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Innovation, R&D and Managerial Compensation

Paroma Sanyal[1] and Laarni Bulan[2]

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Abstract

This paper investigates whether aligning manager and owner incentives can improve the innovation performance of firms. We find that innovation magnitude, R&D and technology concentration have an inverted U-shape relationship with price pay sensitivity. These first increase with price pay sensitivity, and then decrease at very high levels of price pay sensitivity. However, the quadratic term occurs beyond the 95th percentile of the distribution, and thus for the majority of the sample greater sensitivity of managerial wealth to stock price changes encourages innovation & R&D, and makes firms concentrate on their core technology areas. Only patent quality has a positive linear relationship with pay sensitivity. We also find that more entrenched managers, as measured by increased stock holdings, have a negative impact on patenting and R&D investment. Short-term monetary incentives have no impact on the innovation strategy of a firm.

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[1] Dept. of Economics and IBS, Brandeis University, psanyal@brandeis.edu
[2] International Business School, Brandeis University, lbulan@brandeis.edu
[3] Please do not cite without the authors' permission.

1. Introduction

Separation of ownership and control within a firm can benefit the owners by allowing them to hire managers who have expertise and in-dept knowledge in the business field that the owners themselves may not necessarily possess. However, it also gives rise to the classic principal-agent problem, where asymmetric information between the owner (principal) and the manager (agent) may lead to a suboptimal outcome for the owner. Agency theory predicts that managers may use this superior information and make decisions to divert resources away from the principal's interest (Jensen and Meckling, 1976; Fama and Jensen, 1983). This setting gives rise to agency costs due to the misalignment of the principal's and agents' incentives. This is of particular importance in spheres where it is difficult to judge the decision of the manager, and assess performance based on measurable metrics. Innovation effort is one such area.

Since managers control the day-to-day operations of the firms, they are likely to exercise effective control over the firm (Berle and Means, 1932), and possess better information when compared to the owners or share-holders (Pratt and Zeckhauser, 1985). This is of particular concern for innovation where the end product may not be a perfect signal of manager ability due to uncertainties in the innovation process. This may allow them to invest in innovation projects that do not serve the interests of the owners. In addition, capital markets often cannot correctly value investment in long-term research and development (R&D) activities, leading to large information asymmetries and high agency costs. For example, a manager with an expected short tenure may forgo long-term R&D projects for short-term ones, even though the former may yield a higher expected positive net present value (NPV) for the principal than the latter. The principal attempts to counter this problem through two channels: compensation contracts that align the managers' interests with those of the owners, and monitoring the agent's actions (Jensen and Meckling, 1976; Holstrom, 1979; Fama and Jensen, 1983; Jensen, 1983).

In this paper we focus on compensation contracts as a mechanism for aligning the rights of managers with those of the owners. Payoff contracts between the principal and the agent usually specifies the rights of the parties involved, performance metrics, and the reward structure for agents (Fama and Jensen, 1983). These contracts are designed to align the owners' and managers' incentives, and incentivize managers to make decisions that are in the best interests of owners (Jensen, 1983). Theoretical research has shown that agency costs are minimized when executive compensation is related to firm performance (Holmstrom, 1979; Grossman and Hart, 1983), and thus incentive alignment through compensation schemes increase firm value. However, there is considerable heterogeneity in findings on the empirical side. Some authors find that incentive alignment either has a positive or a non-monotonic effect on firm value, while others find no relationship.[4]

We contribute to this literature by focusing on an important channel through which managers may increase firm value, namely innovation. Using patents as a metric for innovation, this paper shows how top 3 executive stock ownership, their wealth sensitivity to changes in the firm's stock price, and short-term incentives such as bonuses, influence the innovation strategies of firms. However, increasing the number of patents may not necessarily contribute to firm value. According to Hall et. al (2005), the quality of patents, as measured by citations, increases the value of a firm, as measure by Tobin's Q. Thus we focus on innovation magnitude, quality, level of R&D and the technology class concentration to investigate how well incentive contracts align managers' and shareholder's incentives in enhancing long term firm value. We choose the top 3 executives since this includes the Chief Executive Officer (CEO), Chief Financial Officer

[4] Lazear and Rosen, 1981; Lambert, 1983; Murphy, 1986; Morck, Shleifer and Vishny, 1988; McConnell and Servaes, 1990; Hermalin and Weisbach, 1991; Loderer and Martin, 1997; Cho, 1998; Himmelberg, Hubbard and Palia, 1999; Holderness, Kroszner, and Sheehan, 1999; Demsetz and Villalonga, 2001; Palia, 2001; Claessens, Djankov, Fan and Lang, 2002; Cui and Mak, 2002; Brick, Palia and Wang , 2005; Coles, Lemmon and Meschke, 2007.

