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 associated with more patent filings and patents of greater originality. Short-term incentives appear to be unrelated to measures of innovation.

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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 takes an initial step in addressing this gap, by seeking to understand the association between shifts in performance pay given to central corporate research executives and the innovation process.

The central corporate R&D laboratory was a dominant feature of the innovation landscape for most of the 20th 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, corporations began fundamentally rethinking the role of these centralized research facilities (see Rosenbloom and Spencer [1996]). Reflecting both a perception of disappointing commercial returns and intensified competitive pressures, firms deemphasized central research facilities in favor of divisional laboratories and linked the compensation of central research personnel more closely to the economic objectives of the corporation.[1]

We address two research questions in this paper: First, how has performance pay of corporate R&D executives changed over the 1990s? Second, are these changes related to R&D productivity and the innovation of firms? Since one of the most important roles

[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 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).

of corporate R&D heads is to allocate funds across projects and the R&D executive has better information about project potential than others, pay linked to firm performance should mitigate incentives to make decisions that increase private benefits at the expense of shareholders, such as funding of "pet projects" or showing favoritism to select labs. Since decisions by R&D executives affect outcomes with a considerable lag, long-term incentives should play a larger role in aligning interests with those of shareholders.

This paper examines the relationship between innovation and the shifting compensation of the managers responsible for corporate research and development. First, we document 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 expected value of long-term incentives to expected total compensation for corporate R&D heads has increased by more than 50% over the period from 1988 to 1998 with the expected value of long-term incentives (in 1996 dollars) almost tripling. These shifts are not unique to corporate R&D managers and mirror similar shifts in senior management compensation more broadly.[2]

Next, we turn to understanding the relationship between compensation and innovation. Among firms with a centralized R&D organization, a clear relationship emerges: more long-term incentives granted to corporate R&D heads are associated with more heavily cited patents. These incentives also appear to be associated with more frequent awards and patents of greater originality. We find little association between short-term incentives for corporate R&D heads and innovation.

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

In order to address concerns about spurious correlations driven by unobserved firm heterogeneity, we examine the relationship between innovation and corporate R&D head incentives using compensation of other corporate executives as a control. We focus on three corporate executives who are unlikely to be directly involved in the innovation process: the chief financial officer (CFO), the human resources head (HRH) and the chief executive officer (CEO). When we control for incentives granted to these positions, we continue to find an association between innovation and R&D executive incentives, suggesting it is the compensation of the research head that is critical in this regard.

In contrast to centralized R&D organizations, we find little association between corporate R&D head long-term incentives and innovation measures in firms with decentralized organizations. This is consistent with our interpretation that corporate R&D heads in centralized organizations—i.e., firms that conduct research only at the corporate level—have greater influence over R&D decisions relative to those in decentralized organizations.

Several caveats are in order. First, while we document that stronger incentives are associated with more innovations, we cannot distinguish whether the effect of performance pay is due to better decisions about project funding or due to selection effects of attracting more innovative R&D managers that in turn foster innovation. While it would be interesting to disentangle these, our data are not sufficient to do so. We do not attempt to establish causality and instead present a set of interesting correlations that are consistent with multiple theories.

Second, in equilibrium, firms should offer the optimal level of incentives. In actuality, this was a time of considerable flux. More generally, 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."[3]

This paper is related to three sets of work. First are papers on incentive compensation. Jensen [1993] argues for higher-powered incentives within corporate research facilities, while the line of work beginning with Holmstrom [1989] warns that the addition of high-powered incentives in an R&D setting could lead to a "multi-tasking" problem. Moreover, the effect of different types of performance pay may differ. Smith and Stulz [1985], Hirshleifer and Suh [1992], and others suggest that compensation in the form of option holdings will lead managers to riskier behavior, but 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.

Second, a number of articles, particularly in the accounting literature, have sought to relate R&D choices to the incentives of top management. Most notably, 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 (see also Dechow and Sloan [1991] and Eng and Shackell [2001]).

