Delta* | 0.019* | 0.017 | 0.008** | -0.001 | 0.006 | -0.003 | 0.001 |
| | (0.011) | (0.017) | (0.003) | (0.003) | (0.005) | (0.004) | (0.003) |
| *CEO Vega* | -0.166 | 0.079 | -0.038 | 0.211** | 0.224*** | -0.033 | -0.001 |
| | (0.285) | (0.296) | (0.089) | (0.906) | (0.088) | (0.090) | (0.004) |
| *Std VP* | -0.004 | 0.018 | -0.003 | 0.007** | -0.008 | -0.006 | 0.001 |
| | (0.012) | (0.015) | (0.004) | (0.003) | (0.005) | (0.005) | (0.004) |
| *CEO Age* | -0.122 | -0.029 | -0.038 | -0.007 | -0.022* | 0.002 | -0.000 |
| | (0.175) | (0.038) | (0.089) | (0.010) | (0.013) | (0.013) | (0.011) |
| *Sales* | 0.251*** | 0.157*** | -0.098*** | 0.037*** | 0.016 | -0.018 | 0.018 |
| | (0.062) | (0.060) | (0.015) | (0.011) | (0.018) | (0.022) | (0.018) |
| *ROA* | -0.028 | -0.025 | 0.059 | -0.194*** | -0.109 | 0.172* | -0.121 |
| | (0.310) | (0.304) | (0.056) | (0.061) | (0.086) | (0.104) | (0.094) |
| *Leverage* | -0.104 | 0.067 | -0.023 | -0.001 | -0.052 | 0.065 | -0.095** |
| | (0.159) | (0.154) | (0.041) | (0.010) | (0.057) | (0.053) | (0.046) |
| *Capex* | 0.017 | -0.787 | -0.199 | -0.571*** | -0.412** | -0.085 | 0.023 |
| | (0.377) | (0.688) | (0.153) | (0.123) | (0.214) | (0.218) | (0.201) |
| *RD/Assets* | 0.163 | -0.396 | - | 0.052 | 0.045 | -0.050 | -0.057 |
| | (0.820) | (0.643) | - | (0.128) | (0.147) | (0.191) | (0.159) |
| *PPE/Assets* | 0.601 | 0.172 | 0.215** | 0.139* | 0.196* | -0.013 | 0.085 |
| | (0.426) | (0.336) | (0.103) | (0.076) | (0.118) | (0.120) | (0.104) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *HHI* | 0.322 | -0.443 | 0.230 | -0.100 | 0.103 | -0.248 | 0.073 |
| | (0.978) | (0.734) | (0.241) | (0.170) | (0.293) | (0.257) | (0.225) |
| *HHI*$^2$ | -0.655 | 1.287* | -0.356 | 0.067 | -0.421 | 0.228 | -0.072 |
| | (0.937) | (0.750) | (0.270) | (0.202) | (0.350) | (0.283) | (0.241) |
| *TobinQ* | 0.028** | 0.022 | -0.003*** | 0.012*** | -0.001 | -0.003 | 0.003 |
| | (0.015) | (0.019) | (0.001) | (0.004) | (0.002) | (0.006) | (0.006) |
| *InstOwn* | 0.206 | 0.225 | 0.053 | -0.028 | -0.016 | -0.114** | 0.140*** |
| | (0.150) | (0.175) | (0.049) | (0.039) | (0.067) | (0.056) | (0.053) |
| *Constant* | 0.154 | 2.378 | 0.918*** | 0.057 | 1.970** | 0.435 | 0.287 |
| | (0.877) | (2.509) | (0.231) | (0.636) | (0.869) | (0.839) | (0.765) |
| Year and Firm Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.92 | 0.86 | 0.73 | 0.69 | 0.63 | 0.56 | 0.56 |
| Observations | 7,708 | 7,708 | 4,486 | 4,131 | 3,248 | 4,543 | 4,543 |

