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# INNOVATION AND INCENTIVES: EVIDENCE FROM CORPORATE R&D

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## ABSTRACT

Beginning in the late 1980s, American corporations began increasingly linking the compensation of central research personnel to the economic objectives of the corporation. This paper examines the impact of the shifting compensation of the heads of corporate research and development. Among firms with centralized R&D organizations, a clear relationship emerges: more long-term incentives (e.g. stock options and restricted stock) are associated with more heavily cited patents. These incentives also appear to be somewhat associated with more patent filings and patents of greater generality. We address endogeniety concerns in a variety of ways, including examining the impact of compensation for other key managers and utilizing an instrument based on spawning activity in the region. While we cannot determine whether the effect is due to better project selection or better people selection, the results continue to be consistent with our interpretation that performance pay of corporate R&D heads is associated with more innovative firms.



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## 1. Introduction

Research and development expenditures have long been understood to be a key driver of economic growth. Yet profound changes in the U.S. corporate R&D sector over the past two decades have attracted remarkably little attention by economists. This paper seeks to address this gap, by seeking to understand whether the increasingly high-powered incentives of central corporate research leaders are related to the innovation process.

The central corporate R&D laboratory was a dominant feature of the innovation landscape in the U.S. for most of the 20th century. While the concept of the centralized laboratory originated in the German chemical industry, U.S. corporations adopted it with enthusiasm by mid century. These campus-like facilities employed many thousands of researchers, many of whom were free to pursue fundamental science with little direct commercial applicability, most notably Bell Laboratories (with 11 Nobel Laureates) and IBM Central Research (with 5).

Beginning in the late 1980s, however, American corporations began fundamentally rethinking the role of these centralized research facilities (see, for example, the discussions in Rosenbloom and Spencer [1996]). Reflecting both a perception of disappointing commercial returns and intensified competitive pressures, firms undertook a variety of changes to these facilities. These included both paring the size of central research facilities in favor of divisional laboratories and more tightly linking the compensation of central research personnel to the economic objectives of the corporation.[1]

[1]These changes were frequently dramatic in magnitude. For instance, the head count of Bell Laboratories (now operated by Lucent Technologies) dropped from 35,000 in 1997 to 9,500 in 2005. Microsoft's $8

Numerous observers within the scientific establishment have expressed concern about the long-run implications of these changes. For instance, the National Science Board in 1992 attributed the decline of centralized research facilities to "risk minimization" on the part of corporations and an inappropriate emphasis on "the needs of today's customers" instead of longer-run objectives. Concerns about these patterns have frequently been expressed as well by organizations such as the National Academies of Science and the Council on Competitiveness.

To economists, however, the issue is not so clear-cut. On the one hand, observers such as Jensen [1993] have contrasted the incentives within corporate research facilities unfavorably with those offered by venture capitalists. He suggests that had higher-powered incentives been offered, some of the poor performance of research-intensive firms would have been avoided. In a similar vein, Kortum and Lerner [2000] find that venture-backed firms are approximately three times as efficient in generating innovations as corporate research.

On the other hand, the addition of high-powered incentives could plausibly have deleterious consequences as well. A critical problem, highlighted by the line of work beginning with Holmstrom and Milgrom [1991], is "multi-tasking." In particular, when an agent has multiple tasks to perform, only some of which can be measured with precision, it may make sense to offer compensation schemes with flat or very limited sensitivity to performance. Otherwise, the agent may neglect the activities that cannot be precisely measured.

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billion in R&D expenditures in 2003 included $1.3 billion in equity (http://www.spectrum.ieee.org/WEBONLY/publicfeature/nov04/1104rd.html, accessed March 12, 2005).

Scientists and engineers in research facilities are likely to have a portfolio of projects that they can work on, with varying degree of observability. As the incentives offered by the corporation increase, researchers may be led to spurn riskier but important long-run projects in favor of straightforward efforts (Holmstrom [1989]). As a result, it may make sense to offer weaker incentives in these settings (see also Lazear [1989]).

Moreover, the effect of different types of performance pay may not be uniform. In particular, a series of papers have suggested that compensation in the form of option holdings will lead managers to riskier behavior, because the increased volatility of the firm will translate into option value. Meanwhile, risk-averse managers who receive extensive stock-based compensation and whose human and financial capital is poorly diversified will prefer that their firms make less risky choices. Examples of literature where this idea has been developed are Smith and Stulz [1985], Hirshleifer and Suh [1992], and many others.

This question is also related to research on the relationship between authority and incentives in uncertain environments. Recent work suggests that for complex jobs it may be optimal to delegate decision-making to better informed agents and keep them in check with high-powered incentives (Prendergast [2002]). Also, firms may link pay to global or firm performance measures for specific positions in order to encourage better decisions over project selection that have firm-wide implications (Athey and Roberts [2001]). While the position of corporate R&D head varies across firms, the responsibilities can be generally characterized as making decisions about research project selection in highly uncertain environments.

This paper examines the relationship between innovation and the shifting compensation of the managers responsible for corporate research and development. We find that the compensation of corporate R&D heads changed dramatically over the course of the 1990s, with much greater use of long-term incentives (e.g., restricted stock and stock options). The ratio of the value of long-term incentives to cash compensation for corporate R&D heads has more than doubled over the period from 1988 to 1998 from 0.39 to 0.87. The value of long-term incentives (in 1996 $) has more than tripled over the period from $136,867 to $416,720. These shifts are not unique to these managers, mirroring those in other senior managers' compensation.[2]

We then turn to understanding the relationship between these changes and shifts in innovation. We are unable to find consistent patterns among firms with a decentralized R&D organization. But, among firms with a centralized R&D organization in which the corporate R&D head has greater firm-wide authority over R&D decisions, a clear relationship emerges: more long-term incentives are associated with more heavily cited patents. These incentives also appear to be associated with patents of greater generality and more frequent awards. There is little evidence that high-powered incentives lead to the neglect of more tangential research or to a substitution of patents for publications in scientific journals: greater incentives generally are not associated with any drop-off in the volume of scientific publication.

Finally, we examine the question of whether there is a causal relationship between the innovation measures and the long-term incentives of corporate R&D heads: specifically, whether we find support for the hypothesis that long-term incentives lead to

[2]Hall and Liebman [1998], Murphy [1999], and others document the significant increase in CEO long-term incentives over a similar time-frame.

either better R&D decisions or more skilled R&D managers and, in turn, more-heavily cited patents. While the very presence of an association may be of interest, understanding causation is also important.

While we must be careful in the interpretation, we present three analyses that support the incentives interpretation of the result. First, we examine the relationship using two other corporate managers who are unlikely to be directly involved in the innovation process: the chief financial officer (CFO) and the human resources head (HRH). If we find a relationship between patent quality and compensation of these officials, it is unlikely that the incentives story holds. We find no relationship between patent quality and generality and the incentives offered to the CFO or the HRH.

Second, we undertake an instrumental variables analysis. We employ an instrument that we believe will be correlated with the likelihood of high-powered incentives but uncorrelated with the technological prospects of the firm: the extent to which there is spawning, or the creation of entrepreneurial venture-backed entities by managers of publicly traded companies, in the county of the firm's headquarters and the year of the observation. In places and periods where there are many departures to venture backed firms, firms should be under more pressure to offer high-powered compensation. High-powered compensation continues to be associated with more heavily cited patents.

Finally, using the methodology of Aggarwal and Samwick [1999], we show that the sensitivity of compensation to performance is positively related to performance, but declines with the volatility of performance. The negative risk-incentive relationship holds in firms with a centralized R&D organization and R&D-intensive firms, which are

precisely the firms where we anticipate that corporate R&D decisions will have the greatest effect on firm value, but not elsewhere.

Several caveats are in order. First, while we document that stronger incentives are associated with more innovations, we cannot distinguish between whether the effect of performance pay is due to better project selection or better people selection. While it would be interesting to disentangle these, both explanations are consistent with performance pay: firms should hire better people to produce higher-quality patents and pay them more in return. Incentive pay plans are supposed to have selection effects, in addition to direct incentive effects [Lazear, 2000].[3]

Second, in equilibrium, firms should offer the optimal level of incentives. During the period under study, competitive pressures have led to a greater importance of innovation giving skilled R&D managers more bargaining power. Also, the effectiveness of property rights over inventions has changed significantly during the late 1980s and 1990s. As Merges [1999] notes in the context of R&D: "The history of intra-firm R&D management is a history of experimentation to find the right set of incentives."[4]

This paper is related to two sets of work. First, a number of articles, particularly in the accounting literature, have sought to relate R&D choices to the incentives of top management. Three pieces deserve special mention. Dechow and Sloan [1991] examines R&D expenditures of firms with chief executive officers (CEOs) in their final years of office, to determine whether they cut spending to improve short-term earnings

[3] We thank Kathryn Shaw for highlighting this distinction.

[4] Demsetz and Lehn [1985] argue that if all firms in the sample are optimizing with respect to long-term incentives, we should not find any relation between performance and the observed endogenous choice, once the exogenous determinants of choice are controlled for. However, as discussed in Ittner, Lambert, and Larcker [2003], Milgrom and Roberts [1992] argue that firms adapt by experimentation and imitation, and, at any given time, not all firms in the cross-section will have adopted optimal organizational practices.

performance. They find that these firms spend less on R&D during the CEOs' final years, unless the CEO has significant equity holdings in the firm. Holthausen, Larcker, and Sloan [1995] examine whether the compensation for the divisional CEO is related to subsequent innovative activity within the division. They find at least weak evidence that when divisional CEOs have a higher proportion of total compensation tied to long-term components, the ratio of patent awards to sales in the division is higher. Finally, Eng and Shackell [2001] find no evidence that the adoption of long-term performance plans for senior management has implications for R&D spending, once the presence of holdings by institutional investors are controlled for. Because the compensation of officials directly responsible for managing R&D are typically not included in filings with the U.S. Securities and Exchange Commission, these works focus on the compensation of senior managers (Holthausen, et al., being an exception).

The second, smaller body of work more explicitly seeks to relate the organizational structure of R&D to innovation. Cockburn, Henderson, and Stern [1999] examine the intensity of research workers' incentives for the distinct tasks of basic and applied research. Motivated by the multi-tasking framework, they suggest that when incentives are strong along one dimension, firms will set high-powered incentives for effort along other dimensions that compete for the worker's effort and attention. They find that firms who promote individuals based on scientific publications (which are likely to reflect basic research) also provide more intense incentives for success in applied research, by increasing program budgets in response to patent filings. Argyres and Silverman [2004] examine how the centralization of a firm's R&D organizational structure and R&D funding authority affects its innovations. They find that in particular,

firms with centralized R&D organizations generate innovations that are more cited, and are cited across a broader range of technological areas, than do firms with decentralized R&D organizations.[5]

The contribution of this paper is to document a new set of facts that performance pay is positively associated with firm innovation. To our knowledge, this relationship has not been documented elsewhere. The facts documented in the paper constitute suggestive evidence that stronger incentives lead to more innovation.

The plan of this paper is as follows. Section 2 describes the data employed in the study. In Section 3, we present the key regression analyses and robustness tests. The final section concludes the paper.