The final body of work relates the organizational structure of R&D to innovation. Cockburn, Henderson, and Stern [1999] examine research workers' incentives for basic and applied research. They suggest that when incentives are strong along one dimension,

[3]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. This was particularly true in the period under study, which saw skilled R&D managers gain more bargaining power and a strengthening of the effectiveness of property rights over innovations.

firms will offer high-powered incentives along other dimensions that compete for the worker's effort and attention. They find that firms who promote individuals based on scientific publications also provide more incentives for success in applied research. Argyres and Silverman [2004] find that firms with centralized R&D organizations generate innovations that are more frequently and broadly cited than do firms with decentralized R&D organizations.[4] But to our knowledge, the changes in pay for corporate R&D executives and the positive association between long-term incentives and innovation have not been documented elsewhere.

The plan of this paper is as follows. Section 2 describes the data. In Section 3, we present the key 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 cross-industry panel of more than 300 publicly traded U.S. firms over the years 1987 to 1998. 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 leaders in their sectors. More than 75% of the firms in the dataset are listed as Fortune

[4] Guedj and Scharfstein [2004], 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. Consistent with agency problems between single-product firm managers and their investors, this pattern is pronounced in firms with large cash reserves.

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 clients. Based on several analyses described in Appendix A, we conclude that the survey sample is probably most representative of Fortune 500 firms.

The survey collects detailed compensation data for 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.[5]

The data for each position include all components of compensation including salary, actual bonus, and grants of 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 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.

[5]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.

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 700 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 Chief Financial Officer (CFO), the Human Resources Head (HRH) and the Chief Executive Officer (CEO) 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 an 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.[6]

The above data are supplemented with financial information from Compustat. While the Hewitt survey is conducted in April of each year and the compensation data

[6] There may be incentives for survey participants to misreport pay data in their survey responses for positions other than those reported in proxy statements. However, several facts offset the likelihood of this practice. First, for Hewitt clients, pay comparisons between the client and survey averages (excluding the client data) are provided to the board of directors making it less likely that clients would misreport their own pay. Second, these surveys are completed by the firm's compensation analyst and it would require a significant amount of internal coordination among several managers to intentionally misreport.

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 data using the year prior to the year of the survey.

In 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 and a ratio of R&D expense to sales of approximately 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). We classify firms with both corporate and divisional R&D managers as firms with a hybrid (or decentralized) R&D organization. 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.

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 three most frequently represented titles are Vice President-Research and Development, Vice President-Technology, and Vice President-Engineering. These titles are consistent with individuals 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). 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:[7]

- The number of awards to the firm in a given year.
- The mean number of citations to the firm's patents awarded in a given year.
- The "originality" 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 citations made by the patent to earlier awards. Thus, a patent with an originality score approaching zero suggests that the patent draws on a narrow array of patents, while a measure of one suggests it builds on a diverse array of patents. We compute the mean of the originality measure for all patents awarded to each firm in every year.[8]

One challenging issue has to do with the timing of patent awards and R&D expenditures. The economics literature has argued that patent applications are generated

[7] We also collect the median number of citations to the firm's patents awarded, the mean and median number of "adjusted citations" to the firm's patents awarded, the "generality" of the firm's awards, the extent of concentration of a firm's awards, and the number of publications by authors associated with each firm through the use of the Web of Science database. See discussion in Section 3.3 for more detailed definitions and a summary of relevant findings.

[8] 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 technological classifications (see Lerner [1994] for a discussion).

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 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.[10]

Importantly, given the complexity of the timing issues and the fact that the effect of compensation in fostering innovation occurs over long periods, we exploit cross-sectional variation in an empirical specification based on executive-level averages. We describe the details of this specification in Section 3. 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., the corporate R&D head). We document each

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

[10] It might be wondered why we do not instead employ applications. 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. Until the end of the period under study, the U.S. Patent and Trademark Office only published issued patents, not applications. Since our compensation data begin in 1987, 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. While the use of awards will introduce noise into the analysis, the approach should not raise concerns about systematic biases.