**Panel B: Long-Term and Short-Term Gap**

| Dep Var = | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| ***Ln(LT Gap)*** | **0.058**** | **0.044**** | **0.012**** | **0.042***** | **0.014**** | **0.015**** | **-0.007** |
| | (0.030) | (0.022) | (0.005) | (0.009) | (0.007) | (0.007) | (0.006) |
| ***Ln(ST Gap)*** | **0.028*** | **-0.015** | **-0.003** | **0.003** | **0.008** | **0.007** | **-0.001** |
| | (0.017) | (0.034) | (0.009) | (0.005) | (0.013) | (0.012) | (0.010) |
| *CEO Delta* | 0.020* | 0.019 | 0.010*** | -0.002 | 0.007 | -0.003 | 0.001 |
| | (0.012) | (0.018) | (0.004) | (0.004) | (0.005) | (0.004) | (0.004) |
| *CEO Vega* | -0.128 | 0.057 | -0.051 | 0.022*** | 0.009 | -0.037 | 0.002 |
| | (0.284) | (0.304) | (0.090) | (0.091) | (0.021) | (0.091) | (0.077) |
| *Std VP* | -0.001 | 0.019 | -0.004 | 0.008** | -0.008 | -0.006 | 0.001 |
| | (0.012) | (0.015) | (0.004) | (0.003) | (0.005) | (0.005) | (0.004) |
| *CEO Age* | -0.153 | -0.026 | -0.007 | -0.008 | -0.021 | 0.002 | -0.000 |
| | (0.174) | (0.038) | (0.010) | (0.010) | (0.135) | (0.012) | (0.011) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Sales* | 0.220*** | 0.150*** | -0.104*** | 0.036*** | 0.020 | -0.018 | 0.018 |
| | (0.058) | (0.060) | (0.017) | (0.111) | (0.018) | (0.022) | (0.018) |
| *ROA* | -0.096 | 0.001 | 0.188*** | -0.201*** | -0.107 | 0.169* | -0.122 |
| | (0.319) | (0.311) | (0.072) | (0.061) | (0.094) | (0.104) | (0.095) |
| *Leverage* | -0.103 | 0.054 | -0.030 | -0.001 | -0.058 | 0.064 | -0.094** |
| | (0.162) | (0.154) | (0.044) | (0.010) | (0.057) | (0.053) | (0.046) |
| *Capex* | 0.021 | -0.783 | -0.254 | -0.568*** | -0.419** | -0.083 | 0.022 |
| | (0.377) | (0.689) | (0.166) | (0.123) | (0.216) | (0.218) | (0.201) |
| *RD/Assets* | -0.067 | -0.416 | - | 0.050 | 0.044 | -0.050 | -0.055 |
| | (0.828) | (0.640) | - | (0.128) | (0.154) | (0.192) | (0.159) |
| *PPE/Assets* | 0.633 | 0.147 | 0.240** | 0.142* | 0.194* | -0.013 | 0.086 |
| | (0.425) | (0.336) | (0.111) | (0.076) | (0.120) | (0.120) | (0.104) |
| *HHI* | 0.358 | -0.444 | 0.353 | -0.101 | 0.088 | -0.251 | 0.074 |
| | (1.000) | (0.737) | (0.250) | (0.170) | (0.294) | (0.257) | (0.225) |
| $HHI^2$ | -0.691 | 1.078 | -0.464* | 0.068 | -0.414 | 0.230 | -0.073 |
| | (0.938) | (0.747) | (0.282) | (0.202) | (0.353) | (0.257) | (0.241) |
| *TobinQ* | 0.030** | 0.023 | -0.009** | 0.012*** | -0.002 | -0.003 | 0.002 |
| | (0.015) | (0.019) | (0.004) | (0.004) | (0.006) | (0.005) | (0.005) |
| *InstOwn* | 0.221 | 0.229 | 0.049 | -0.028 | -0.026 | -0.114** | 0.140*** |
| | (0.151) | (0.175) | (0.054) | (0.039) | (0.067) | (0.059) | (0.053) |
| *Constant* | 0.198 | 2.304 | 1.571*** | 0.092 | 1.824** | 0.420 | 0.297 |
| | (0.875) | (2.508) | (0.635) | (0.639) | (0.873) | (0.840) | (0.765) |
| Year and Firm Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.92 | 0.86 | 0.74 | 0.69 | 0.63 | 0.56 | 0.56 |
| Observations | 7,708 | 7,708 | 4,486 | 4,131 | 3,248 | 4,543 | 4,543 |

**Table 3 2SLS Results – Total Gap**

This table reports the 2SLS regressions of the effect of innovation output on total pay gaps. All dependent, control and instrumental variables are defined in Appendix A. Statistics from tests for relevance and validity of instruments are reported in the bottom panel. Year and firm fixed effects are included. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