## 2. Data Description

### 2.1 Compensation Data

The primary dataset from which we draw our sample is an unbalanced panel of more than 300 publicly traded U.S. firms over the years 1987 to 1998, spanning a number of industries. This has a rich array of compensation data for senior and middle corporate management.

The data are collected from a confidential compensation survey conducted by Hewitt Associates, a leading human resources consulting firm specializing in executive compensation and benefits. The survey is the largest private compensation survey (as measured by the number of participating firms). The survey participants are typically the

[5]This paper is also related to Guedj and Scharfstein [2004], who compare 235 cancer drugs developed by early-stage biotechnology companies and established pharmaceutical corporations. They find that early-stage firms are much more likely to advance drugs from Phase I to Phase II of clinical trials, but that these drugs are much less likely to reach later stages of trials or to be approved. This pattern is particularly pronounced in biotechnology companies with large cash reserves. They attribute this pattern to agency problems between managers of single-product firms and their investors.

leaders in their sectors. More than 75% of the firms in the dataset are listed as Fortune 500 firms in at least one year and more than 85% are listed as Fortune 1000 firms. In general, Hewitt survey participants also participate in other compensation consulting firm surveys (e.g., Hay Associates, Mercer, Towers Perrin, to name a few) and do so primarily to receive information about pay practices to use as a competitive benchmark in evaluating their own compensation programs. It is important to note that the sample includes many more firms than Hewitt's consulting client base, with at least 50% of the survey participants having no other relationship to Hewitt. Based on several analyses described in Appendix A, we conclude that the survey sample is probably most representative of Fortune 500 firms.

The survey is comprehensive in that it collects detailed compensation data on many senior and middle management positions, including both operational positions (e.g., chief operations officer and divisional CEO) and staff positions (e.g., chief financial officer and human resources head). The survey typically covers all the positions at the top of the hierarchy and a sample of positions lower down.[6]

The data for each position include all components of compensation including salary, bonus, restricted stock, stock options, and other forms of long-term incentives (e.g., performance units). An observation in the dataset is a managerial position within a firm in a year. To ensure consistency in matching these positions across firms, the survey provides benchmark position descriptions and collects additional data for each position, leading to a rich dataset. Hence, in addition to data on all aspects of compensation, the dataset includes position-specific characteristics such as job title, the title of the position

[6]The Hewitt database is thus far more comprehensive than the SEC filings which form the basis for the ExecuComp database. Because firms are required to only file information on the top five executive officers, information on R&D executives is rarely included in these sources.

that the job reports to (i.e., the position's boss), number of positions between the position and the CEO in the organizational hierarchy, and both the incumbent's status as a corporate officer and tenure in position.

In this paper, we focus on the subset of firms (a) that report compensation data for the most senior executive responsible for corporate level R&D in the Hewitt survey (corporate R&D head) and (b) that report R&D expenditures in Compustat. This leads to a sample of approximately 800 firm-years and 140 firms. In some cases, the firms also have divisional R&D managers. As a basis of comparison, we also document compensation for the CEO, CFO, and HRH positions. The definitions for each of these positions, and additional R&D positions included in the survey, are described in Appendix B.

We believe the survey data are accurate for several reasons. First, Hewitt personnel are knowledgeable about survey participants because they are assigned to specific participants for several years. Furthermore, while the participating firms initially match their positions to the benchmark positions in the survey, Hewitt personnel follow up to verify accuracy and spend additional eight to ten hours on each questionnaire, evaluating the consistency of responses with public data (e.g., proxy statements) and across years. Finally, participants have an incentive to match positions correctly and provide accurate data because they use the survey results to set pay levels and design management compensation programs.

The above data are supplemented with information from Compustat for financial data and CRSP for shareholder returns. While the Hewitt survey is conducted in April of each year and the compensation data describe the firm in the year of survey completion,

some statistics (e.g., number of employees in the firm) represent the end of the most recent fiscal year. To maintain consistency, we match Compustat and CRSP data using the year prior to the year of the survey.

In Panel A of Table 1, we present descriptive statistics for the firms in the sample. While the dataset includes 141 firms, the exact number varies over the period, as firms enter and exit as survey participants. The firms in the sample are large firms with average sales of approximately $11.0 billion, assets of $12.1 billion, and a ratio of R&D expense to sales of 5%. In 63% of the firm-years, the firm has a centralized R&D organization (i.e., reports a corporate R&D head and does not report divisional R&D managers). In 48% of the firm-years, the corporate R&D head reports directly to the CEO in the organizational hierarchy. Finally, the sample firms span many industrial sectors of the economy, with some concentration in the chemical, machinery, transportation equipment, paper, electrical, and instrumentation industries (Table 1, Panel B).

A natural question is whether the individuals recorded as corporate R&D heads are indeed the key decision-makers, or rather outward-looking officials primarily responsible for being the R&D organizations' "public face." While it is difficult to answer this question definitively, we can examine these individuals' titles. The ten most frequently represented titles are reported in Panel C of Table 1. These titles seem consistent with individuals who are involved with the day-to-day management of the firms' research efforts.

**2.2. Innovation Data**

The survey data for firms reporting a corporate R&D head are linked to patent data from the National Bureau of Economic Research (NBER) and publication data from Thomson/ISI's Web of Science.

For patent data, we employ the NBER Patent Citations Database, which includes all patent awards and patent citations between 1975 and 1999. For each patent awarded to a publicly traded firm and its affiliates, the database includes the firm's CUSIP. We match the CUSIPs of the firms in Hewitt sample to those employed in the Citations Database. One complication is posed by firms that went public after 1989 that are included in the Hewitt database, as the CUSIPs for these firms are not included in the NBER database. In these instances, we add the CUSIP to the patents awarded to the firm and any subsidiaries in the NBER database.

From the NBER database, we collect the following information:

- The number of awards to the firm in a given year.
- The mean and median number of citations to the firm's patents awarded in a given year.
- The mean and median number of adjusted citations to the firm's patents awarded in a given year: that is, the number of citations adjusted by the expected number of citations that we would anticipate that the firms' patents would receive. We undertake this adjustment by estimating a regression using all patents awarded over this period, with controls for the year of the award, the technology subclass (see Hall, Jaffe, and Trajtenberg [2001] for a description), and a dummy indicating the patentee is a domestic entity.[7]

[7]We employ the subclasses in the NBER scheme rather than U.S. Patent and Trademark Office's Patent Classification scheme due to the limitations of the latter scheme, which does not correspond well to

- The "generality" of the firm's awards in a given year. This frequently employed measure (see Jaffe and Trajtenberg [2002]) is one minus the Herfindahl Index across technology classes of the patent citations received by a patent. Thus, a patent with a generality score approaching zero suggests that the patent has very narrow use, while a measure of one suggests that a diverse array of subsequent patents draw upon the award. We compute the mean of the generality measure for all patents awarded each firm in every year.
- The "originality" of the firm's awards in a given year. This measure is computed similarly, but captures the concentration of the citations made by the patent to earlier awards. Once again, we average the patents awarded in each firm-year.
- The extent of concentration of the firm's awards in a given year. We compute the Herfindahl Index of the firm's awards, again employing the technology subclasses in the NBER Patent Citations Database.

While our primary focus is on patented technologies, we also wish to understand the changes in publications. We determine the number of publications by authors associated with each firm through the use of the Web of Science database. We use as keywords the names of the firms in the Hewitt database and their major subsidiaries.[8]

One challenging issue has to do with the timing of awards and R&D expenditures. The economics literature has argued that patent applications are generated nearly contemporaneously with R&D expenditures (Hall, Griliches, and Hausman [1986]). Thus, it would be clearly problematic to relate the number of patent awards in 1995 to

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technological classifications (see Lerner [1994] for a discussion). Foreign patentees may be cited less, as often their original patent filing in another nation is cited instead of the award in the United States.

[8]Our search procedure did not allow us to identify citations to these articles akin to those of patents. While Thomson offered to sell us the citation data, the cost would have been in the six figures.

compensation levels in 1995, as the patents would have been filed on average two years before (the typical patent took approximately two years to issue over this period[9]). Instead, we employ in our base specifications a two-year lag for patents, relating patents awarded in 1995 to compensation levels in 1993. Similarly, reflecting the relatively short pendencies at most applied science and engineering journals (Adams, Clemmons, and Stephan [2004]), we relate publications appearing in 1995 to compensation levels in 1994.

It might be wondered why we do not instead employ applications: for instance, relating applications filed in 1995 to compensation levels in that year. Our reluctance to do so reflects the facts that (a) the extent of patent pendency is not random and (b) the substantial truncation bias affecting the sample. Johnson and Popp [2003] show that more important patents appear to take longer to issue, with a significant tail of patents taking 10 years or more.[10] Since our compensation data begins in 1988, this would mean that the count of applications in a significant number of years (certainly, at least half the sample) would be truncated. Moreover, some of the most important patents would not be included in the tabulations of mean citations and other measures. If we could be assured that this pattern would introduce no systematic bias, we could perhaps ignore it, but it is hard to be confident. While the use of awards will introduce noise into the analysis (some awards will actually have been applied for less than two years before, while others will have been done so three or more years earlier), the approach should not raise concerns about systematic biases.

[9]For instance, Popp, Juhl, and Johnson [2004] find that the median patent awarded between 1976 and 1996 took 23 months to issue.

[10]Until the end of the period under study, the U.S. Patent and Trademark Office only published issued patents. The fact that a firm had made a patent application that had not issued was not disclosed.

Below, we will examine the robustness of the analysis to different approaches. For instance, rather than employing a two-year lag between patent awards and compensation data, we employ a one- and three-year lag. Similarly, we employ the application data despite our reservations with it. The critical results continue to hold as before.

As noted above, the NBER Patent database includes all awards and citations through the end of 1999. Thus, in our regressions, we will be only employing data on compensation levels between 1988 and 1997.[11]

### 2.3. Summary Statistics

This study primarily focuses on compensation for the most senior executive with corporate R&D responsibility (i.e., corporate R&D heads). We document each component of pay: salary, bonus, and long-term compensation. The pay tied to long-term components includes restricted stock, stock options, and other components of long-term compensation as calculated by Hewitt Associates.[12] We also report the ratio of bonus to cash compensation (or salary plus bonus) and the ratio of long-term compensation to cash compensation. We focus on long-term compensation because decisions made by corporate R&D heads have a longer-time horizon relative to decisions made by other

[11]An additional complication is introduced by the fact that few patents garner a significant number of citations in their first year of issue. When employing citation analyses, we explore the robustness to only employing patents that have had at least two years to be cited: for instance, we repeat Table 4, only employing compensation data between 1988 and 1995 in the citation regressions. The results are little changed.

[12]These measures represent ex ante assessments of the value of long-term compensation and are computed by Hewitt Associates. Stock options are valued using a modified version of Black-Scholes that takes into account firm-specific vesting and termination provisions in addition to the standard variables of interest rates, stock price volatility, and dividends. As is standard practice among compensation consulting firms, the other components of long-term incentives (i.e., restricted stock, performance units, and performance shares) are valued using an economic valuation similar to Black-Scholes that takes into account firm-specific vesting, term provisions, and the probability of achieving performance goals.

executives, e.g., those responsible for manufacturing, marketing and sales. And, payoffs associated with investing in innovation are not likely to be realized immediately.