[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 2, only employing compensation data between 1988 and 1995 in the citation regressions. The results are little changed.

component of pay: salary, bonus, and expected 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] As mentioned earlier, we are particularly interested in long-term compensation because outcomes associated with decisions made by corporate R&D heads can only be observed with a considerable lag. The delay between most actions and outcomes is arguably shorter for other executives, e.g., those responsible for manufacturing, marketing and sales. Payoffs associated with investing in innovation are not likely to be realized immediately.

We 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 expected value of long-term compensation to expected total compensation. Short-term incentives are typically provided through bonus plans which are linked to annual performance, while long-term incentives are commonly associated with equity-based pay (i.e. stock options and restricted stock) that is subject to vesting restrictions. 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 expected value of stock options to total compensation and the ratio of the expected value of restricted stock to total compensation. Finally, as a measure of short-term incentives, we analyze the fraction of

[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, termination provisions, and the probability of achieving performance goals.

[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 (Core and Guay [1999]; Baker and Hall [2004]). To partially address this issue, our econometric specification uses executive-level averages. That is, we average executive observations over the period and analyze variation across corporate R&D heads.

total compensation from annual bonus payouts.

In Table 1, we report summary statistics of several pay measures for the corporate R&D head, the CFO, the HRH, and the CEO position. Compensation variables are denominated in 1996 dollars. Sample averages for the corporate R&D head for total compensation and the ratio of expected long-term compensation to total compensation (long-term incentive ratio) are $623,265 and 32.0%, respectively. Comparable sample averages for total compensation and the long-term incentive ratio for the CFO, HRH and CEO are $964,231 and 38.3%, $551,487 and 32.0%, and $2,820,811 and 42.2%, respectively. Consistent with the findings of the CEO literature, long-term compensation comprises a greater proportion of CEO pay relative to corporate R&D, CFO, and HRH positions. The long-term incentive ratio for the CEO, on average, is more than 30% greater than that for the corporate R&D head and HRH positions and 10% greater than that for the CFO position.

The ratio of long-term compensation to total 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, the ratio of the value of long-term incentives to total compensation for corporate R&D heads, on average, has increased by more than 50% over the period from 1988 to 1998 from 25.8 % to 41.1 %.[14]

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

[14] These statistics across years are based on the sample of 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.

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.

It might be anticipated that offering long-term incentives to the corporate R&D head would have a stronger association with innovation 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.

3. Econometric Specification and Results

3.1. Specification

Regressions reported in Tables 2 through 5 are based on innovation and compensation measures averaged at the corporate R&D executive-level.[15] That is, we average executive observations over the period and analyze variation between corporate R&D heads. There are several advantages to using averages. First, it addresses concerns about the timing challenges in matching R&D expenditures, compensation and innovation measures, and the fact that the effect of compensation on innovation occurs at long frequencies. Second, most of the variation is in the cross-section. Finally, taking

[15]We determine turnover of the corporate R&D head from the Hewitt data.

averages reduces measurement error from the use of flow compensation as a proxy for incentives since we are limited to annual grants of stock options and restricted stock.

In all of the reported tables, we estimate OLS regressions and report robust standard errors. Since we do not have a balanced panel, each regression includes averages of year effects to identify the years that the executive appears in the sample. We use executive-level averages instead of firm-level averages because the use of firm-level averages would throw away executive-specific information that may be important to the relationship between innovation and compensation. Consistent with this, our results are qualitatively similar when using firm-level averages, but the estimated coefficients are less precise.

3.2. Results

In Table 2, we analyze the relationship between citations and compensation of the corporate R&D head for the sub-sample of firms that have a centralized R&D organization. We start with a parsimonious regression and add additional controls across the columns. The dependent variable in all models is the mean number of citations to the firm's patents awarded in a given year averaged by R&D executive. In column (1), we regress citations on the ratio of long-term incentives to total compensation for the corporate R&D head and find that the coefficient is positive and statistically significant. It is also economically significant. A one-standard deviation increase in the long-term incentive ratio is associated with an increase of 1.27 mean citations for the firm, which is 25.9 % of the sample mean.