| | First Stage (for NumPat and CitePat) | | | Second Stage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dep Var = | *Ln(Total Gap)* | *CEO Delta* | *CEO Vega* | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| ***Ln(Total Gap)*** | | | | **0.141**** | **0.061***** | **0.043***** | **0.050***** | **0.024*** | **0.049**** | **-0.005** |
| | | | | (0.069) | (0.021) | (0.016) | (0.019) | (0.014) | (0.024) | (0.034) |
| *CEO Delta* | | | | 0.172* | -0.034 | 0.009 | 0.018 | -0.153 | -0.033* | 0.035 |
| | | | | (0.092) | (0.139) | (0.011) | (0.026) | (0.120) | (0.018) | (0.049) |
| *CEO Vega* | | | | -0.347 | 0.701 | 0.315** | 0.317*** | 0.416* | 0.213 | -0.459** |
| | | | | (0.383) | (0.775) | (0.127) | (0.112) | (0.263) | (0.204) | (0.214) |
| *Sales* | 0.203*** | 0.265*** | 0.010*** | 0.160*** | 0.072 | -0.069*** | 0.007 | 0.087* | -0.021 | 0.013 |
| | (0.023) | (0.049) | (0.002) | (0.049) | (0.072) | (0.011) | (0.013) | (0.047) | (0.017) | (0.027) |
| *ROA* | 0.128 | -0.749*** | -0.003 | 0.988 | 0.781*** | -0.040 | -0.055 | -0.239* | 0.154** | -0.099 |
| | (0.131) | (0.232) | (0.010) | (0.187) | (0.272) | (0.047) | (0.047) | (0.130) | (0.075) | (0.073) |
| *Leverage* | -0.253*** | -0.154 | -0.019*** | -0.043 | 0.172 | -0.037 | -0.018 | -0.114* | 0.072** | -0.098*** |
| | (0.074) | (0.127) | (0.005) | (0.095) | (0.145) | (0.025) | (0.026) | (0.060) | (0.037) | (0.036) |
| *Capex* | 0.564** | 1.257*** | 0.024 | -0.221 | 1.965*** | -0.014 | -0.438*** | -0.307 | -0.085 | -0.003 |
| | (0.247) | (0.481) | (0.018) | (0.351) | (0.567) | (0.119) | (0.098) | (0.198) | (0.176) | (0.173) |
| *RD/Assets* | -1.121*** | -2.216*** | -0.021 | 0.060 | 1.271** | - | 0.192* | -0.388 | -0.068 | 0.002 |
| | (0.287) | (0.528) | (0.027) | (0.504) | (0.658) | - | (0.117) | (0.327) | (0.147) | (0.180) |
| *PPE/Assets* | -0.669** | -0.276 | -0.017* | 0.837*** | 1.277*** | 0.156*** | 0.082 | 1.660* | 0.010 | 0.083 |
| | (0.130) | (0.214) | (0.009) | (0.207) | (0.279) | (0.061) | (0.054) | (0.106) | (0.089) | (0.079) |
| *HHI* | -0.154 | -0.709 | -0.012 | 0.451 | 0.297 | 0.099 | 0.081 | 0.118 | -0.230 | 0.053 |
| | (0.255) | (0.492) | (0.018) | (0.458) | (0.575) | (0.124) | (0.109) | (0.222) | (0.166) | (0.143) |
| *$HHI^2$* | 0.168 | 0.749* | 0.019 | -0.775* | -0.251 | -0.216 | -0.106 | -0.441* | 0.208 | -0.051 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (0.269) | (0.439) | (0.017) | | (0.458) | (0.610) | (0.148) | (0.126) | (0.253) | (0.190) | (0.161) |
| *TobinQ* | 0.067*** | 0.368*** | -0.003*** | | 0.096** | 0.045 | -0.018*** | -0.004 | 0.067 | 0.007 | -0.012 |
| | (0.010) | (0.029) | (0.001) | | (0.039) | (0.058) | (0.005) | (0.107) | (0.048) | (0.008) | (0.020) |
| *InstOwn* | -0.070 | -0.704*** | -0.013*** | | 0.445*** | 0.372** | 0.045 | 0.000 | -0.138 | -0.119*** | 0.144*** |
| | (0.076) | (0.176) | (0.004) | | (0.114) | (0.183) | (0.031) | (0.033) | (0.110) | (0.042) | (0.046) |
| *Std VP* | 0.162*** | 0.009 | 0.003*** | | -0.025* | -0.412* | -0.008** | -0.008** | -0.002 | -0.013** | 0.003 |
| | (0.009) | (0.014) | (0.001) | | (0.015) | (0.023) | (0.004) | (0.004) | (0.010) | (0.005) | (0.007) |
| *CEO Age* | -0.005 | 0.332*** | 0.004*** | | -0.066* | 0.012 | -0.019*** | -0.012 | 0.040 | 0.011 | -0.009 |
| | (0.016) | (0.028) | (0.001) | | (0.037) | (0.057) | (0.006) | (0.010) | (0.047) | (0.011) | (0.019) |
| Instrumental Variables | | | | | | | | | | | |
| *Ln(Median Ind_TotalGap)* | 0.739*** | -0.206*** | -0.006*** | | | | | | | | |
| | (0.043) | (0.065) | (0.002) | | | | | | | | |
| *Median Ind_CEO Delta* | -0.199*** | 0.966*** | 0.010** | | | | | | | | |
| | (0.0468) | (0.127) | (0.005) | | | | | | | | |
| *Median Ind_CEO Vega* | 0.807*** | -1.133* | 0.673*** | | | | | | | | |
| | (0.275) | (0.693) | (0.036) | | | | | | | | |
| *Constant* | -0.148 | -17.119*** | -0.296*** | | 4.152** | 6.263*** | 2.144*** | 0.937* | 3.028*** | 1.362 | 2.084 |
| | (1.164) | (2.442) | (0.114) | | (1.811) | (1.032) | (0.501) | (0.580) | (0.829) | (1.028) | (2.937) |
| Year and Firm Fixed Effects | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 7,708 | 7,708 | 7,708 | | 7,708 | 7,708 | 4,486 | 4,131 | 3,248 | 4,543 | 4,543 |
| Tests of Eodogeneity, Relevance, and Validity of Instruments | | | | | | | | | | | |
| Shea partial $R^2$ | 0.20 | 0.13 | 0.15 | - | - | - | - | - | - | - | - |
| *F*-statistic | 107.11*** | 20.37*** | 125.55*** | - | - | - | - | - | - | - | - |
| Anderson-Rubin *F*-statistic | - | - | - | | 4.52*** | 2.45** | 4.53*** | 2.99** | 2.98** | 3.08** | 2.62** |