We analyze both cash compensation (salary and bonus) and total compensation. We also analyze several measures of performance-based pay as proxies for the incentives of corporate R&D heads. The first measure is the ratio of the value of long-term compensation to cash compensation. This measure is similar to that used in Holthausen, Larcker, and Sloan [1995].[13] We also analyze two distinct measures of long-term compensation: the ratio of the value of stock options to cash compensation and the ratio of restricted stock to cash compensation. Finally, as a measure of short-term incentives, we analyze the fraction of cash compensation from annual bonuses.

In Panel A of Table 2, we report summary statistics of several pay measures for the corporate R&D head, the CEO, the CFO, and the HRH position. Compensation variables are denominated in 1996 dollars. Sample averages for the corporate R&D head for salary and bonus (or cash compensation), ratio of bonus to cash compensation (ST incentive ratio), ratio of long-term compensation to cash compensation (LT incentive ratio), and total compensation are $380,039, 27.7%, 59.2%, and $641,559, respectively. Comparable sample averages for the CEO are $1,390,899, 35.7%, 98.9%, and $2,994,476 respectively. Finally, sample averages for the CFO are $538,340, 30.5%, 78.9%, and $1,011,812, and for the HRH are $339,366, 27.2%, 58.5% and $567,935, respectively. Consistent with the findings of the CEO literature, long-term compensation comprises a much greater proportion of CEO pay relative to corporate R&D, CFO, and HRH

[13] Since we only observe flow compensation and not stock of incentives, we may worry about measurement error in our pay variables as proxies for performance-based incentives (Baker and Hall [2004]; Core and Guay [2002]). To partially address this issue, we also estimate between regressions by averaging executive observations over the period and analyzing variation between corporate R&D heads.

positions. The long-term incentive ratio for the CEO, on average, is more than 50% greater than that for the corporate R&D head and HRH positions and 25% greater than that for the CFO position.[14]

In Panel B of Table 2, we document changes in cash compensation and both the fraction of bonus and the fraction of long-term compensation of salary plus bonus for the corporate R&D heads, the CEO, the CFO and the HRH position over the period of study. The table includes firms that appear in the dataset for two consecutive years. By focusing on this set of observations, we minimize biases from the exit and entry of firms. As we see, there is an upward trend in both annual and long-term compensation as a fraction of cash compensation for all four positions over time for this sample. Also, the increase in the ratio of long-term compensation is much greater than that of the ratio of annual bonus and the increase in the former is much greater for the CEO relative to the other positions, especially the corporate R&D head and HRH positions. (The patterns for the whole sample are qualitatively similar.)

The ratio of long-term compensation to cash compensation is one measure of performance-based pay that might be particularly important in the effect it has on the corporate R&D head's decisions to invest in innovation. It is also an *ex ante* measure in that its value is based on expectations of future performance. And, as mentioned earlier,

[14]This "flow" measure of long-term compensation understates incentive pay for the CEO relative to other executives because CEOs hold a much higher percentage of a firm's stock in comparison to other managers. Recent research on CEO compensation accounts for the incentives from the holding of stock and stock options (in addition to annual grants of restricted stock and options). In contrast to ExecuComp data, we only observe annual grants of options and restricted stock and not stock holdings. In order for us to construct an explicit measure of incentives for an executive based on stock ownership from annual grants of options and restricted stock, we would have to make many assumptions about initial holdings, exercising of options, and vesting restrictions on both options and restricted stock. However, this data limitation is less problematic in our context because of the panel structure of our data and our econometric specification. Since we are exploiting both within firm and between firm variations in our random effects regressions, annual grants of options and restricted stock are an appropriate measure.

the ratio of the value of long-term incentives to cash compensation for corporate R&D heads has more than doubled over the period from 1988 to 1998.

One important consideration is that while all firms in the sample have a head of corporate research, not all of them have a centralized R&D organization. Approximately 37% of the firm-year observations in our sample also have divisional R&D managers who typically report to division heads and are responsible for applied R&D and design and development engineering for the division. In firms with a centralized R&D organization, corporate R&D heads have greater firm-wide authority over R&D since these firms do not have divisional R&D managers. Argyres and Silverman [2004] argue that there are fundamental differences between the manner in which firms with centralized versus decentralized research structures evaluate new projects. In addition, centralized R&D organizations generate innovations that have a higher level of impact and affect a broader range of technological areas than do firms with decentralized R&D organizations.

It might be anticipated that offering high-powered incentives to the corporate R&D head would have a much more dramatic impact among firms that have a centralized R&D organization than in ones which also have divisional R&D managers. The ability of the corporate R&D head to have an effect on firm value is likely to be much lower in the case where R&D responsibilities reside in large part within the divisions.

In Table 3, we report summary statistics of firm characteristics, pay measures for corporate R&D head and CEO positions, and innovation measures for both the samples with centralized R&D organizations and those with decentralized organizations. The centralized R&D firms are smaller firms operating in more volatile environments. These

firms tend to have lower levels of compensation and lower ratios of performance-based pay for the CEO and the corporate R&D head positions.

## 3. Econometric Specification and Results

### 3.1 Specification

In each table of regressions, we use firm-years as units of observation. We estimate regressions with the same nine measures of innovation as dependent variables introduced above.[15] We typically employ a random effects specification. In these analyses, as well as the subsequent ones, we employ controls for each corporate R&D head separately.[16] While unobserved executive heterogeneity is a concern, we are limited to random effects specifications. The fixed effects coefficients are imprecisely estimated, because there is not enough variation within R&D head compensation variables during the relatively short average tenure of each head.

In each case, we employ as independent variables the logarithm of firm sales (denominated in 1996 dollars), the research intensity (the ratio of the firms' R&D to sales), and dummy variables for the year of the observation. (Again, we explore the robustness of the results to additional control variables below.)

As mentioned earlier, we might worry about measurement error in our use of flow compensation as a proxy for incentives since we are limited to annual grants of stock options and restricted stock. To address this, we examine the robustness of the results in a

[15]Due to the skewed distributions of the number of patents and publications (as documented in Jaffe and Trajtenberg [2002], we employ the logarithm of (one plus) these measures as dependent variables. The results are also robust to the use of a negative binomial specification based on the count of patents and publications.

[16]We determine turnover of the corporate R&D head from the Hewitt data. In an alternative specification, we employ effects for each firm. We find that while the explanatory power is not quite as high, the results are qualitatively unchanged.

between regression that takes averages of observations over time periods for each corporate R&D head and analyzes variation between these positions.

In most tables, we report four sets of analyses. In these analyses, we vary the dependent variable measuring compensation. In particular, we employ:

- The overall compensation level of the corporate R&D head, where we use the logarithm of compensation in 1996 dollars as the dependent variable.[17]
- The ratio of long-term compensation of the corporate R&D head to the sum of the base compensation and bonus in that year.
- The ratio of long-term compensation of the corporate R&D head to the sum of base compensation and bonus in that year, as well as the ratio of short-run incentives (the ratio of bonus to the sum of base salary and bonus).
- The ratio of the two key components of long-term compensation of the corporate R&D head (stock options and restricted stock) to the sum of base compensation and bonus in that year.

### 3.2 Baseline Results

Table 4 presents the base-line analyses for the firms with centralized R&D organizations. Here, we see several distinct patterns:

- Higher compensation levels for the corporate R&D head are associated with more patent awards, more heavily cited patents, and more concentrated patents (Table 4a). A one-standard deviation increase in the log of total compensation is associated with an increase of 0.65 in mean citations for the

[17]Salary increases are another measure that partially captures promotion incentives. However, they are small relative to the importance of other types of incentives for corporate R&D heads. The results are robust to the inclusion of the log of changes in salary for each manager in our regressions.

firm, which is 14.3 % of the sample mean. Or, an increase in total compensation from the 25th percentile ($344,400) to the 75th percentile ($764,309) is associated with an increase of 0.8 in mean citations for the firm, which is 18.6 % of the sample mean.

- Long-term incentives for the corporate R&D head are associated with more patent awards, more heavily cited patents, and patents with greater generality (Table 4b). A one-standard deviation increase in the ratio of long-term incentives to salary plus bonus is associated with an increase of 9.0% in patent awards to the firm. A one-standard deviation increase in the ratio of long-term incentives to salary plus bonus is associated with an increase of 0.48 in mean citations for the firm, which is 10.4 % of the sample mean. An increase in the ratio of long-term incentives to salary plus bonus from the 25th percentile (28.6%) to the 75th percentile (74.3%) is associated with an increase of 0.41 in mean citations for the firm, which is 9.1% of the sample mean.
- Short-term incentives appear to have little impact, with the exception of the median number of adjusted citations (Table 4c).
- The long-term incentive effect appears to work through both stock options and restricted stock. Restricted stock grants have the strongest relationship with citations, while options are associated with more patent awards (Table 4d). A one-standard deviation increase in the ratio of the value of restricted stock to salary plus bonus is associated with an increase of 0.47 in mean citations for the firm, which is 10.4 % of the sample mean. For stock options, the associated increase is 8.0 % of the sample mean. An increase in the ratio of

the value of stock options to salary plus bonus from the 25th percentile (15.6%) to the 75th percentile (52.1%) is associated with an increase of 0.27 in mean citations for the firm, which is 5.9% of the sample mean.

- Turning to the control variables, larger firms appear to patent more frequently and widely (i.e., the Herfindahl Index of patent classes is lower), and to have fewer citations, as well as to publish more. More research-intensive firms publish more.[18]

These results appear to be more consistent with the Jensen hypothesis: high-powered incentives are associated with more research output and higher research quality. There seem to be few of the anticipated costs associated with higher-powered incentives: these firms do not increase the concentration of their patent portfolio or reduce the number of publications.

When we look at the firms with a decentralized R&D organization in Table 5, the results are much weaker. In Table 5a, the only significant patterns are that firms with higher compensation levels for the corporate R&D head patent more. In Table 5b, there is no significant relationship between long-term incentives and innovation. When we repeat the analyses in Tables 4c and 4d in unreported analyses, few significant patterns emerge.

Moreover, these results are not robust to slight changes in the specification. For instance, when we repeat the analyses in Tables 4 and 5 with some slight changes, such as using random effects for each firm (rather than for each R&D manager) and winsorizing the compensation measures at the 99% level, the basic patterns in Table 4 remain, while the few significant results in Table 5 disappear.

[18] When we exclude R&D intensity from the baseline regressions in Table 4b, the magnitude of the coefficients are somewhat larger with no change in significance levels.

To sum up, we find positive relations between innovation measures and long-term incentives for corporate R&D heads in the centralized R&D sample, but not in the sample of firms with a decentralized R&D organization.

### 3.3. Robustness Checks

We undertake a variety of robustness checks of the results. Table 6 is an example of the additional analyses we perform.

In this table, we employ applications rather than awards, though as discussed above, the use of this measure may pose some concerns about truncation biases. The basic patterns go through as before. Higher compensation is associated more patenting, more citations, and now more focused awards. More long-term incentives are associated with more patenting, more citations, and more general awards. The results continue to hold when we control for short-term compensation. Interestingly, more short-term incentives are associated with more focused awards. When we divide the long-term compensation into stock options and restricted stock, both stock options and restricted stock have a statistically significant effect on the number of citations.