In columns (2) and (3), we include additional control variables. First, we add the logarithm of firm sales (denominated in 1996 dollars) and research intensity (the ratio of

the firms' R&D to sales). Subsequently, we add a measure of the firm's degree of diversification.[16] The closer this index is to one, the more focused are the business operations of the firm. In both columns, we find that the coefficient on the long-term incentive ratio remains statistically significant and is relatively stable in terms of magnitude. Also, the coefficient on the concentration index is positive and statistically significant, suggesting that .business focus is associated with more heavily cited patents.

In columns (4) through (6), we include additional measures of incentives: the short-term incentive ratio defined as bonus divided by total compensation, and total compensation (denominated in millions of 1996 dollars). The coefficient on each of these measures is not statistically significant. While the coefficient on the long-term incentive ratio declines in magnitude when controlling for total compensation, it remains statistically and economically significant. Using the estimate in column (6), a one-standard deviation increase in the long-term incentive ratio is associated with an increase in mean citations for the firm that is 20.1 % of the sample mean. In column (7), in place of the long-term incentive ratio, we include the expected value of stock options as a fraction of total compensation and the expected value of restricted stock as a fraction of total compensation. We find that the coefficient on restricted stock is larger than that on stock options. A one-standard deviation increase in stock options is associated with an increase of 0.93 mean citations for the firm, which is 18.8 % of the sample mean. For restricted stock, the associated increase is 14.6 % of the sample mean.

Since our regressions are cross-sectional, one concern is that our results are driven by unobserved firm heterogeneity and that the long-term incentive ratio is a proxy for an

[16] This concentration measure is defined as the sum of squared share of sales for each of the business segments in a firm-year.

omitted firm characteristic. The results in Table 2 demonstrate that as we include additional covariates, the magnitude of the coefficient on the long-term incentive ratio is quite stable. It is not surprising that the estimate of this coefficient declines when we include total compensation (columns (5) and (6)) because the long-term incentive ratio and total compensation are highly correlated. The relatively stable coefficient on long-term incentives across the columns in Table 2 suggests that our results are not driven by an omitted characteristic.

In Table 3, we evaluate the robustness of the relationship between long-term incentives for the corporate R&D head and innovation using two additional measures of innovation: patent awards and the originality of the patents. In each case, we average by R&D executive and repeat select models from Table 2. In columns (1) through (4), we define the innovation measure as the logarithm of (one plus) the number of patents for the firm.[17] In the first three columns, we find a positive coefficient on the long-term incentive ratio for the corporate R&D head and the magnitude of the coefficient is relatively stable across the columns. Using the estimates from column (3), a one-standard deviation increase in the fraction of total pay in long-term incentives is associate with a 22.8 % increase in patent count. As earlier, the coefficient on the short-term incentive ratio is negative and insignificant. In column (4), when we include both short-term and long-term ratios and total compensation, the coefficient on long-term incentives is no longer significant and the magnitude is smaller.

We use the originality measure as a proxy for innovation in regressions reported in columns (5) through (8). As a reminder, a patent with an originality score approaching

[17]Due to the skewed distributions of the number of patents (as documented in Jaffe and Trajtenberg [2002], we employ the logarithm of (one plus) these measures as dependent variables. The results are robust in a negative binomial regression using the average of patent count as the dependent variable.

zero suggests that the patent draws on a narrow array of patents, while a measure of one suggests it builds on a diverse array of patents. In all models, we find a positive coefficient on the long-term incentive ratio for the corporate R&D head. The magnitudes of the coefficient range from 0.131 to 0.249. Using the estimates from column (8), a one-standard deviation increase in the fraction of total pay in long-term incentives is associated with a 0.03 increase in the originality score, which is 7.1 % of the sample mean.