**Table 4 2SLS Results – Long-Term and Short-Term Gap**

This table reports the 2SLS regressions of the effect of innovation output on long-term pay gaps and short-term pay gaps. All dependent, control and instrumental variables are defined in Appendix A. Statistics from tests for relevance and validity of instruments are reported in the bottom panel. Year and firm fixed effects are included. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

| | First Stage (for NumPat and CitePat) | | | | Second Stage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dep Var = | *Ln(LT Gap)* | *Ln(ST Gap)* | *CEO Delta* | *CEO Vega* | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| ***Ln(LT Gap)*** | | | | | **0.124**** | **0.059**** | **0.044**** | **0.032**** | **0.101*** | **0.059**** | **-0.021** |
| | | | | | (0.059) | (0.031) | (0.019) | (0.016) | (0.061) | (0.028) | (0.023) |
| ***Ln(ST Gap)*** | | | | | **0.034** | **0.144** | **0.029** | **0.009** | **0.057** | **-0.006** | **0.013** |
| | | | | | (0.059) | (0.098) | (0.022) | (0.016) | (0.045) | (0.031) | (0.027) |
| *CEO Delta* | | | | | 0.251** | -0.179 | 0.010 | -0.019 | -0.169 | -0.016 | 0.018 |
| | | | | | (0.122) | (0.183) | (0.012) | (0.034) | (0.142) | (0.014) | (0.016) |
| *CEO Vega* | | | | | -0.002 | 1.238*** | 0.283** | 1.379*** | 0.668 | 0.168 | -0.430** |
| | | | | | (0.020) | (0.471) | (0.128) | (0.262) | (0.797) | (0.206) | (0.209) |
| *Sales* | 0.138*** | 0.076*** | 0.267*** | 0.012*** | 0.163*** | 0.050 | -0.072*** | 0.010 | 0.114* | -0.024 | 0.020 |
| | (0.022) | (0.016) | (0.048) | (0.002) | (0.050) | (0.075) | (0.011) | (0.014) | (0.062) | (0.017) | (0.014) |
| *ROA* | -0.121 | 0.754*** | -0.729*** | 0.002 | 0.124 | -0.895*** | -0.054 | -0.099* | -0.222 | 0.166** | -0.117* |
| | (0.119) | (0.091) | (0.235) | (0.011) | (0.221) | (0.326) | (0.050) | (0.058) | (0.158) | (0.078) | (0.069) |
| *Leverage* | -0.151** | -0.286*** | -0.101 | -0.025*** | -0.101 | 0.294* | -0.031 | -0.001 | -0.131* | 0.064* | -0.095*** |
| | (0.066) | (0.048) | (0.127) | (0.005) | (0.097) | (0.151) | (0.026) | (0.027) | (0.071) | (0.038) | (0.034) |
| *Capex* | 0.340 | -0.058 | 1.316*** | 0.036* | -0.303 | -1.944*** | -0.013 | -0.408*** | -0.205 | -0.088 | 0.020 |
| | (0.222) | (0.175) | (0.496) | (0.197) | (0.378) | (0.611) | (0.119) | (0.104) | (0.248) | (0.174) | (0.162) |
| *RD/Assets* | -0.830*** | -0.570*** | -2.211** | -0.029 | 0.221 | 0.953 | - | 0.120 | -0.521 | -0.099 | -0.007 |
| | (0.275) | (0.172) | (0.538) | (0.028) | (0.537) | (0.703) | - | (0.130) | (0.431) | (0.140) | (0.119) |
| *PPE/Assets* | -0.463*** | -0.613*** | -0.238 | -0.026*** | 0.797*** | 1.246*** | 0.166*** | 0.083 | 0.072 | 0.009 | 0.074 |
| | (0.124) | (0.091) | (0.214) | (0.010) | (0.213) | (0.283) | (0.063) | (0.055) | (0.123) | (0.091) | (0.078) |
| *HHI* | 0.046 | -0.104 | -0.713 | -0.019 | 0.427 | 0.256 | 0.094 | 0.070 | 0.108 | -0.218 | 0.036 |
| | (0.241) | (0.193) | (0.503) | (0.020) | (0.470) | (0.592) | (0.126) | (0.112) | (0.238) | (0.166) | (0.142) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *HHI*$^2$ | -0.087 | 0.206 | 0.747* | 0.026 | -0.758* | -0.257 | -0.214 | -0.102 | -0.4378* | 0.205 | -0.046 |
| | (0.249) | (0.210) | (0.444) | (0.019) | (0.472) | (0.625) | (0.150) | (0.129) | (0.266) | (0.192) | (0.161) |
| *TobinQ* | 0.044*** | 0.037*** | 0.377*** | -0.004*** | 0.131** | 0.151** | -0.018*** | 0.016 | 0.080 | 0.000 | -0.004 |
| | (0.009) | (0.005) | (0.029) | (0.001) | (0.052) | (0.077) | (0.005) | (0.014) | (0.063) | (0.007) | (0.007) |
| *InstOwn* | -0.004 | -0.015 | -0.764*** | 0.022*** | 0.491*** | 0.368* | 0.040 | -0.009 | -0.140 | -0.107** | 0.128*** |
| | (0.075) | (0.049) | (0.181) | (0.005) | (0.131) | (0.206) | (0.032) | (0.038) | (0.112) | (0.043) | (0.038) |
| *Std VP* | 0.154*** | 0.019*** | 0.012 | 0.003*** | -0.020 | 0.008 | -0.009** | -0.003 | 0.012 | -0.015** | 0.005 |
| | (0.008) | (0.005) | (0.014) | (0.001) | (0.014) | (0.032) | (0.004) | (0.004) | (0.011) | (0.006) | (0.005) |
| *CEO Age* | -0.030** | 0.090*** | 0.324*** | 0.004*** | -0.084** | 0.012 | -0.021*** | -0.008 | 0.047 | 0.008 | -0.004 |
| | (0.015) | (0.011) | (0.028) | (0.001) | (0.041) | (0.063) | (0.007) | (0.011) | (0.053) | (0.010) | (0.009) |
| Instrumental Variables | | | | | | | | | | | |
| *Ln(Median Ind_LT Gap)* | 0.374*** | -0.036*** | -0.114*** | -0.002** | | | | | | | |
| | (0.016) | (0.010) | (0.027) | (0.001) | | | | | | | |
| *Ln(Median Ind_ST Gap)* | -0.073*** | 0.440*** | 0.077** | -0.003*** | | | | | | | |
| | (0.019) | (0.016) | (0.039) | (0.001) | | | | | | | |
| *Median Ind_CEO Delta* | -0.187*** | -0.147*** | 0.818*** | 0.022*** | | | | | | | |
| | (0.067) | (0.048) | (00125) | (0.005) | | | | | | | |
| *Median Ind_CEO Vega* | -2.359** | -1.347* | 1.685* | 1.598*** | | | | | | | |
| | (1.073) | (0.710) | (1.021) | (0.086) | | | | | | | |
| *Constant* | 6.075*** | -2.378*** | -22.775*** | -3.101*** | 8.411*** | 10.635*** | 5.847*** | 0.738 | 1.373*** | 1.948** | 0.847 |
| | (0.997) | (0.766) | (1.902) | (0.861) | (2.838) | (3.016) | (1.630) | (0.593) | (0.839) | (0.935) | (0.938) |
| Year and Firm Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 7,708 | 7,708 | 7,708 | 7,708 | 7,708 | 7,708 | 4,486 | 4,131 | 3,248 | 4,543 | 4,543 |
| Tests of Eodogeneity, Relevance, and Validity of Instruments | | | | | | | | | | | |
| Shea partial $R^2$ | 0.39 | 0.28 | 0.40 | 0.45 | - | - | - | - | - | - | - |
| *F*-statistic | 143.12*** | 200.84*** | 14.45*** | 91.95*** | - | - | - | - | - | - | - |
| Anderson-Rubin *F*-statistic | | | | | 3.94*** | 6.62*** | 3.14*** | 2.78** | 2.26** | 3.04*** | 1.98* |