(CFO) and the Chief Operating Officer (COO), one of whom is also the President of the company in a majority of cases. These are the three most influential people in the company in charge of charting out a company's future and thus their actions should have important consequences for the innovation strategy of a firm.

First, we find that price pay sensitivity, i.e. the sensitivity of managers' wealth to percent changes in his firm's stock price is the most important incentive mechanism that aligns managers' and shareholders' goals. We find that innovation magnitude, innovation quality, R&D and technology concentration have an inverted U-shape relationship with price pay sensitivity. Most of these variables first increase with price pay sensitivity, and then decrease at very high levels of price pay sensitivity. However, the quadratic term is economically insignificant is all cases and the overall impact is a positive one. We also find that increased managerial stock holdings have a significant negative impact on patent magnitudes and R&D investment.

Our paper complements the findings of Lerner and Wulf (2007). Using a sample of 140 publicly traded U.S. firms between 1987 and 1998, they find that the long-term incentive compensation of corporate R&D managers is positively associated with patent citations, patent awards and patent originality. Our paper is different from theirs in two respects. First, instead of R&D managers, we focus on the firm's top executive. While we acknowledge that the corporate R&D manager has direct authority over research and development decisions within the firm, we believe that the top executives retain authority over the "big-picture" strategic direction of R&D. Moreover, their findings apply to a subset of firms with a centralized R&D organizational structure identified by the presence of a corporate R&D head. For firms without a corporate R&D head, long-term incentives are not related to their innovation measures. In these instances, we believe the top executives would have more influence on R&D decision-making.

Second, we measure managerial incentives as the pay-for-performance sensitivity of these top executives. They measure long-term incentive compensation as the value of restricted stock, stock options, performance units and performance shares granted to the manager. Lerner and Wulf acknowledge that in their data, they are limited to observing incentive compensation flows as opposed to the stock of incentive compensation. In our data, we do not have this limitation and hence, we are able to construct these measures of managerial incentives that are more closely related to performance than just the flow value of compensation.

A closely related paper is by Aghion, Van Reenen and Zingales (2009). They find that institutional ownership is positively related to cite-weighted patents. They explain this finding in a theoretical model where the presence of institutional investors (external monitors) alleviates a CEO's aversion to risky R&D due to his possible termination in the event of failure. Unsuccessful innovation strategies may be a result of bad luck and not necessarily due to bad managers. More effective monitoring of managerial actions can "insulate the manager against the reputational consequences of bad income realizations," thus creating greater incentives for CEOs to undertake risky innovation. Our work builds on this paper by illustrating one of the channels through which the institutional investors may influence managerial decision-making, namely managerial compensation contracts.

2. Data and Variables

2.1. Data

Our primary interest is to investigate how incentive alignment and monitoring of managers affect the innovation strategy of firms, and the channels through which it occurs. Using patents as a metric of innovation we empirically model how the magnitude and nature of innovation by firms change when they are subject to different corporate governance mechanisms.

In addition we explore the channel through which managers may affect innovation magnitudes. We focus on two primary channels: change in R&D spending and change in innovation quality. The number of patents, or R&D, or innovation characteristics (such as quality or technology diversification) for firm *i* in year *t* in industry *j*, (Y_{jt}) is modeled as a function of a executive payoff structure ($exec\_pay_{it}$), firm financial variables ($firm_{it}$), firm innovation culture captured by variables such as past patenting activity ($innov_{ijt}$), and industry conditions such as market concentration and other industry characteristics (*indjt*), and a set of year dummies.

$$Y_{it} = \left(exec\_pay_{it}, firm_{it}, innov_{it}, ind_{jt}\right) \qquad (1)$$

Thus the primary categories of data that this paper relies on are: 1) information on patents, 2) data on financial and other firm characteristics, and 3) variables characterizing incentive contracts. The patent data is from NBER's (National Bureau of Economic Research) 'Patent Citations Database' which was originally constructed by Hall Jaffee and Trajtenberg (1999). We use the updated version of this dataset provided by the NBER. This data contain information on all patents granted in the US from 1976 to 2005. These comprise application and grant years, geographical distribution of these patents, technology classifications, backward[5] and forward citations (i.e. citations to and from a patent), standardized assignee names, and assignee numbers that help in tracking patent assignees across years. In addition, for publicly traded companies it matches the unique GVKEY identifier from the COMPUSTAT database with unique assignee numbers[6], the key component for correctly assigning patents to specific firms.