To sum up the results in Tables 2 and 3, we find that long-term incentives for the corporate R&D head are associated with more heavily cited patents, more patent awards, and patents with greater originality in the sample of firms with centralized R&D organizations. Short-term incentives appear to have little impact. The long-term incentive appears to work through both stock options and restricted stock. The magnitudes of the effects are economically important and our findings are generally robust to the inclusion of various control measures including firm size, research intensity, degree of diversification, and total compensation.

3.3. Robustness Checks

We undertake several robustness checks of the results. Table 4 is an example of the additional analyses we perform. We repeat the analysis of Table 2 using the centralized R&D sample, but evaluate whether the positive association between citations and long-term incentives of corporate R&D heads is robust to the inclusion of incentives provided to other key executives that are not directly involved in the innovation process: the Chief Financial Officer (CFO), the Human Resources Head (HRH), and the Chief Executive Officer (CEO). If our findings are just spurious correlations driven by

unobserved firm heterogeneity, then we might expect to find that our results are not robust when we control for incentives offered to other executive positions. Or, we might find a positive association between incentives of the control group and innovation.

In Table 4, we report select regressions from Table 2, but include the firm-level average of the long-term incentive ratio for three executive positions: in the first two columns, we include the average of the CFO ratio; in the second two columns, the HRH ratio; and, in the last two columns, the CEO ratio. We find that the long-term incentive ratio for the corporate R&D head is positive and statistically significant in all models. The magnitudes of the estimated coefficients are generally consistent with those estimated in Table 2, with the exception of a larger estimate in columns (3) and (4) when we include the long-term incentive ratio for the Human Resources executive.

Importantly, the uniqueness and robustness 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. While all of these positions also receive long-term incentive compensation (see Table 1), it is only the R&D head's long-term incentive ratio that is positively related to innovation. These results support our interpretation of the findings.

As mentioned earlier, it might be anticipated that long-term incentives for corporate R&D executives may have differential effects in firms with different organizational structures for R&D. In centralized R&D organizations that only conduct research and development at the corporate level, the corporate R&D head has greater firm-wide authority over R&D decisions in comparison to firms with decentralized R&D organizations. We might expect the relationship between incentives for corporate R&D

heads and innovation to be stronger in centralized firms. In Table 5, we analyze the subset of firms with a hybrid (or decentralized) R&D organization. That is, firms that report both corporate and division R&D managers and conduct research at both the corporate and divisional levels. We repeat select specifications from Table 2, and find no relation between citations and long-term incentives of corporate R&D heads. One simple explanation is that there is no relation between incentives of R&D managers and innovation in decentralized organizations. Another more plausible explanation is that the influence of the corporate R&D head on the allocation of R&D funding and innovation is limited in decentralized R&D organizations and the importance of analyzing incentives for divisional R&D managers becomes critical. We plan to pursue this in follow-on work.

We also undertake a variety of unreported robustness checks. 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. More long-term incentives are associated with more patenting, more citations, and more original awards. The results continue to hold when we control for short-term and total compensation. 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.

As mentioned earlier, we also collect data on additional measures of innovation and evaluate the association between incentive compensation and these other measures (unreported). Using innovation and compensation measures averaged at the executive-level, we find a positive association between long-term incentives and three additional

measures of citations: the median number of citations, the mean and median number of adjusted citations to the firm's patents awarded. In general, we find a positive association between long-term incentives and generality of the firm's patent awards. We find no association between incentive compensation and either the extent of concentration of a firm's awards or the number of publications by authors associated with each firm, which suggests that these firms are not abandoning more tangential or scientific research in the face of high-powered incentives.[18]

Also, we undertake an analysis addressing the possibility that our basic findings 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. One 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

[18] We define "adjusted citations" as 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. The "generality" of the firm's awards is a frequently employed measure (see Jaffe and Trajtenberg [2002]) defined as one minus the Herfindahl Index across technology classes of the patent citations received by a patent. Thus, a patent with a generality score approaching one suggests that a diverse array of subsequent patents draw upon the award. The extent of concentration of the firm's awards is based on a Herfindahl Index of the firm's awards. Refer to NBER working paper No. 11944 for an analysis of these additional measures of innovation.