In Table 7a, we undertake an analysis addressing the possibility that the above results may be driven by differences in the position of the corporate R&D head in the organizational hierarchy. It might be that more incentive-based compensation is offered to positions closer to the CEO, which in turn drives the nature of the innovation. Thus, we might be falsely imputing significance to the compensation variables, when it is really the hierarchical position that is critical.

We are already partially addressing this issue by employing random effects in the regressions. A wealth of sociological literature (e.g., Baron, Hannon, and Burton [1999]) has suggested that organizational features are very persistent, and typically survive even as the management team turns over. Thus, these effects should absorb much of the differences.

Another way to address this concern is to explicitly control for position within the hierarchy. In particular, it might be argued that during this period, the decision-making authority of the corporate R&D head's position was considerably augmented. Put in the language of economic theory, R&D chiefs may have moved from having "formal" to "real" authority over the allocation of R&D budgets (Aghion and Tirole [1997], Dessein [2002]).

To control for this possibility, we examine whether the head of corporate R&D reports directly to the CEO. We add a dummy variable for such observations, as well as an interaction between the compensation measures and the dummy. Table 7a shows that these controls make little difference to the results.

We also undertake a variety of unreported robustness checks. As noted above, we winsorize the compensation measures, to delineate the effects of outliers. We estimate ordinary least squares regressions merely employing dummy variables for each industry, but without fixed or random effects. In addition, we include the mean compensation of a number of other staff positions as a control. We also vary the period that we lag the patent awards: that is, we look at the results if we assume the awards are issued one and three years after the application date. Also, we estimate the patent and publication

regressions using a negative binomial specification that recognizes the dependent variable as a count measure. In each case, the same basic patterns appear.

Since there appears to be limited variation across time periods within firms, we repeat the specification in Table 4, but estimate between regressions. In this analysis, we take averages of the observations over time for each executive, which allows us to limit the errors-in-variables problems brought about by annual fluctuations of the independent variables. We find similar qualitative patterns as in the random effects specifications, but with larger coefficients and greater statistical significance.[19]

### 3.4. Examining the Incentives Hypothesis

We have been circumspect in the interpretation of these results. The positive association between innovation measures and long-term incentives of corporate R&D heads is consistent with the hypothesis that equity-based incentives lead to better decisions about project selection at the corporate level. However, alternative explanations certainly exist, such as the possibility that these incentives are offered to attract or retain high-quality managers or that these awards are a reward for past successful performance.[20] Definitively establishing one hypothesis is very challenging and beyond the scope of this paper. However, we do explore evidence in light of the incentives hypothesis.

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[19]When we undertake instrumental variable analyses using the between specification, we also do not see to the same extent the dramatic increase in the coefficients as we do in the random effects specifications discussed in Section 3.4.

[20]Based on interviews with Hewitt Associates and human resource personnel, awarding stock options and restricted stock for past performance is relatively uncommon. This is consistent with the finding of Cohen, Nelson, and Walsh [2000] that patents are infrequently used to measure internal performance. Moreover, if stock options and restricted stock are granted as rewards for past performance, we might expect a positive contemporaneous relation between grants and pay. To evaluate this, we estimate our baseline regression in Table 4b, but use contemporaneous measures of grants instead of lagged grants. We find that the coefficient on long-term incentive pay is no longer significant in the citation regressions.

We address this concern in three ways. First, we repeat the analysis of Table 4, but replace compensation of the corporate R&D head with compensation of two senior staff positions: Chief Financial Officer and Human Resources Head. In effect, we are using these other positions as a control group. If our results are just spurious correlations driven by unobserved firm heterogeneity, then we might expect to find similar results for other senior staff positions. In Tables 7b and 7c, we report the regressions analogous to Table 4b for the CFO and HRH positions based on the centralized R&D sample: that is, we regress the innovation measure on the ratio of long-term incentives to salary plus bonus, firm size, ratio of R&D to sales, firm and year indicators. While (the logarithm of) patents are weakly positively correlated with long-term incentives for the CFO position, there is no association for the HRH position, plus no association between the citation measures and long-term incentives for either of these positions. When we estimate the patent count regressions based on a negative binomial specification, the weakly significant result between patents and long-term incentives for the CFO disappears.

Importantly, the uniqueness of the positive associations between long-term incentives and citations for the corporate R&D head are consistent with the explanation that incentives affect decisions of managers responsible for corporate R&D. Both the CFO and the HRH position receive roughly comparable levels of long-term incentives as the corporate R&D head (see Table 2, Panel A), but it is only the R&D head incentives that are related to either patents or citations. These results are also consistent with the explanation that greater performance pay attracts more skilled R&D managers.

Second, since compensation is a choice variable and endogenously chosen, we undertake an instrumental variables analysis. An ideal instrument is one that is correlated

with the independent variable of interest but not with the unobserved error in the dependent variable. For an instrument, we use the extent of spawning: the number of instances where an employee left a publicly traded firm headquartered in that county in that year to begin a venture-backed firm.

The extent of spawning is likely to be correlated with incentive compensation. In many cases, these individuals obtained substantial equity stakes and/or stock option grants in the new ventures. It can be anticipated that these defections will create pressures for local firms to offer higher-powered compensation. Meanwhile, this variable should be uncorrelated with circumstances affecting the extent of innovation in the firm itself: in calculating this measure, we exclude spawning by both the Hewitt firm and by firms in the same two-digit industry within the same county as the Hewitt firm. Because by construction the spawned enterprises are in other industries than the Hewitt firm, it is unlikely that the rate of spawning is closely linked to the overall technological opportunity set facing the firm. We obtain this information from Gompers, et al. [2005], who compile this information from the DowJones Venture Source data-set.

Table 8 presents the second-stage results of our instrumental variables regression. The number of citations continues to be explained by the instrumented long-term compensation ratio. Two results, however, are less easily explained. First, the mean originality of the patents actually declines with higher-powered incentives. Second, the magnitude of the coefficients increases quite dramatically in the instrumented regressions.

Third, since agency theory predicts a negative relation between risk and incentives, if performance-based pay is offered to provide incentives, we should expect to

see the sensitivity of pay to performance declining as the volatility of the performance measure rises. To test this for the corporate R&D heads in our sample of firms, we replicate the analysis of Aggarwal and Samwick [1999] using total compensation, shareholder returns as the performance measure, and the empirical cumulative distribution function (CDF) of the standard deviation of monthly returns over the prior 60 months as the measure of risk. We use standard deviations based on historical stock returns in order to somewhat mitigate the manager's ability to influence stock return volatility. Based on the "implicit" method, we estimate a regression of total compensation for the corporate R&D head on stock returns, the CDF of return standard deviation, an interaction term between stock returns and the CDF, and firm and year indicators. Total compensation is defined as salary, bonus, and the value of long-term incentives. In Table 9, we use two measures of shareholder returns and report the estimated coefficients on the performance measure, the interaction term between performance and risk, and the risk measure. We first estimate the coefficients for the whole sample and then split the sample using two criteria: (i) firms with centralized versus decentralized R&D organizations; and (ii) firms above the sample median in the ratio of R&D to sales and firms below the median.

Based on the whole sample and for both shareholder return measures, we find a negative risk-incentive relation, i.e., the coefficient on the performance measure is positive and significant, while that on the interaction between performance and risk is negative and significant.[21] The sensitivity of pay is positively related to performance and declines in the volatility of the performance measure. These findings are consistent with offering stock-based pay to provide incentives. Furthermore, we find that this relation

[21]These results are robust to inclusion of firm size measured as log of firm sales.

holds in the partition of firms with centralized R&D organizations and R&D-intensive firms, but not in firms with decentralized R&D organizations or low R&D firms. These results are consistent with the explanation that stock-based pay is more effective when the decisions of the corporate R&D head have the greatest effect on stock returns: that is, in R&D-intensive firms with centralized R&D organizations. It is also consistent with Prendergast [2002], who argues that the mixed empirical results on the negative tradeoff between risk and incentives are due to the omission of measures of authority. When we partition the sample by characteristics that proxy for the importance of the corporate R&D head's decision-making authority (centralized R&D and R&D-intensive firms), we find stronger support of the negative tradeoff between risk and incentives.

Taken together, our findings suggest that incentives play some role in corporate R&D heads making better decisions over project selection. Once again, we cannot determine whether the effect is due to better project selection or better people selection. However, both explanations are consistent with performance pay: firms should hire more skilled managers to produce more patents and pay them more in return.

## 4. Conclusions

Beginning in the late 1980s, American corporations began linking the compensation of central research personnel to the economic objectives of the corporation. This trend has attracted considerable concern in technology policy circles, while economic theory suggests widely different consequences.

This paper examines the relationship between innovation and the shifting compensation of corporate R&D heads over the 1990s. Among firms with centralized

R&D organizations, a clear relationship emerges: more long-term incentives are associated with more heavily cited patents. These incentives also appear to be more weakly associated with more frequent awards and patents of greater generality. We undertake a variety of analyses to address concerns that the results reflect dynamics other than performance pay improving project selection by, or skill selection of, corporate R&D heads. Furthermore, the results appear to be robust to many of the controls we employ.

Two important limitations of this analysis—and opportunities for future work—should be noted. We confine our analysis here to the relationship between innovation and the shifting compensation on the head of corporate R&D. It would certainly be interesting to examine the compensation schemes of divisional research managers as well. We intend to examine this question in future work.

At the same time, the Hewitt data does not enable us to examine what are arguably the most interesting compensation choices: the incentives offered rank-and-file scientists and engineers. Field-based evidence suggests that the compensation has traditionally been extremely flat (Orth, Bailey, and Wolek [1964], Neumayer [1973]). Understanding the extent to which this pattern still holds, and its implications for innovation, is an important challenge.

Second, it is by no means clear that our measures can capture shifts in truly groundbreaking research. It may be that profound changes in corporate research have occurred, but that the consequences of these shifts can only be measured after several decades. Nonetheless, the absence of deleterious patterns using the measures that we can employ is striking.