We obtain firm characteristics from the COMPUSTAT database that contains financial data on all publicly traded companies in the US. Matching the COMPUSTAT firm data with the patent database, we find that a large number of corporations do not patent. These zero patent firms are included in our dataset as well. We then match the above data to the annual executive

[5] US citation only.
[6] The updated match was provided by Prof. James Bessen.

compensation data from ExecuComp for the period 1992-2005. Our estimation sample begins in 1992, when ExecuComp came into existence, and extends to 2005. We limit our sample to firms that have at least one patent during our sample period.

2.2 Variable Construction

2.2.1 Dependent Variables

We have four dependent variables: measures of patenting activity, citation based patent quality, R&D expenditures and technology class concentration. To measure patenting activity, we construct patent counts by firm and year[7] and use the natural log[8] of patent counts as the primary dependent variable. The number of citations received per patent is often used as a measure of patent quality. It is based on the idea that patents that make significant contributions will have more citations, i.e. a greater number other patents will cite these, than those that embody minor innovations (Pakes, 1985; Jaffe, 1986; Griliches, Pakes, and Hall, 1987; Connolly and Hirschey, 1988; Griliches, Hall, and Pakes, 1991; Hall, 1993; Blundell, Griffith, and van Reenen, 1999). However, the raw number of citation that a patent receives can be misleading. A patent may receive more citations simply because there are more patents in a given field in the following years or it may come from a field where it is customary to cite frequently. To solve this, we purge the citations of the year and field effects as suggested by Hall et. al (2001). We then create the average and total citations by firm and year and use the use the natural log of these numbers as our dependent variable.

The technology class concentration is also based on granted patents as well. This measures how concentrated each firm is in patent technology classes in each year, i.e. are they patenting in a narrow set of classes (concentration) or a broad set of classes (diversification).

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[7] We count patents by application year, i.e. say for all patents applied for in 1990, how may were granted.
[8] For patent counts equal to zero we use the log (10^{-10}).

This is constructed as a Hirschman-Herfindahl index.[9] Our fourth dependent variable is R&D expenditures in 200 dollars[10]. This variable too has a significant number of zero and missing observations similar to the patent and citation measures.

2.2.2 Measuring Incentive Alignment

We use three measures of incentive alignment for the top 3 executives by rank, i.e. the CEO, CFO and the COO. First, we construct top 3 executive *holdings* using the standard definition of the fraction of equity shares held by the top 3 executives to total shares outstanding. Top 3 *Holdings* = number of shares of the firm held by the Top 3 Executives/total shares outstanding

However, stock ownership is just one component of managerial pay. It does not reflect option contracts and does not capture the sensitivity of managerial wealth, *per se*, to share performance. The manager's wealth sensitivity to changes in the stock price (*price pay sensitivity* or *delta* as it is popularly called in the finance literature) is more indicative of managerial incentives than just equity ownership since the former is more closely tied to firm performance. A manager's expected risk will depend primarily on *price pay sensitivity.*

We thus define *price pay sensitivity* as the top 3 executive's wealth sensitivity to changes in the firm's stock price and construct this as a dollar change in the top 3 executive's equity and option holdings in response to a one-percent change in the firm's stock price (o). Our measure is constructed following Core and Guay (2002) who develop a methodology to estimate these sensitivities using information from the firm's most recent proxy statement. This is further

[9] For each firm, in a given year, we first calculate the number of unique and repeated patent technology classes. We then create shares where the denominator is 500, since there are approximately 500 patent technology classifications at the USPTO. We then construct the HHIit = $10000\Sigma(\text{no. of patent class}_{it}/500)^2$, where i=patent technology class

[10] Again since we use log values, for zero R&D we use the log (10^{-10}).

described in the appendix.[11] Briefly, we calculate a top 3 executive's price pay sensitivity as follows:

Top3 *price pay sensitivity* = Equity *delta* + Option *delta* (or Equity *delta* if Option *delta* is missing)

$$\text{Equity } delta = [\partial(\text{equity value}) / \partial(\text{stock price})] * \text{stock price} * 0.01$$

$$= \text{number of shares outstanding} * \text{stock price} * 0.01$$

$$\text{Option } delta = \sum_{j=1}^{N} [\partial(\text{option value}_j) / \partial(\text{stock price})] * \text{stock price} * 0.01$$

Our third measure of managerial compensation moves away from equity-based constructs and assesses the short-term incentives faced by the managers. This measure is constructed from the cash compensation received by the top 3 managers as given below.

Top 3 Short-term Incentives = Bonus/ Total Salary

The total salary of managers comprises the base salary and an annual bonus. Base salary is the fixed component of managerial pay that modestly increases from year to year. Base salary is usually benchmarked at the industry level and is highly correlated with firm size, especially for firms that have strong stock return performance. Annual bonus is calculated as a percentage of base salary and is very often tied to short term performance (e.g. if certain targets for accounting profitability are met for the year).[12] Thus, this variable should capture the short-term incentives faced by the mangers.

2.2.3 Innovation Environment of the Firm

We use four variables to capture the innovation environment of the firm: the stock of R&D expenditure, stock of past patents, average quality of past innovation and the technology concentration of the firm. R&D is a critical input in any innovation process and greater R&D usually leads to more patents after factoring in uncertainties within the innovation and patent

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[11] In the finance literature, pay sensitivity is often called *delta*.
[12] See Murphy (1999).

process. R&D expenditure is obtained from COMPUSTAT and is measured in 2000 dollars. We create the stock of R&D expenditure by using a 12 percent depreciation rate for past R&D and using the current and past 4 years R&D expenditure. This should have a positive impact on innovation magnitude and quality. It may have a negative impact on technology concentration since firms with larger R&D budgets may tend to explore newer technology areas.

The stock of past patents is created in a similar manner as the R&D stock, and captures the past innovation portfolio of the firms. We can interpret this as a critical input to current innovation and a firm with a greater stock of past patents has a larger input base to use in current innovation. Thus a firm with a larger stock of patents may be expected to obtain a larger number of current patents, invest more in R&D and have a higher quality of current patents. However, the effect on technology concentration is unclear. Larger patent portfolios may lead firms to further concentrate on core technologies that they have found success in earlier, or they may explore new technology fields.

The average quality of past patents proxies for the quality of innovation inputs in the firm and its construction has been described earlier in the paper. We hypothesize that a firm with high quality innovation inputs will generate a larger number of patents. However, the effect on R&D and technology concentration is ambiguous. Existence of high quality innovation inputs may allow a firm to invest less in current research and live off its earlier research output. In addition, higher quality innovation inputs may increase technology concentration since the firm may invest only in those technology fields that it has already found success in. On the other hand, such firms already have a solid base of inputs and may attempt to innovate outside their core areas.

Last, the technology concentration, as mentioned earlier measures whether the firms are focused in a few core areas or whether they have a broad technology portfolio. We hypothesize that greater technology concentration would increase the number of patents and innovation quality since the firms would be building a narrow set of past knowledge fields in which they had gained expertise. The effect on R&D is unclear. Firms may actually have to spend less on R&D if they concentrate on a few technology areas rather than explore a broad set of fields.

2.2.4 Measuring Firm Characteristics

To evaluate what aspects of the executive reward structure and monitoring efforts influence innovation, we need to control for other confounding factors. Following previous work, we control for require firm size (total assets), firm age, industry concentration (Herfindahl index), and managerial tenure. Firm size is measures by the log of total assets[13]. Firm age is measured by the difference between the current year and the incorporation year[14], if the latter is available. If the incorporation year is unavailable, we use the earliest year on CRSP that a firm has a positive stock price or the earliest year in Compustat that a firm has non-missing data for total assets. Industry concentration is measured by the Herfindahl Index based on Compustat data. This is given by: $\Sigma\alpha_i^2$ where α_i is the output (sales) share of each firm in the industry in that particular year and is summed over all firms in the industry. This measure varies between zero and one, with a more competitive industry having a Herfindahl Index closer to zero. Managerial tenure is measured as the difference between the current year and year the executive became CEO/CFO/COO, as reported in ExecuComp.