whether the head of corporate R&D reports directly to the CEO. We add a dummy variable for such executives, as well as an interaction between the compensation measures and the dummy. These controls make little difference to the 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 long-term incentives are offered to attract or retain high-quality managers.[19] Another explanation is that these awards are a reward for past successful performance.[20] Definitively establishing one hypothesis is very challenging and not possible given our data. As such, it is beyond the scope of this paper. We do, however, find that long-term incentives of corporate R&D executives are positively associated with innovation, while short-term incentives are not. These results hold in the centralized R&D sample where the corporate R&D executive has greater authority and influence over R&D decisions, but not in the sample of firms with hybrid (or decentralized) R&D organizations. Taken together, our findings suggest that long-term incentives play some role in corporate R&D heads making better decisions over project selection that in turn lead to more productive R&D efforts.

4. Conclusion

[19] Several recent papers explore effects related to selection or sorting. For example, Oyer and Schaefer [2005] find evidence suggesting that firms grant stock options to all employees for sorting and retention purposes. Andersson, Freedman, Haltiwanger, Lane and Shaw [2005] show that firms that operate in product markets with high variance in payoffs pay talented workers higher starting salaries and higher performance pay.

[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. More generally, if agents are risk-averse, it is always optimal for firms to reward executives with cash instead of with forms of pay that are inherently risky.

This paper examines the association between innovation and the shifting compensation of corporate R&D heads over the 1990s. We find that the ratio of long-term incentives to total compensation for corporate R&D heads has increased by more than 50% over the period from 1988 to 1998. Among firms with centralized R&D organizations, a clear relationship emerges: more long-term incentives are associated with more heavily cited patents, more frequent awards, and patents of greater originality. In contrast, we find little relation between short-term incentives and measures of innovation. And, we find no association in firms with decentralized R&D organizations, where authority of the corporate R&D head over R&D decisions is more limited.

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. While incentives of top corporate R&D executives in firms with decentralized R&D organizations don't appear to be associated with innovation, the reason might simply be that most research decisions are being made at the divisional level.

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], Neumeyer [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. We hope to explore these questions in future work.

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Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Citations (mean)	734	4.577053	4.482133	0	29
Patent Count	734	82.21935	168.1914	0	1936
Originality (mean)	734	0.423405	0.1324394	0	0.73928
Corporate R&D Head					
Salary ($ 1996)	734	256934.6	95015.33	99951.58	650335.2
Bonus	734	119037.2	122359.5	0	1412346
Value of Long-term Incentives	734	247293	316161.7	0	4394422
Total Compensation	734	623264.7	468557	99951.58	5267421
Short-term Incentive Ratio	734	0.18123	0.0976243	0	0.5263552
Long-term Incentive Ratio	734	0.3201348	0.1560246	0	0.8342645
Stock option Ratio	733	0.2280706	0.1583638	0	0.8342645
Restricted stock Ratio	733	0.0293098	0.0699158	0	0.6692812
Chief Financial Officer					
Total Compensation	602	964230.5	704204.7	173897.3	8378033
Long-term Incentive Ratio	602	0.3824856	0.1589756	0	0.8472579
Human Resource Head					
Total Compensation	651	551487.1	384913.5	104298.9	3932550
Long-term Incentive Ratio	651	0.3204141	0.152419	0	0.8097926
Chief Executive Officer					
Total Compensation	707	2820811	2723233	364477.7	33600000
Long-term Incentive Ratio	707	0.4217069	0.1781109	0	0.9168563
Firm Sales ($ millions 1996)	734	11425.26	22337.36	238.1639	168572.4
R&D/Sales	734	0.04756	0.0466756	0	0.4853113
Herfindahl index of business segments	734	0.6680925	0.2938458	0.1800421	1
Centralized R&D organization	734	0.6226158	0.4850628	0	1

Note: Sample includes firms that report both a corporate R&D head in the compensation survey and R&D expenditures in Compustat. Citations are defined as the mean of the number of citations in patents awarded in that firm-year. Originality is a measure of the breadth of patents that the firm's patents cite in a given year. 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, termination provisions, and the probability of achieving performance goals. Herfindahl index of business segments is defined as the sum of squared share of sales for each of the business segments in a firm-year. 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.