**Table 5 Effects of Pay Gaps on Executive Inventor Productivity**

This table reports the 2SLS regressions of executive inventor productivity on pay gaps. The dependent variable *Ln(1+AverageExecutiveInventorProductivity)* is the natural logarithm of one plus average executive inventor productivity, where executive inventor productivity is measured by the number of patents obtained by an executive in a given year. Other variables are defined in Appendix A. Control variables are the same as in the baseline models. Year and firm fixed effects are included in all regressions but the coefficients are not reported. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

| Dep Var = | *Ln(1+AverageExecutiveInventorProductivity)* | |
|---|---|---|
| | (1) | (2) |
| ***Ln(Total Gap)*** | 0.066*** | |
| | (0.024) | |
| ***Ln(LT Gap)*** | | 0.092** |
| | | (0.045) |
| ***Ln(ST Gap)*** | | -0.038 |
| | | (0.044) |
| Controls | Yes | Yes |
| Year and Firm Fixed Effects | Yes | Yes |
| Within $R^2$ | 0.25 | 0.24 |
| Observations | 1,194 | 1,194 |

**Table 6 Effects of Pay Gaps on the Presence of Top Executive Inventors**

This table reports the instrumental variable probit regressions of the presence of top executive inventors on pay gaps. "Top Executive Inventors" equals one if firm *i* has at least one top executive inventor in year *t* and zero otherwise. We define a top executive inventor if an inventor is in the top 5 percentile distribution of innovation productivity among all executive inventors in year *t*. Other variables are defined in Appendix A. Control variables are the same as in the baseline models. Year and industry fixed effects are included in all regressions but the coefficients are not reported. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

| Dep Var = | *Prob (Top Executive Inventors =1)* | |
|---|---|---|
| | (1) | (2) |
| ***Ln(Total Gap)*** | 0.116** | |
| | (0.055) | |
| ***Ln(LT Gap)*** | | 0.353*** |
| | | (0.085) |
| ***Ln(ST Gap)*** | | -0.003 |
| | | (0.064) |
| Controls | Yes | Yes |
| Year and Industry Fixed Effects | Yes | Yes |
| Wald $Chi^2$ | 638.94 | 826.53 |
| Observations | 1,194 | 1,194 |