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**Table 1 (Panel A): Summary Statistics**

| Variable | Mean | Std. Dev. | Min | Max | Obs |
|---|---|---|---|---|---|
| Firm Sales ($ millions) | 11038 | 21307 | 86 | 165370 | 818 |
| Assets ($ millions) | 12142 | 29465 | 103 | 279097 | 818 |
| R&D/Sales ratio | 0.05 | 0.05 | 0.00 | 0.49 | 818 |
| Volatility of Shareholder Returns | 8.71 | 3.53 | 3.62 | 50.55 | 762 |
| Patent Count | 82.15 | 168.09 | 0.00 | 1936.00 | 735 |
| Citations (mean) | 4.58 | 4.48 | 0.00 | 29.00 | 735 |
| Citations (median) | 3.11 | 3.44 | 0.00 | 29.00 | 735 |
| Adjusted Citations (mean) | 0.56 | 2.99 | -4.85 | 21.39 | 735 |
| Adjusted Citations (median) | -0.74 | 2.33 | -5.49 | 21.39 | 735 |
| Generality (mean) | 0.28 | 0.16 | 0.00 | 0.86 | 702 |
| Originality (mean) | 0.42 | 0.13 | 0.00 | 0.74 | 735 |
| Firm Herfindahl of Patents (HHI) | 0.28 | 0.20 | 0.00 | 1.00 | 735 |
| Publications | 112.67 | 323.41 | 0.00 | 2651.00 | 779 |
| Centralized R&D organization | 0.63 | 0.48 | 0.00 | 1.00 | 818 |
| Direct Report to CEO (corporate R&D head) | 0.48 | 0.50 | 0.00 | 1.00 | 813 |

Note: Sample includes firms that report both a corporate R&D head in the compensation survey and R&D expenditures in Compustat. Volatility of Shareholder Returns is defined as the standard deviation of monthly returns (percentage) based on the previous 60 months. Patent count is defined as the sum of the number of patents awarded in that firm-year. Citations are defined as the mean and median of the number of citations in patents awarded in that firm-year. Adjusted citations is defined as the mean and median of the number of adjusted citations per firm-year, where the adjustment entails subtracting the mean number of patents received by awards in that technology class in the same award year. Generality is a measure of the breadth of patents that cite the firm's patents in a given year; originality the breadth of cited patents. Patent Herfindahl (HHI) is an index of the number of patent classes into which the firm's patents fall. Publications are defined as the number of publications by affiliates of that company included in the ISI Web of Science. Centralized R&D organization is a dummy variable equal to one if the firm reports a corporate R&D head, but no divisional R&D managers in a firm-year, and zero otherwise. Direct Report to CEO is a dummy variable equal to one if the corporate R&D head reports directly to the CEO in the organizational hierarchy.

**Table 1 (Panel B): Industries of Firms in Sample**
**Distribution by 2-digit SIC Code**

| Industry (2-digit SIC) | N (firm-yrs) | % of Sample |
|---|---|---|
| Chemical (28) | 167 | 20.4 |
| Machinery (35) | 120 | 14.7 |
| Transportation Equipment (37) | 109 | 13.3 |
| Paper (26) | 66 | 8.1 |
| Electrical (36) | 57 | 7.0 |
| Instrumentation (38) | 56 | 6.8 |
| Food (20) | 52 | 6.4 |
| Communications (48) | 25 | 3.1 |
| Other | 166 | 20.3 |
| Total | 818 | 100 |

Note: Sample includes firms that report both a corporate R&D head in the compensation survey and R&D expenditures in Compustat.

**Table 1 (Panel C): Ten Most Frequent Titles for Corporate R&D Head in Sample**

| Rank | Title |
|---|---|
| 1 | Vice President- Research and Development |
| 2 | Vice President- Technology |
| 3 | Vice President- Engineering |
| 4 | Senior Vice President- Technology |
| 5 | Senior Vice President- Research and Development |
| 6 | Director- Research and Development |
| 7 | Vice President- Science and Technology |
| 8 | Executive Vice President- Research and Development |
| 9 | Vice President- Research |
| 10 | Vice President – Corporate Technology |

**Table 2 (Panel A): Summary Statistics**
**Compensation of Corporate R&D Head, CEO, CFO, and Human Resources Head Positions**

| Variable | Mean | Std. Dev | Min | Max | Obs |
|---|---|---|---|---|---|
| **Corporate R&D Head** | | | | | |
| Salary+Bonus (constant 1996 $) | 380039 | 204768 | 99952 | 1969598 | 817 |
| ST incentive ratio (Bonus/(Salary+Bonus)) | 0.277 | 0.142 | 0.000 | 0.750 | 817 |
| LT incentive ratio (Long-Term Incentive/(Salary+Bonus)) | 0.592 | 0.521 | 0.000 | 5.034 | 817 |
| Total Compensation (constant 1996 $) | 641559 | 502934 | 99952 | 5267421 | 817 |
| **Chief Executive Officer (CEO)** | | | | | |
| Salary+Bonus (constant 1996 $) | 1390899 | 904192 | 361536 | 11100000 | 786 |
| ST incentive ratio (Bonus/(Salary+Bonus)) | 0.357 | 0.182 | 0.000 | 0.870 | 786 |
| LT incentive ratio (Long-Term Incentive/(Salary+Bonus)) | 0.989 | 0.911 | 0.000 | 11.027 | 786 |
| Total Compensation (constant 1996 $) | 2994476 | 3113832 | 364478 | 35600000 | 786 |
| **Chief Financial Officer (CFO)** | | | | | |
| Salary+Bonus (constant 1996 $) | 538340 | 290377 | 156142 | 3778934 | 674 |
| ST incentive ratio (Bonus/(Salary+Bonus)) | 0.305 | 0.158 | 0.000 | 0.795 | 674 |
| LT incentive ratio (Long-Term Incentive/(Salary+Bonus)) | 0.789 | 0.622 | 0.000 | 5.547 | 674 |
| Total Compensation (constant 1996 $) | 1011812 | 778089 | 173897 | 8378033 | 674 |
| **Human Resources Head (HRH)** | | | | | |
| Salary+Bonus (constant 1996 $) | 339366 | 162991 | 99698 | 1535105 | 722 |
| ST incentive ratio (Bonus/(Salary+Bonus)) | 0.272 | 0.141 | 0.000 | 0.703 | 722 |
| LT incentive ratio (Long-Term Incentive/(Salary+Bonus)) | 0.585 | 0.474 | 0.000 | 4.257 | 722 |
| Total Compensation (constant 1996 $) | 567935 | 405922 | 103922 | 3932550 | 722 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey and R&D expenditures in Compustat. Compensation variables are denominated in 1996 dollars. The value of long-term compensation is computed by Hewitt Associates. Stock options are valued using a modified version of Black-Scholes that takes into account vesting and termination provisions in addition to the standard variables of interest rates, stock price volatility, and dividends. As is standard practice among compensation consulting firms, the other components of long-term incentives (i.e., restricted stock, performance units and performance shares) are valued using an economic valuation similar to Black-Scholes that takes into account vesting, term provisions, and the probability of achieving performance goals.

**Table 2 (Panel B): Trends in Compensation**
**Corporate R&D Head, CEO, CFO and Human Resources Head Positions**

| | Corporate R&D Head | | | CEO | | | CFO | | | Human Resources Head (HRH) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Salary+ Bonus | LT Incentive Ratio | ST Incentive Ratio | Salary+ Bonus | LT Incentive Ratio | ST Incentive Ratio | Salary+ Bonus | LT Incentive Ratio | ST Incentive Ratio | Salary+ Bonus | LT Incentive Ratio | ST Incentive Ratio | Firm-years (N) |
| 1988 | 353661 | 0.387 | 0.278 | 1158623 | 0.637 | 0.341 | 510314 | 0.490 | 0.297 | 294477 | 0.355 | 0.270 | 50 |
| 1989 | 355525 | 0.380 | 0.253 | 1215221 | 0.605 | 0.314 | 516050 | 0.518 | 0.286 | 289417 | 0.349 | 0.245 | 51 |
| 1990 | 341902 | 0.455 | 0.222 | 1187175 | 0.738 | 0.296 | 483097 | 0.615 | 0.254 | 293616 | 0.423 | 0.226 | 56 |
| 1991 | 344507 | 0.568 | 0.218 | 1128942 | 0.810 | 0.271 | 441818 | 0.700 | 0.224 | 294977 | 0.509 | 0.210 | 62 |
| 1992 | 384016 | 0.524 | 0.262 | 1256524 | 0.848 | 0.319 | 485261 | 0.679 | 0.271 | 326281 | 0.501 | 0.246 | 66 |
| 1993 | 353783 | 0.600 | 0.231 | 1267873 | 0.851 | 0.318 | 503907 | 0.710 | 0.258 | 317149 | 0.549 | 0.229 | 72 |
| 1994 | 409573 | 0.610 | 0.321 | 1576426 | 0.911 | 0.416 | 581149 | 0.771 | 0.355 | 378858 | 0.550 | 0.316 | 62 |
| 1995 | 438664 | 0.696 | 0.339 | 1741238 | 1.215 | 0.446 | 602749 | 0.860 | 0.367 | 423784 | 0.700 | 0.340 | 54 |
| 1996 | 412076 | 0.822 | 0.307 | 1910300 | 1.517 | 0.422 | 638727 | 1.320 | 0.347 | 443626 | 1.040 | 0.334 | 52 |
| 1997 | 430593 | 0.872 | 0.328 | 1908689 | 1.747 | 0.442 | 619821 | 1.260 | 0.356 | 429787 | 0.976 | 0.326 | 48 |
| 1998 | 480092 | 0.868 | 0.345 | 2037057 | 1.677 | 0.444 | 726682 | 1.290 | 0.366 | 386705 | 0.800 | 0.305 | 39 |

Note: Sample includes firms that report both a corporate R&D head in the compensation survey for two consecutive years and R&D expenditures in Compustat. Compensation variables are denominated in 1996 dollars. The value of long-term compensation is computed by Hewitt Associates. Stock options are valued using a modified version of Black-Scholes that takes into account vesting and termination provisions in addition to the standard variables of interest rates, stock price volatility, and dividends. As is standard practice among compensation consulting firms, the other components of long-term incentives (i.e., restricted stock, performance units and performance shares) are valued using an economic valuation similar to Black-Scholes that takes into account vesting, term provisions, and the probability of achieving performance goals. LT incentive ratio is the ratio of long-term incentives, such as restricted stock and option grants, to salary and bonus. ST incentive ratio is the ratio of bonus to salary and bonus.

**Table 3: Summary Statistics--Sample Split by Organizational Structure of R&D—Centralized R&D vs. Decentralized R&D**

**I. Firm Variables--Sample Means and Medians**

| | Sales | R&D/Sales | Volatility | Direct Report to CEO | Sales | R&D/Sales | Volatility | Direct Report to CEO |
|---|---|---|---|---|---|---|---|---|
| | Mean | | | | Median | | | |
| Centralized R&D | 7556.07 | 0.044 | 9.02 | 0.42 | 3227.3 | 0.027 | 8.19 | 0 |
| Decentralized R&D | 16945.44 | 0.049 | 8.20 | 0.58 | 6125.95 | 0.039 | 7.60 | 1 |

**II. Pay Measures—Sample Means and Median**

| | Total Comp. 1996 $ | Bonus/ Cash | LT Comp./ Cash | Options/ Cash | Rest. Stock/ Cash | Total Comp. 1996 $ | Bonus/ Cash | LT Comp./ Cash | Options/ Cash | Rest. Stock/ Cash |
|---|---|---|---|---|---|---|---|---|---|---|
| **a. Corporate R&D Head** | | | | | | | | | | |
| | Mean | | | | | Median | | | | |
| Centralized R&D | 608329.1 | 0.266 | 0.590 | 0.433 | 0.052 | 493691.1 | 0.286 | 0.469 | 0.305 | 0 |
| Decentralized R&D | 697634.9 | 0.296 | 0.596 | 0.437 | 0.044 | 558679.5 | 0.305 | 0.479 | 0.324 | 0 |
| **b. Chief Executive Officer** | | | | | | | | | | |
| | Mean | | | | | Median | | | | |
| Centralized R&D | 2647631 | 0.343 | 0.974 | 0.714 | 0.097 | 1933995 | 0.392 | 0.758 | 0.455 | 0 |
| Decentralized R&D | 3117808 | 0.379 | 1.015 | 0.727 | 0.107 | 2161250 | 0.404 | 0.840 | 0.515 | 0 |