Table 2: Firm Citations (mean) and Corporate R&D Compensation--Centralized R&D Sample; R&D Executive Averages

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Long-term incentives/total compensation for Corp. RD Head	8.371 (2.449)**	9.539 (2.971)**	8.951 (2.688)**	9.163 (2.661)**	6.955 (2.758)*	6.508 (2.830)*	
Short-term incentives/total compensation for Corp. RD Head				0.885 (3.178)		-0.991 (3.581)	-0.585 (3.445)
Total compensation for Corp. RD Head ($ millions)					1.359 (1.259)	1.502 (1.425)	1.449 (1.157)
Stock options/total compensation for Corp. RD Head							6.217 (2.395)*
Restricted stock/total compensation for Corp. RD Head							9.714 (5.760)+
Log (firm sales)		-0.610 (0.288)*	-0.408 (0.257)	-0.424 (0.253)+	-0.496 (0.267)+	-0.487 (0.262)+	-0.282 (0.225)
R&D/Sales		12.713 (8.478)	5.560 (7.702)	5.462 (7.734)	3.433 (7.931)	3.319 (7.981)	2.682 (7.367)
Herfindahl of business segments			4.618 (0.921)**	4.618 (0.923)**	4.533 (0.898)**	4.524 (0.901)**	4.364 (0.877)**
Constant	5.970 (2.502)*	9.846 (3.181)**	4.979 (2.714)+	4.852 (2.651)+	5.671 (2.844)*	5.885 (2.805)*	4.654 (2.705)+
Observations	177	177	177	177	177	177	177
R-squared	0.42	0.47	0.53	0.53	0.53	0.53	0.54

Note: Sample includes firms that report a corporate R&D head in the compensation survey and R&D expenditures in Compustat. 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). All regressions include unreported average year fixed effects. See earlier tables/text for variable definitions. Robust standard errors; + significant at 10%; * significant at 5%; ** significant at 1%

Table 3: Firm Innovation Measures and Corporate R&D Compensation--Centralized R&D Sample; R&D Executive Averages

	Logarithm of Patent Count				Originality			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Long-term incentives/total compensation for Corp. RD Head	1.684 (0.553)**	1.747 (0.534)**	1.498 (0.701)*	1.116 (0.814)	0.131 (0.077)+	0.141 (0.077)+	0.249 (0.094)**	0.199 (0.117)+
Short-term incentives/total compensation for Corp. RD Head				-0.847 (0.933)				-0.111 (0.122)
Total compensation for Corp. RD Head ($ millions)			0.126 (0.280)	0.248 (0.307)			-0.080 (0.030)**	-0.064 (0.034)+
Log (firm sales)	0.678 (0.072)**	0.656 (0.073)**	0.670 (0.076)**	0.677 (0.077)**	-0.010 (0.008)	-0.013 (0.008)	-0.005 (0.008)	-0.004 (0.008)
R&D/Sales	9.519 (2.315)**	10.289 (2.646)**	9.310 (2.371)**	9.202 (2.386)**	-0.066 (0.153)	0.055 (0.179)	0.067 (0.164)	0.053 (0.163)
Herfindahl of business segments		-0.497 (0.317)				-0.078 (0.033)*		
Constant	-3.446 (0.692)**	-2.922 (0.727)**	-3.390 (0.719)**	-3.214 (0.742)**	0.357 (0.078)**	0.439 (0.078)**	0.322 (0.077)**	0.345 (0.082)**
Observations	177	177	177	177	177	177	177	177
R-squared	0.51	0.52	0.52	0.52	0.13	0.16	0.16	0.16