**Table 7 Effects of Pay Gaps on All Inventor Productivity**

This table reports the 2SLS regressions of inventor productivity on pay gaps. The dependent variable *Ln (1+AverageInventorProductivity)* is the natural logarithm of one plus average inventor productivity in year *t* for each of three types of inventors. "Stayer" equals one if the inventor working for firm *i* in year *t* produces at least one patent for firm *i* both three years before and after year *t* and zero otherwise; "New Hire" equals one if the inventor working for firm *i* in year *t* produced at least one patent in a different firm three years before year *t*, but produces at least one patent in firm *i* three years after year *t* and zero otherwise; "Leaver" equals one if the inventor working for firm *i* in year *t* produced at least one patent in firm *i* three years before year *t*, but produced at least one patent in a different firm three years after year *t* and zero otherwise. Other variables are defined in Appendix A. Panel A reports the distribution of inventor annual productivity by inventor type. Panel B reports the second stage results of 2SLS regressions. Control variables are the same as in the baseline models. Year and firm fixed effects are included in all regressions but the coefficients are not reported. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

**Panel A: Distribution of inventor annual productivity by type**

| | Mean | Median | Std.Dev |
|---|---|---|---|
| Stayer Productivity | 0.11 | 0.02 | 0.26 |
| New Hire Productivity | 0.78 | 1 | 0.77 |
| Leaver Productivity | 0.36 | 0 | 0.80 |

**Panel B: 2SLS results**

| Dep Var = | *Ln(1+AverageInventorProductivity)* | | | | | |
|---|---|---|---|---|---|---|
| | Stayers | | New Hires | | Leavers | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ***Ln(Total Gap)*** | 0.047** | | 0.065* | | 0.049 | |
| | (0.022) | | (0.040) | | (0.035) | |
| ***Ln(LT Gap)*** | | 0.038** | | 0.045** | | 0.032 |
| | | (0.019) | | (0.024) | | (0.052) |
| ***Ln(ST Gap)*** | | -0.041** | | -0.021 | | 0.007 |
| | | (0.021) | | (0.040) | | (0.049) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year and Firm Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Within $R^2$ | 0.14 | 0.15 | 0.10 | 0.09 | 0.05 | 0.04 |
| Observations | 4,305 | 4,305 | 3,604 | 3,604 | 3,562 | 3,562 |

**Table 8 Effects of Pay Gaps on Attraction and Departure of Top Inventors**

This table reports the instrumental variable probit regressions of attractions and departures of top inventors on pay gaps. "Top New Hire" equals one if firm *i* has at least one top new hire in year *t* and zero otherwise. We define a top new hire if a new hire is in the top 5 percentile distribution of innovation productivity three years after year *t* among all new hires; "Top Leaver" equals 1 if firm *i* has at least one top leaver in year *t*. We define a top leaver if a leaver is in the top 5 percentile distribution of innovation productivity three years before year *t* among all leavers. Other variables are defined in Appendix A. Control variables are the same as in the baseline models. Year and industry fixed effects are included in all regressions but the coefficients are not reported. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

| Dep Var = | *Prob (Top New Hire=1)* | | *Prob (Top Leaver=1)* | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| ***Ln(Total Gap)*** | 0.184*** | | 0.061 | |
| | (0.072) | | (0.271) | |
| ***Ln(LT Gap)*** | | 0.151** | | 0.124 |
| | | (0.071) | | (0.304) |
| ***Ln(ST Gap)*** | | -0.009 | | -0.234 |
| | | (0.175) | | (0.256) |
| Controls | Yes | Yes | Yes | Yes |
| Year and Industry Fixed Effects | Yes | Yes | Yes | Yes |
| Wald $Chi^2$ | 1,253.37 | 1228.43 | 978.38 | 931.94 |
| Observations | 3,604 | 3,604 | 3,562 | 3,562 |

**Table 9 Effects of Pay Gaps on Board Monitoring Intensity**

This table reports the 2SLS results of pay gaps on board monitoring intensity and board monitoring intensity on innovation output. In Panel A, the dependent variable *Monitoring_Intensive_Board* equals one if more than half of independent directors are monitoring intensive and zero otherwise. Monitoring intensive directors are independent directors serving on at least two principal monitoring committees (audit, compensation, nominating, and governance). Other variables are defined in Appendix A. Panel B reports subsample results on total gap partitioned by board monitoring intensity. Panel C reports subsample results on long-term and short-term gap partitioned by board monitoring intensity. For Panel B and C, control variables are the same as in the baseline models. Year and firm fixed effects are included in all regressions but the coefficients are not reported. Robust standard errors clustered by firm are displayed in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