**III. Innovation Measures—Sample Means**

| | Patent Count | Mean of Citations | Median of Citations | Mean of Adj. Citations | Median of Adj. Citations | Mean of Generality | Mean of Originality | HHI for Firm | Publications | Firm-Years (N) |
|---|---|---|---|---|---|---|---|---|---|---|
| Centralized R&D | 82.88 | 4.66 | 3.25 | -0.69 | 0.60 | 0.28 | 0.42 | 0.30 | 94.43 | 513 |
| Decentralized R&D | 81.14 | 4.44 | 2.86 | -0.36 | 0.98 | 0.28 | 0.42 | 0.25 | 139.31 | 304 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat and 60 months of historical stock returns to calculate standard deviations. Volatility of Shareholder Returns is defined as the standard deviation of monthly returns (percentage) based on the previous 60 months. The sample is split into firms with a centralized R&D function vs. firms with decentralized R&D (i.e. firms with both a corporate R&D function and divisional R&D managers). Options/ Cash and Restricted Stock/ Cash are the ratios of the value of stock option grants and restricted stock to salary plus bonus, respectively. Patent Count is the number of patent awards. Mean and median of citations are based on citations through 1999 and are computed on a yearly basis. Adjusted citations control for the technology subclass, year of the award, and the location of the patentee. Original and generality are based on citation patterns (see text). HHI for firm is the Herfindahl Index of the firms' patent filings in each year across technology subclasses. Publications are the number of publications in Web of Science. See earlier tables for other variable definitions.

**Table 4a: Firm Innovation Measures and Corporate R&D Head (log) Total Compensation--Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Log (total comp.) for Corp RD Head | 0.249*** | 1.066** | 0.999*** | 1.124*** | 1.060*** | 0.010 | -0.015 | 0.045* | 0.130 |
| | (0.089) | (0.437) | (0.374) | (0.386) | (0.309) | (0.016) | (0.015) | (0.024) | (0.094) |
| Log (firm sales) | 0.638*** | -0.492* | -0.653*** | -0.552*** | -0.660*** | -0.006 | -0.000 | -0.075*** | 0.843*** |
| | (0.065) | (0.253) | (0.203) | (0.211) | (0.158) | (0.008) | (0.008) | (0.012) | (0.080) |
| R&D/firm sales | 8.047*** | 16.313*** | 5.275 | 6.825 | -3.478 | 0.457*** | 0.125 | -0.505** | 12.235*** |
| | (1.349) | (5.226) | (4.183) | (4.330) | (3.218) | (0.167) | (0.171) | (0.251) | (1.633) |
| Constant | -5.714*** | -1.963 | -1.585 | -8.882** | -9.027*** | 0.295 | 0.596*** | 0.320 | -6.963*** |
| | (1.069) | (5.006) | (4.235) | (4.380) | (3.464) | (0.181) | (0.175) | (0.269) | (1.163) |
| Observations | 457 | 457 | 457 | 457 | 457 | 433 | 457 | 457 | 486 |
| Number of Corp RD Heads | 177 | 177 | 177 | 177 | 177 | 170 | 177 | 177 | 175 |

**Table 4b: Firm Innovation Measures and Corporate R&D Head LT Incentive Ratio--Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for Corp RD Head | 0.171** | 0.908** | 0.820** | 0.773** | 0.578** | 0.030** | 0.019 | 0.010 | 0.069 |
| | (0.076) | (0.390) | (0.340) | (0.353) | (0.293) | (0.015) | (0.014) | (0.023) | (0.079) |
| Log (firm sales) | 0.685*** | -0.329 | -0.499*** | -0.361* | -0.455*** | -0.008 | -0.008 | -0.064*** | 0.871*** |
| | (0.061) | (0.227) | (0.181) | (0.191) | (0.143) | (0.007) | (0.007) | (0.011) | (0.076) |
| R&D/firm sales | 8.628*** | 18.593*** | 7.541* | 9.608** | -0.482 | 0.428*** | 0.023 | -0.341 | 12.499*** |
| | (1.320) | (4.957) | (3.932) | (4.143) | (3.085) | (0.155) | (0.162) | (0.240) | (1.618) |
| Constant | -2.988*** | 9.944*** | 9.590*** | 3.636** | 2.673** | 0.424*** | 0.454*** | 0.807*** | -5.565*** |
| | (0.515) | (1.942) | (1.551) | (1.632) | (1.230) | (0.062) | (0.064) | (0.096) | (0.644) |
| Observations | 457 | 457 | 457 | 457 | 457 | 433 | 457 | 457 | 486 |
| Number of Corp RD Heads | 177 | 177 | 177 | 177 | 177 | 170 | 177 | 177 | 175 |

**Table 4c: Firm Innovation Measures and Corporate R&D Head LT Incentive and ST Incentive Ratio--Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for Corp RD Head | 0.172** | 0.927** | 0.853** | 0.823** | 0.661** | 0.026* | 0.016 | 0.012 | 0.077 |
| | (0.076) | (0.392) | (0.342) | (0.354) | (0.292) | (0.015) | (0.014) | (0.023) | (0.079) |
| Bonus/(salary+bonus) for Corp RD Head | 0.042 | 0.682 | 1.106 | 1.530 | 2.318*** | -0.075* | -0.092** | 0.061 | 0.246 |
| | (0.211) | (1.132) | (1.008) | (1.040) | (0.883) | (0.045) | (0.042) | (0.069) | (0.220) |
| Log (firm sales) | 0.683*** | -0.356 | -0.541*** | -0.420** | -0.544*** | -0.005 | -0.004 | -0.067*** | 0.862*** |
| | (0.061) | (0.232) | (0.185) | (0.194) | (0.145) | (0.007) | (0.008) | (0.011) | (0.076) |
| R&D/firm sales | 8.625*** | 18.493*** | 7.351* | 9.351** | -0.907 | 0.445*** | 0.039 | -0.353 | 12.556*** |
| | (1.322) | (4.971) | (3.940) | (4.143) | (3.052) | (0.156) | (0.161) | (0.239) | (1.615) |
| Constant | -2.984*** | 9.975*** | 9.628*** | 3.688** | 2.743** | 0.420*** | 0.451*** | 0.809*** | -5.556*** |
| | (0.516) | (1.946) | (1.553) | (1.631) | (1.216) | (0.062) | (0.064) | (0.095) | (0.642) |
| Observations | 457 | 457 | 457 | 457 | 457 | 433 | 457 | 457 | 486 |
| Number of Corp RD Heads | 177 | 177 | 177 | 177 | 177 | 170 | 177 | 177 | 175 |

**Table 4d: Firm Innovation Measures and Corporate R&D Head LT Compensation Components (Stock Options & Restricted Stock)—Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Options/ (salary+bonus) for Corp RD Head | 0.182** | 0.741* | 0.722* | 0.580 | 0.388 | 0.025 | 0.004 | 0.007 | 0.119 |
| | (0.085) | (0.437) | (0.382) | (0.395) | (0.328) | (0.017) | (0.016) | (0.025) | (0.088) |
| Rest. Stock/ (salary+bonus) for Corp RD Head | -0.297 | 2.931*** | 2.386*** | 2.502*** | 1.793*** | 0.050 | 0.052 | 0.071 | -0.371 |
| | (0.211) | (0.933) | (0.782) | (0.817) | (0.657) | (0.033) | (0.033) | (0.051) | (0.239) |
| Log (firm sales) | 0.687*** | -0.245 | -0.429** | -0.283 | -0.391*** | -0.006 | -0.004 | -0.063*** | 0.869*** |
| | (0.061) | (0.223) | (0.177) | (0.187) | (0.139) | (0.007) | (0.007) | (0.011) | (0.075) |
| R&D/firm sales | 8.740*** | 18.041*** | 7.149* | 9.298** | -0.473 | 0.430*** | 0.041 | -0.354 | 12.595*** |
| | (1.329) | (4.916) | (3.896) | (4.115) | (3.072) | (0.157) | (0.163) | (0.241) | (1.616) |
| Constant | -2.982*** | 9.444*** | 9.159*** | 3.163** | 2.273* | 0.411*** | 0.436*** | 0.797*** | -5.556*** |
| | (0.517) | (1.917) | (1.529) | (1.612) | (1.216) | (0.062) | (0.064) | (0.095) | (0.641) |
| Observations | 456 | 456 | 456 | 456 | 456 | 432 | 456 | 456 | 485 |
| Number of Corp RD Heads | 177 | 177 | 177 | 177 | 177 | 170 | 177 | 177 | 175 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. The sample is only those firms with a centralized R&D organization (i.e. firms with a corporate R&D head, but no division R&D managers). Log (Patent Count) and Log (Publications) are defined as the logarithm of (one plus) the number of patents and publications. All regressions include unreported year fixed effects. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for variable definitions.

**Table 5a: Firm Innovation Measures and Corporate R&D Head (log) Total Compensation--Decentralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Log (total comp.) for Corp RD Head | 0.276** | -0.202 | -0.067 | -0.109 | 0.147 | -0.011 | -0.000 | 0.029 | -0.037 |
| | (0.118) | (0.469) | (0.324) | (0.417) | (0.251) | (0.019) | (0.018) | (0.029) | (0.145) |
| Log (firm sales) | 0.508*** | -0.092 | -0.000 | -0.157 | -0.116 | -0.004 | -0.005 | -0.052*** | 0.905*** |
| | (0.077) | (0.232) | (0.146) | (0.194) | (0.102) | (0.009) | (0.010) | (0.013) | (0.098) |
| R&D/firm sales | 4.888** | 13.770** | 4.465 | 3.401 | -5.634* | 0.432 | -0.587** | -0.004 | 9.159*** |
| | (2.084) | (6.663) | (4.231) | (5.603) | (3.043) | (0.263) | (0.274) | (0.372) | (2.606) |
| Constant | -4.698*** | 10.686** | 5.749 | 3.605 | -2.476 | 0.551** | 0.465** | 0.299 | -4.893*** |
| | (1.379) | (5.214) | (3.564) | (4.600) | (2.756) | (0.215) | (0.206) | (0.315) | (1.664) |
| Observations | 277 | 277 | 277 | 277 | 277 | 268 | 277 | 277 | 292 |
| Number of Corp RD Heads | 101 | 101 | 101 | 101 | 101 | 96 | 101 | 101 | 102 |

**Table 5b: Firm Innovation Measures and Corporate R&D Head LT Incentive Ratio--Decentralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for Corp RD Head | 0.070 | 0.005 | 0.116 | -0.187 | -0.136 | 0.004 | -0.008 | 0.017 | -0.010 |
| | (0.089) | (0.363) | (0.260) | (0.329) | (0.218) | (0.015) | (0.014) | (0.023) | (0.098) |
| Log (firm sales) | 0.580*** | -0.146 | -0.026 | -0.172 | -0.070 | -0.007 | -0.004 | -0.046*** | 0.895*** |
| | (0.070) | (0.197) | (0.119) | (0.160) | (0.080) | (0.008) | (0.008) | (0.010) | (0.088) |
| R&D/firm sales | 5.895*** | 12.768** | 3.867 | 3.202 | -4.559* | 0.377 | -0.577** | 0.113 | 9.013*** |
| | (2.054) | (6.281) | (3.904) | (5.191) | (2.722) | (0.248) | (0.261) | (0.343) | (2.553) |
| Constant | -1.827*** | 8.587*** | 5.078*** | 2.411 | -0.974 | 0.436*** | 0.459*** | 0.607*** | -5.266*** |
| | (0.644) | (1.833) | (1.127) | (1.502) | (0.782) | (0.072) | (0.077) | (0.099) | (0.804) |
| Observations | 277 | 277 | 277 | 277 | 277 | 268 | 277 | 277 | 292 |
| Number of Corp RD Heads | 101 | 101 | 101 | 101 | 101 | 96 | 101 | 101 | 102 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. The sample is only those firms with a decentralized R&D organization (i.e. firms with both a corporate R&D head and division R&D managers. Log (Patent Count) and Log (Publications) are defined as the logarithm of (one plus) the number of patents and publications. All regressions include unreported year fixed effects. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for variable definitions.