Note: Sample includes firms that report a corporate R&D head in the compensation survey and R&D expenditures in Compustat. 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) is defined as the logarithm of (one plus) the number of patents. All regressions include unreported average year fixed effects. See earlier tables/text for variable definitions. Robust standard errors; + significant at 10%; * significant at 5%; ** significant at 1%

Table 4: Firm Citations (mean), Corporate R&D and Senior Executive Compensation--Centralized R&D Sample; R&D Executive Averages

	Chief Financial Officer (CFO)		Head of Human Resources (HRH)		Chief Executive Officer (CEO)	
	(1)	(2)	(3)	(4)	(5)	(6)
Long-term incentives/total compensation for Corp. RD Head	8.728	8.329	10.927	11.494	7.723	7.089
	(4.278)*	(4.289)+	(4.968)*	(5.101)*	(3.396)*	(3.470)*
Long-term incentives/total compensation for Additional Corp. Exec. Position	-2.875	-2.765	-4.468	-4.705	-0.939	-0.849
	(3.410)	(3.291)	(4.668)	(4.563)	(1.930)	(1.919)
Short-term incentives/total compensation for Corp. RD Head	1.428	1.542	1.111	0.966	1.573	1.763
	(1.449)	(1.617)	(1.357)	(1.496)	(1.366)	(1.549)
Total compensation for Corp. RD Head ($ millions)		-0.707		0.902		-1.270
		(3.810)		(3.392)		(3.819)
Log (firm sales)	-0.569	-0.566	-0.599	-0.601	-0.677	-0.669
	(0.297)+	(0.297)+	(0.283)*	(0.284)*	(0.301)*	(0.297)*
R&D/Sales	10.267	10.125	11.293	11.468	10.294	10.101
	(9.151)	(9.241)	(8.688)	(8.795)	(9.041)	(9.107)
Constant	10.581	10.725	10.456	10.263	10.560	10.825
	(3.453)**	(3.425)**	(3.491)**	(3.469)**	(3.329)**	(3.325)**
Observations	167	167	171	171	177	177
R-squared	0.47	0.47	0.49	0.49	0.48	0.48

Note: Sample includes firms that report a corporate R&D head in the compensation survey and R&D expenditures in Compustat. 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). All regressions include unreported average year fixed effects. See earlier tables/text for variable definitions. Robust standard errors; + significant at 10%; * significant at 5%; ** significant at 1%

Table 5: Firm Citations (mean) and Corporate R&D Compensation—Hybrid (or Decentralized) R&D Sample; R&D Executive Averages

	(1)	(2)	(3)	(4)
Long-term incentives/total compensation for Corp. RD Head	-0.197	-1.057	-0.316	-1.451
	(2.142)	(2.462)	(2.743)	(3.098)
Short-term incentives/total compensation for Corp. RD Head		-4.359		-4.497
		(4.771)		(4.855)
Total compensation for Corp. RD Head ($ millions)			0.046	0.141
			(0.366)	(0.358)
Log (firm sales)	-0.108	0.018	-0.113	0.004
	(0.231)	(0.304)	(0.249)	(0.312)
R&D/Sales	12.778	13.064	12.692	12.810
	(8.422)	(8.349)	(8.455)	(8.374)
Constant	8.401	8.422	8.462	8.611
	(3.399)*	(3.415)*	(3.608)*	(3.602)*
Observations	101	101	101	101
R-squared	0.48	0.48	0.48	0.48

Note: Sample includes firms that report a corporate R&D head in the compensation survey and R&D expenditures in Compustat. The sample is only those firms with a hybrid (or decentralized) R&D organization (i.e. firms with both a corporate R&D head and division R&D managers. All regressions include unreported average year fixed effects. See earlier tables/text for variable definitions. Robust standard errors; + significant at 10%; * significant at 5%; ** significant at 1%

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).[21] 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

[21]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.