**Panel A: Substitution Effect Between Board Monitoring and Pay Gap**

| Dep Var = | *Prob(Monitoring_Intensive_Board)=1* | |
|---|---|---|
| | (1) | (2) |
| ***Ln(Total Gap)*** | -0.300** | |
| | (0.146) | |
| ***Ln(LT Gap)*** | | -0.267** |
| | | (0.132) |
| ***Ln(ST Gap)*** | | -0.051 |
| | | (0.114) |
| *Boardsize* | -0.168*** | -0.179*** |
| | (0.009) | (0.012) |
| *DirectorAge* | 0.623** | 0.264 |
| | (0.321) | (0.447) |
| *DirectorTenure* | 0.067* | 0.124** |
| | (0.041) | (0.056) |
| *Sales* | 0.181*** | 0.191*** |
| | (0.041) | (0.066) |
| *ROA* | 0.306 | 1.116** |
| | (0.221) | (0.572) |
| *RD_Intensity* | -0.429 | -0.736 |
| | (0.445) | (0.649) |
| *InstOwn* | -0.457*** | -0.879*** |
| | (0.147) | (0.337) |
| *CEO Delta* | -0.156*** | -0.457** |
| | (0.047) | (0.216) |
| *CEO Vega* | 3.513*** | 7.441*** |
| | (1.252) | (3.044) |
| *Std VP* | 0.018 | 0.029 |
| | (0.042) | (0.063) |
| *CEO Age* | -0.015 | 0.067 |
| | (0.044) | (0.896) |
| Year & Industry Fixed Effects | Yes | Yes |
| Wald $Chi^2$ | 777.69 | 679.26 |
| Number of Obs | 3,223 | 3,223 |

**Panel B: 2SLS Subsample Results - Total Gaps**

| | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
|---|---|---|---|---|---|---|---|
| | | | | Monitoring_Intensive_Board=1 | | | |
| ***Ln(Total Gap)*** | 0.151 | 0.213** | -0.018 | 0.005 | 0.073 | -0.086 | 0.032 |
| | (0.101) | (0.110) | (0.030) | (0.033) | (0.044) | (0.082) | (0.075) |
| | | | | Monitoring_Intensive_Board=0 | | | |
| ***Ln(Total Gap)*** | 0.150** | 0.558*** | 0.056*** | 0.031* | 0.206* | 0.119*** | -0.060* |
| | (0.073) | (0.185) | (0.018) | (0.017) | (0.123) | (0.042) | (0.034) |
| Test of Equal Coefficients (null) | | | | | | | |
| Wald-$Chi^2$ | 4.23** | 3.84** | 4.93*** | 3.14* | 2.63* | 4.89*** | 2.96* |

**Panel C: 2SLS Subsample Results - LT Gaps and ST Gaps**

| | *NumPat* | *CitePat* | *PatEff* | *Originality* | *Generality* | *Explore60* | *Exploit60* |
|---|---|---|---|---|---|---|---|
| | | | | Monitoring_Intensive_Board=1 | | | |
| ***Ln(LT Gap)*** | -0.034 | 0.026 | 0.043 | 0.015 | -0.055 | -0.018 | 0.007 |
| | (0.090) | (0.099) | (0.029) | (0.019) | (0.152) | (0.100) | (0.091) |
| ***Ln(ST Gap)*** | -0.008 | 0.020 | -0.057 | 0.013 | 0.079 | 0.017 | -0.053 |
| | (0.094) | (0.121) | (0.038) | (0.023) | (0.386) | (0.064) | (0.058) |
| | | | | Monitoring_Intensive_Board=0 | | | |
| ***Ln(LT Gap)*** | 0.169*** | 0.280* | 0.044** | -0.024 | 0.521 | 0.084*** | -0.039 |
| | (0.069) | (0.162) | (0.022) | (0.024) | (0.488) | (0.032) | (0.027) |
| ***Ln(ST Gap)*** | -0.066 | 0.052 | 0.042 | 0.003 | 0.289 | -0.035 | 0.025 |
| | (0.085) | (0.169) | (0.028) | (0.030) | (0.210) | (0.049) | (0.041) |
| Test of Equal Coefficients (null) | | | | | | | |
| Wald-$Chi^2$ (LT Gap) | 4.05*** | 2.14* | 2.73* | 0.65 | 0.85 | 4.12*** | 1.99 |
| Wald-$Chi^2$ (ST Gap) | 0.94 | 0.42 | 1.02 | 0.82 | 1.23 | 0.38 | 0.84 |

**Appendix Variable Definitions**

| Variable | Definition |
|---|---|
| **Measures of innovation** | |
| *NumPat* | Natural logarithm of one plus firm *i*'s total number of patents filed (and eventually granted) in year *t+3*; |
| *CitePat* | Natural logarithm of one plus firm *i*'s total number of citations received on the firm's patents filed (and eventually granted), scaled by the number of patents filed (and eventually granted) in year *t+3*; |
| *PatEff* | Natural logarithm of one plus total number of patents filed (and eventually granted) by a firm in year *t+3* divided by the firm's R&D expenditures in year *t* ; |
| *Originality* | One minus the Herfindahl index of the citations made by the patent portfolio (patents filed by the firm in the previous five years) in year *t+3* based on two-digit technology classes; |
| *Generality* | One minus the Herfindahl index of the citations received by the patent portfolio (patents filed by the firm in the previous five years) in year *t+3* based on two-digit technology classes; |
| *Explore60* | Number of exploratory patents filed in year *t+3* divided by the number of all patents filed by the firm in the same year; a patent is classified as exploratory if at least 60% of its citations are based on new knowledge; |
| *Exploit60* | Number of exploitative patents filed in year *t+3* divided by the number of all patents filed by the firm in the same year; a patent is classified as exploitive if at least 60% of its citations are based on current knowledge; |
| **Measures of pay gap** | |
| *Ln(Total Gap)* | Natural logarithm of the difference between the CEO's total compensation and the median value of total compensation among all VPs in year *t*; |
| *Ln(LT Gap)* | Natural logarithm of the difference between the CEO's long-term compensation and the median value of long-term compensation of among all VPs in year *t*; |
| *Ln(ST Gap)* | Natural logarithm of the difference between the CEO's short-term compensation and the median value of short-term compensation of among all VPs in year *t*; |
| **Measures of other variables** | |
| *CEO Delta* | Natural logarithm of the CEO's total portfolio delta which is computed as her dollar increase in wealth for a 1% increase in stock price in year *t*; |
| *CEO Vega* | The CEO's dollar increase in wealth for a 1% standard deviation increase in the firm's return volatility in a given |