**Table 6a: Firm Innovation Measures and Corporate R&D Head (log) Total Compensation--Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)--Applications**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Log (total comp.) for Corp RD Head | 0.372*** | 2.398*** | 1.969*** | 2.017*** | 1.719*** | 0.024 | 0.008 | 0.069*** | 0.110 |
| | (0.101) | (0.595) | (0.491) | (0.510) | (0.396) | (0.021) | (0.016) | (0.027) | (0.119) |
| Log (firm sales) | 0.660*** | -0.672** | -0.863*** | -0.614** | -0.780*** | -0.017 | -0.007 | -0.089*** | 0.845*** |
| | (0.067) | (0.297) | (0.241) | (0.249) | (0.190) | (0.010) | (0.008) | (0.014) | (0.090) |
| R&D/firm sales | 7.177*** | 14.907** | 3.991 | 9.568* | -1.050 | 0.421** | -0.136 | -0.787*** | 13.812*** |
| | (1.446) | (5.979) | (4.869) | (5.046) | (3.883) | (0.207) | (0.173) | (0.279) | (1.966) |
| Constant | -7.551*** | -18.337*** | -13.277** | -20.914*** | -17.675*** | 0.191 | 0.386** | 0.154 | -6.869*** |
| | (1.187) | (6.692) | (5.513) | (5.721) | (4.431) | (0.231) | (0.179) | (0.298) | (1.429) |
| Observations | 384 | 304 | 304 | 304 | 304 | 304 | 384 | 384 | 378 |
| Number of Corp RD Heads | 160 | 139 | 139 | 139 | 139 | 139 | 160 | 160 | 154 |

**Table 6b: Firm Innovation Measures and Corporate R&D Head LT Incentive Ratio—Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)--Applications**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for | 0.181** | 2.216*** | 1.714*** | 1.781*** | 1.142*** | 0.041** | 0.010 | -0.002 | 0.020 |
| Corp RD Head | (0.090) | (0.576) | (0.484) | (0.505) | (0.409) | (0.020) | (0.015) | (0.026) | (0.100) |
| Log (firm sales) | 0.740*** | -0.320 | -0.558*** | -0.303 | -0.455*** | -0.016* | -0.006 | -0.069*** | 0.875*** |
| | (0.062) | (0.262) | (0.212) | (0.222) | (0.171) | (0.009) | (0.007) | (0.012) | (0.084) |
| R&D/firm sales | 8.390*** | 19.826*** | 8.348* | 13.841*** | 3.644 | 0.427** | -0.124 | -0.490* | 14.200*** |
| | (1.395) | (5.608) | (4.562) | (4.773) | (3.729) | (0.192) | (0.163) | (0.268) | (1.922) |
| Constant | -3.537*** | 8.632*** | 8.816*** | 1.711 | 1.297 | 0.475*** | 0.481*** | 0.874*** | -5.720*** |
| | (0.529) | (2.235) | (1.810) | (1.894) | (1.468) | (0.076) | (0.064) | (0.105) | (0.716) |
| Observations | 384 | 304 | 304 | 304 | 304 | 304 | 384 | 384 | 378 |
| Number of Corp RD Heads | 160 | 139 | 139 | 139 | 139 | 139 | 160 | 160 | 154 |

**Table 6c: Firm Innovation Measures and Corporate R&D Head LT Incentive and ST Incentive Ratio--Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)--Applications**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for | 0.204** | 2.300*** | 1.810*** | 1.851*** | 1.252*** | 0.040** | 0.011 | 0.010 | 0.041 |
| Corp RD Head | (0.091) | (0.582) | (0.487) | (0.510) | (0.408) | (0.020) | (0.015) | (0.026) | (0.101) |
| Bonus/(salary+bonus) for | 0.389* | 1.822 | 2.255 | 1.583 | 2.811** | -0.020 | 0.016 | 0.268*** | 0.318 |
| Corp RD Head | (0.226) | (1.627) | (1.397) | (1.461) | (1.202) | (0.055) | (0.042) | (0.072) | (0.246) |
| Log (firm sales) | 0.721*** | -0.387 | -0.640*** | -0.361 | -0.560*** | -0.015 | -0.006 | -0.080*** | 0.860*** |
| | (0.063) | (0.270) | (0.218) | (0.229) | (0.174) | (0.009) | (0.008) | (0.013) | (0.085) |
| R&D/firm sales | 8.341*** | 19.336*** | 7.798* | 13.446*** | 3.025 | 0.432** | -0.127 | -0.543** | 14.231*** |
| | (1.396) | (5.640) | (4.572) | (4.792) | (3.700) | (0.192) | (0.164) | (0.265) | (1.917) |
| Constant | -3.501*** | 8.655*** | 8.839*** | 1.733 | 1.360 | 0.475*** | 0.481*** | 0.887*** | -5.694*** |
| | (0.529) | (2.243) | (1.810) | (1.897) | (1.452) | (0.076) | (0.064) | (0.104) | (0.715) |
| Observations | 384 | 304 | 304 | 304 | 304 | 304 | 384 | 384 | 378 |
| Number of Corp RD Heads | 160 | 139 | 139 | 139 | 139 | 139 | 160 | 160 | 154 |

**Table 6d: Firm Innovation Measures and Corporate R&D Head LT Compensation Components (Stock Options and Restricted Stock) -- Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)--Applications**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Options/ (salary+bonus) for | 0.192* | 1.909*** | 1.533*** | 1.570*** | 1.092** | 0.032 | -0.013 | 0.010 | 0.046 |
| Corp RD Head | (0.101) | (0.677) | (0.565) | (0.593) | (0.476) | (0.023) | (0.017) | (0.030) | (0.111) |
| Rest. Stock/ (salary+bonus) for | -0.274 | 3.158*** | 2.592*** | 2.371** | 1.392* | 0.051 | 0.048 | -0.026 | -0.352 |
| Corp RD Head | (0.212) | (1.079) | (0.904) | (0.948) | (0.775) | (0.037) | (0.031) | (0.053) | (0.249) |
| Log (firm sales) | 0.743*** | -0.196 | -0.469** | -0.209 | -0.407** | -0.013 | -0.002 | -0.071*** | 0.874*** |
| | (0.062) | (0.260) | (0.209) | (0.221) | (0.170) | (0.009) | (0.007) | (0.012) | (0.084) |
| R&D/firm sales | 8.473*** | 19.844*** | 8.226* | 13.810*** | 3.446 | 0.435** | -0.085 | -0.512* | 14.277*** |
| | (1.405) | (5.647) | (4.579) | (4.822) | (3.770) | (0.194) | (0.166) | (0.270) | (1.918) |
| Constant | -3.536*** | 7.977*** | 8.355*** | 1.218 | 1.064 | 0.462*** | 0.461*** | 0.885*** | -5.719*** |
| | (0.531) | (2.231) | (1.800) | (1.897) | (1.471) | (0.077) | (0.064) | (0.105) | (0.713) |
| Observations | 383 | 303 | 303 | 303 | 303 | 303 | 383 | 383 | 377 |
| No. of Corp RD Heads | 160 | 139 | 139 | 139 | 139 | 139 | 160 | 160 | 154 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. The sample is only those firms with a centralized R&D organization (i.e. firms with a corporate R&D head, but no division R&D managers). Log (Patent Count) and Log (Publications) are defined as the logarithm of (one plus) the number of patents and publications. All regressions include unreported year fixed effects. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for variable definitions.

**Table 7a: Firm Innovation Measures and Corporate R&D Head LT Incentive Ratio and Reporting Relationship to CEO**
**Centralized R&D Sample**
**Random Effects Specification (Corp RD Head Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| Direct Report to CEO | 0.069 | 0.417 | 0.693 | 0.300 | 0.624 | 0.022 | 0.024 | -0.006 | -0.120 |
| | (0.096) | (0.502) | (0.447) | (0.459) | (0.393) | (0.020) | (0.019) | (0.031) | (0.097) |
| LT comp./ (salary+bonus) for Corp RD Head | 0.064 | 1.181** | 1.050** | 0.994* | 0.805* | 0.038 | 0.027 | 0.015 | 0.007 |
| | (0.110) | (0.587) | (0.527) | (0.540) | (0.469) | (0.024) | (0.022) | (0.036) | (0.105) |
| LT comp./ (salary+bonus) for Corp RD Head*Direct Report to CEO | 0.170 | -0.533 | -0.523 | -0.447 | -0.497 | -0.019 | -0.017 | -0.007 | 0.131 |
| | (0.137) | (0.707) | (0.627) | (0.644) | (0.550) | (0.028) | (0.026) | (0.043) | (0.122) |
| Log (firm sales) | 0.696*** | -0.251 | -0.445** | -0.299 | -0.418*** | -0.006 | -0.007 | -0.064*** | 0.870*** |
| | (0.061) | (0.220) | (0.178) | (0.185) | (0.141) | (0.007) | (0.007) | (0.011) | (0.076) |
| R&D/firm sales | 8.540*** | 18.793*** | 7.411* | 9.813** | -0.632 | 0.427*** | 0.011 | -0.328 | 12.685*** |
| | (1.315) | (4.801) | (3.880) | (4.019) | (3.068) | (0.155) | (0.162) | (0.243) | (1.611) |
| Constant | -3.057*** | 9.041*** | 8.875*** | 2.923* | 2.120* | 0.402*** | 0.441*** | 0.808*** | -5.502*** |
| | (0.519) | (1.907) | (1.553) | (1.608) | (1.244) | (0.063) | (0.065) | (0.098) | (0.647) |
| Observations | 455 | 455 | 455 | 455 | 455 | 431 | 455 | 455 | 483 |
| Number of Corp RD Heads | 176 | 176 | 176 | 176 | 176 | 169 | 176 | 176 | 174 |