| | |
|---|---|
| | year; |
| *Std VP* | Standard deviation of VPs' total compensation in year *t*; |
| *CEO Age* | Natural logarithm of CEO age in year *t*; |
| *Sales* | Firm size, defined as the natural logarithm of sales (#12) measured at the end of fiscal year *t*; |
| *ROA* | Return on assets ratio defined as operating income before depreciation (#13) divided by book value of total assets (#6), measured at the end of fiscal year *t*; |
| *Leverage* | Leverage ratio, defined as book value of debt (#9 + #34) divided by book value of total assets (#6) measured at the end of fiscal year *t*; |
| *Capex* | Capital expenditure (#128) scaled by book value of total assets (#6) measured at the end of fiscal year *t*; |
| *R&DAssets* | Research and development expenditure (#46) divided by book value of total assets (#6) measured at the end of fiscal year *t*; |
| *PPEAssets* | Property, Plant & Equipment (net, #8) divided by book value of total assets (#6) measured at the end of fiscal year *t*; |
| *HHI* | Herfindahl index of 4-digit SIC industry where firm belongs, measured at the end of fiscal year *t*; |
| $HHI^2$ | The square term of *HHI*; |
| *TobinQ* | Firm's market-to-book ratio in fiscal year *t*, calculated as [market value of equity (#199 × #25) plus book value of assets (#6) minus book value of equity (#60) minus balance sheet deferred taxes (#74, set to 0 if missing)] divided by book value of assets (#6); |
| *InstOwn* | Firm's institutional holdings (%) in fiscal year *t*, calculated as the arithmetic mean of the four quarterly institutional holdings reported through form 13F; |
| *Ln(Median Ind_TotalGap)* | Natural logarithm of median Total Gap for firms in the same two-digit SIC and same size quartile in year *t*; |
| *Ln(Median Ind_LT Gap)* | Natural logarithm of median Log-term Gap for firms in the same two-digit SIC and same size quartile in year *t*; |
| *Ln(Median Ind_ST Gap)* | Natural logarithm of median Short-term Gap for firms in the same two-digit SIC and same size quartile in year *t*; |
| *Median Ind_CEO Delta* | Median CEO delta for firms in the same two-digit SIC and same size quartile in year *t*; |
| *Median Ind_CEO Vega* | Median CEO vega for firms in the same two-digit SIC and same size quartile in year *t*; |
| *Stayer* | Dummy variable that equals 1 if the inventor produces at least one patent for the firm both three years before and three years after year *t*; |
| *New Hire* | Dummy variable that equals 1 if the inventor working produced at least one patent in a different firm three years before year *t*, but produces at least one patent for the current firm three years after year *t*; |
| *Leaver* | Dummy variable that equals 1 if the inventor produced at least one patent for the current firm three years before year *t*, but |

| | |
|---|---|
| | produced at least one patent in a different firm three years after year *t*; |
| *Top New Hires* | Dummy variable that equals 1 if a firm has at least one top new hire in year *t*. We define a top new hire if a new hire is in the top 5 percentile distribution of innovation productivity in three years after year *t* among all new hires; |
| *Top Leavers* | Dummy variable that equals 1 if a firm has at least one top leaver in year *t*. We define a top leaver if a leaver is in the top 5 percentile distribution of innovation productivity in the three years before year *t* among all leavers; |
| *Executive Inventor* | Dummy variable that equals 1 if the inventor is an executive at the firm; |
| *Top Executive Inventors* | Dummy variable that equals 1 if a firm has at least one top executive inventor in year *t*. We define a top executive inventor if an inventor is in the top 5 percentile distribution of innovation productivity among all executive inventors in year *t*; |
| *Monitoring_Intensive_Board* | Dummy variable that equals 1 if more than half of independent directors are monitoring intensive, and 0 otherwise. Monitoring intensive directors are independent directors serving on at least two principal monitoring committees (audit, compensation, nominating, and governance) in year *t*; |
| *Boardsize* | Natural logarithm of total number of directors in year *t*; |
| *DirectorAge* | Natural logarithm of average age of all directors in year *t*; |
| *DirectorTenure* | Natural logarithm of average tenure of all directors in year *t*, where tenure is the number of years a director has served on the board; |