**Table 7b: Firm Innovation Measures and Chief Financial Officer (CFO) LT Incentive Ratio--Centralized R&D Sample**
**Random Effects Specification (Firm Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for CFO | 0.123* | -0.303 | -0.262 | -0.380 | -0.344 | -0.002 | 0.003 | -0.005 | -0.007 |
| | (0.065) | (0.312) | (0.274) | (0.294) | (0.255) | (0.013) | (0.012) | (0.019) | (0.064) |
| Log (firm sales) | 0.534*** | -0.211 | -0.309 | -0.197 | -0.255 | -0.000 | -0.011 | -0.066*** | 0.892*** |
| | (0.079) | (0.281) | (0.226) | (0.238) | (0.179) | (0.010) | (0.010) | (0.015) | (0.094) |
| R&D/firm sales | 8.639*** | 16.351*** | 7.514* | 10.024** | 1.321 | 0.423** | 0.006 | -0.287 | 12.010*** |
| | (1.546) | (5.480) | (4.409) | (4.633) | (3.487) | (0.184) | (0.191) | (0.299) | (1.832) |
| Constant | -1.782*** | 9.525*** | 8.251*** | 2.815 | 1.315 | 0.380*** | 0.488*** | 0.814*** | -5.618*** |
| | (0.661) | (2.379) | (1.922) | (2.022) | (1.530) | (0.082) | (0.083) | (0.131) | (0.790) |
| Observations | 371 | 371 | 371 | 371 | 371 | 348 | 371 | 371 | 395 |
| Number of firms | 105 | 105 | 105 | 105 | 105 | 101 | 105 | 105 | 101 |

**Table 7c: Firm Innovation Measures and Human Resources Head (HRH) LT Incentive Ratio--Centralized R&D Sample**
**Random Effects Specification (Firm Random Effects)**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for HRH | 0.029 | -0.063 | -0.059 | -0.010 | -0.063 | -0.006 | 0.023 | -0.007 | 0.065 |
| | (0.082) | (0.394) | (0.344) | (0.368) | (0.314) | (0.015) | (0.014) | (0.023) | (0.079) |
| Log (firm sales) | 0.602*** | -0.629** | -0.621*** | -0.541** | -0.524*** | -0.008 | -0.011 | -0.059*** | 0.985*** |
| | (0.074) | (0.267) | (0.216) | (0.224) | (0.172) | (0.009) | (0.009) | (0.014) | (0.087) |
| R&D/firm sales | 8.436*** | 15.082*** | 7.197 | 8.643* | 0.529 | 0.442** | 0.020 | -0.138 | 11.420*** |
| | (1.598) | (5.634) | (4.543) | (4.715) | (3.602) | (0.182) | (0.194) | (0.292) | (1.889) |
| Constant | -2.209*** | 12.554*** | 10.739*** | 5.138*** | 3.325** | 0.428*** | 0.469*** | 0.748*** | -6.362*** |
| | (0.620) | (2.247) | (1.822) | (1.895) | (1.457) | (0.074) | (0.077) | (0.118) | (0.730) |
| Observations | 408 | 408 | 408 | 408 | 408 | 387 | 408 | 408 | 437 |
| Number of firms | 110 | 110 | 110 | 110 | 110 | 107 | 110 | 110 | 108 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. The sample is only those firms with a centralized R&D organization (i.e. firms with a corporate R&D head, but no division R&D managers). Direct Report to CEO is a dummy variable that equals one if the Corporate R&D Head reports directly to the CEO in the organizational hierarchy and zero otherwise. Log (Patent Count) and Log (Publications) are defined as the logarithm of (one plus) the number of patents and publications. All regressions include unreported year fixed effects. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for other variable definitions.

**Table 8: Firm Innovation Measures and Corporate R&D Head LT Incentive Ratio--Centralized R&D Sample**
**2SLS Random Effects Specification (Corp RD Head Random Effects)**
**Instrument is number of spawned firms in county of headquarters per year excluding own firm and firms in own 2-digit industry**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Log (Patent Count) | Mean of Citations | Median of Citations | Mean of Adjusted Citations | Median of Adjusted Citations | Mean of Generality | Mean of Originality | HHI for Firm | Log (Publications) |
| LT comp./ (salary+bonus) for Corp RD Head | -0.198 | 6.825** | 5.754** | 3.500* | 1.605 | 0.044 | -0.295** | -0.157 | 0.076 |
| | (0.779) | (2.695) | (2.719) | (2.086) | (1.672) | (0.137) | (0.127) | (0.266) | (2.766) |
| Log (firm sales) | 0.763*** | -1.135** | -1.250*** | -0.713** | -0.628** | -0.011 | 0.031 | -0.038 | 0.772* |
| | (0.132) | (0.458) | (0.476) | (0.354) | (0.284) | (0.023) | (0.022) | (0.044) | (0.408) |
| R&D/firm sales | 15.843*** | 16.169** | 2.083 | 8.605 | -1.989 | 0.666** | 0.784** | -0.219 | 10.325*** |
| | (2.237) | (7.745) | (7.580) | (5.994) | (4.806) | (0.330) | (0.365) | (0.598) | (2.188) |
| Constant | -3.685*** | 13.572*** | 13.189*** | 5.003** | 3.306* | 0.422*** | 0.240* | 0.677*** | -4.544** |
| | (0.862) | (2.985) | (3.028) | (2.310) | (1.852) | (0.138) | (0.141) | (0.260) | (1.990) |
| Observations | 431 | 431 | 431 | 431 | 431 | 407 | 431 | 431 | 459 |
| Number of Corp RD Heads | 164 | 164 | 164 | 164 | 164 | 157 | 164 | 164 | 161 |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. The sample is only those firms with a centralized R&D organization (i.e. firms with a corporate R&D head, but no division R&D managers). Log (Patent Count) and Log (Publications) are defined as the logarithm of (one plus) the number of patents and publications. All regressions include unreported year fixed effects. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for other variable definitions.

**Table 9: Pay-Performance Sensitivities Based on Measures of Total Compensation for Corporate R&D Head Positions**
**Firm Fixed Effects Regressions**

| | | Sample Partition by R&D Organization | | Sample Partition by R&D Intensity | |
|---|---|---|---|---|---|
| | Whole Sample | Centralized R&D | Decentralized R&D | High R&D | Low R&D |
| **Shareholder Returns excluding dividends** | | | | | |
| Stock Return | 2.488*** | 3.110*** | 1.352 | 2.778** | -2.099 |
| | (0.964) | (1.092) | (1.776) | (1.414) | (1.412) |
| Stock Return*CDF of Std. Deviation | -2.489*** | -3.148*** | -0.499 | -2.817** | 6.374*** |
| | (0.972) | (1.098) | (2.687) | (1.421) | (1.853) |
| CDF of Std. Deviation | 373.09*** | 523.47*** | 248.77 | 423.99*** | -41.10*** |
| | (108.33) | (140.60) | (157.89) | (162.00) | (152.56) |
| **Shareholder Returns including dividends** | | | | | |
| Stock Return | 2.825*** | 3.416*** | 3.214* | 3.756*** | -0.054 |
| | (1.122) | (1.299) | (1.925) | (1.620) | (1.666) |
| Stock Return*CDF of Std. Deviation | -2.312* | -3.386** | -2.781 | -3.807** | 2.361 |
| | (1.385) | (1.542) | (2.910) | (1.898) | (2.348) |
| CDF of Std.Deviation | 392.58*** | 521.67*** | 160.88 | 548.42*** | 98.72 |
| | (112.54) | (139.46) | (173.71) | (169.62) | (149.95) |

Note: Sample includes firms that report a corporate R&D head in the compensation survey, R&D expenditures in Compustat, and 60 months of historical stock returns to calculate standard deviations. Centralized R&D sub-sample includes firms that report corporate R&D heads, while decentralized R&D sub-sample includes firms that report both corporate R&D heads and division R&D managers. High R&D sub-sample includes firms with ratio of R&D to sales above the sample median, while low R&D includes those below the sample median. The dependent variable is total flow compensation for the corporate R&D head: salary, bonus and the value of long-term incentives (including stock options, restricted stock, performance unit plans and performance share plans). Stock returns are measured as annual shareholder returns (excluding dividends) and annual total shareholder returns (average of monthly returns), both stated in percentage points. CDF of Std. Deviation represents the empirical cumulative distribution function of the standard deviation of monthly % returns over prior 60 months. Each regression includes firm and year indicators. ***/**/* represent significance at the 1%/5%/10% level. See earlier tables/text for other variable definitions.

**Appendix A: Survey Representativeness**

We evaluate the representativeness of Hewitt survey participants by comparing key financial measures of the survey participants to a matched sample from Compustat. We begin by matching each firm in the Hewitt dataset to the Compustat firm that is closest in sales within its two-digit SIC industry in the year the firm joins the sample. We then perform Wilcoxon signed rank tests to compare the Hewitt firms with the matched firms. While the firms in the Hewitt dataset are, on average, slightly larger in sales than the matched sample, we found no statistically significant difference in employment and profitability (return on sales).[22] We also found no statistically significant difference in sales growth, employment growth, or annual changes in profitability for all sample years. In sum, while the Hewitt firms are larger (measured by sales) on average than the matched sample, there is little additional evidence that these firms are not representative of the population of industrial firms that are leaders in their sectors.

We also calculate financial measures for the sample of Compustat firms with 10,000 employees or greater over the period from 1987 to 1998 (excluding firms operating in financial services). We find that, on average, survey participants are more profitable, but growing at a slower rate relative to the sample of large Compustat firms. Specifically, the sample average return on sales for survey participants is 17.8% versus 15.7% for the sample of large Compustat firms and the average sales growth is 5.7% vs. 7.4%. This is consistent with the observation that the firms in the sample are likely to be industry leaders (hence slightly more profitable) and also large (hence the slightly slower

[22]The Hewitt firms are larger in sales than the matched sample of firms because in a number of the cases, the Hewitt firm is the largest firm in the industry thus forcing me to select a matched firm smaller in size.

growth). To sum up, the survey sample is probably most representative of Fortune 500 firms.

**Appendix B: Position Descriptions from Hewitt Survey**

1. Chief Executive Officer (CEO). The highest executive authority in the corporation. Reports to the Board of Directors. May also be Chairman or President.

Research and Development Positions:

2. Corporate Level Research and Development (Corporate R&D Head). Responsible for applied research and development and design and development engineering for the entire corporation. Oversees and directs R&D activities of the corporation leading to new or improved products or processes. Provides technical assistance and, when necessary, correlates research activities with other functions and operating units.

3. Division Level Research and Development. The head of all applied R&D and design and development engineering for the division. Responsibilities include investigation and experimentation aimed at practical applications of scientific theories, as well as the application of existing engineering and scientific theories and techniques to the design and development of new products.

4. Principal Scientist. Top R&D technical position, responsible for research leadership in creating or improving products or processes. Originates and coordinates research projects, evaluates results, and makes recommendations to senior management. This is the top position on the technical (non-managerial) career ladder within R&D and may be equivalent to the R&D Director in terms of level.

Senior Staff Positions:

5. Human Resources Head (HRH). Head of all human resources with responsibility for establishing and implementing corporate-wide policies.

6. Chief Financial Officer (CFO). Functional head responsible for all financial operations of the corporation. Has responsibility for both the treasury and accounting functions. Indicate whether responsibilities also include data processing, investor relations, internal audit, and tax.