3. Empirical Methodology and Results

3.1 Innovation Magnitude

Our four dependent variables - patent counts, R&D expenditures, measures of patent quality and technology concentration have some peculiar characteristics that are different from

[13] The use of total sales as a measure of firm size leaves our results mostly unchanged and qualitatively similar.
[14] We are grateful to John Ritter for the use of his data on incorporation dates.

other types of data. Patent counts are non-negative integer numbers, and thus we cannot use the usual least squares estimation approach.[15] The usual approach is to use a negative binomial panel fixed effects model[16], which accounts for the count nature of the dependent variable, and controls for firm specific fixed effects. As a robustness check we also use a linear fixed effects model with errors clustered at the industry level, and a panel data tobit model[17] with year and industry fixed effects. There are a large number of firms that have only 1 patent. We wanted to test whether our conclusions would hold if we treated these firms as having zero patents. Thus we use the tobit model to account for the left-censored data (at one, in this case) or a "corner solution outcome" (Wooldridge, 2001)[18]. We estimate the model below using the alternative estimation techniques outlined above. In the specification below i indexes the firm, j indexes the industry and t indexes the year. Table 2 presents the results.

$$Patno_{it} = \alpha + \sum_{k=1}^{4} \beta_4 Exec\_pay_{it} + \sum_{l=1}^{L} \gamma_l Firm_{it} + \sum_{m=1}^{M} \delta_m Innov_{it} \sum_{p=1}^{P} \phi_p Ind_{jt} + \varepsilon_{it} \qquad (3)$$

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[15] Using OLS will yield some negative predicted values. But since the dependent variable is non-negative, the predicted values should also be non-negative for all explanatory variables. If all values of the dependent variable were strictly positive, we could have used a log transformation. However, since some of the values are zero we may prefer using a count data model.

[16] An alternative is to use a Poisson model, but our data violate the assumption of mean-variance equality and displays over-dispersion. Hence a negative binomial model is used.

[17] We assume that the random effects, v_i, are normally distributed with zero mean and constant variance σ^2_v, i.e. $N(0, \sigma^2_v)$. Thus we have: $\Pr(y_i \mid x_i) = \int_{-\infty}^{+\infty} \frac{e^{-v_i^2/\sigma_v^2}}{\sqrt{2\pi\sigma_v}} \left(\prod_{t=1}^{n_i} F(x_{it}\beta + v_i) \right) dv_i$

where: $$F(\Delta_{it}) = \begin{cases} (-1/\sqrt{2\pi\sigma_\varepsilon})e^{-(y_{it}-\Delta_{it})^2/)2\sigma_\varepsilon^2)} & \text{if } y_{it} \text{ is non-censored}, \quad \Phi\left(\frac{y_{it}-\Delta_{it}}{\sigma_\varepsilon}\right) \quad \text{if } y_{it} \text{ is left-censored} \\ 1-\Phi\left(\frac{y_{it}-\Delta_{it}}{\sigma_\varepsilon}\right) & \text{if } y_{it} \text{ is right-censored} \end{cases}$$

This model is estimated in Stata by Gauss-Hermite quadrature. The error has two components: v_i - the random disturbance that varies by group but not over time ($v_i \sim N(0, \sigma^2_v)$) and ε_{it} - is the idiosyncratic error component ($\varepsilon_{it} \sim N(0, \sigma^2_\varepsilon)$).

[18] The issue here is not that we do not observe data below a certain threshold – as is the case with most censored models. But we are interested in E(y|x, y>0). Therefore a simple OLS model would be inconsistent.

Theory suggests that when managers own more shares of their firm, they benefit more from value-maximizing decisions since these, result in share-price increases, the "incentive alignment" effect. However, when managers own a large fraction of corporate shares they can become "entrenched," i.e. independently powerful and difficult to dislodge. In this case, they may attempt to benefit themselves at the expense of less powerful shareholders. This could create an inverse U-shaped relationship between executive ownership and corporate performance. From column (1) we find that managerial holdings do not impact the innovation magnitude of a firm. However, from the alternative specifications in column 2 and 3 we find that innovation declines as managers become more entrenched, i.e. greater managerial holdings have a negative effect on innovation magnitude. Thus if owners are looking to put firms on an increased innovation trajectory, increasing the shareholding of top managers will not achieve that goal.

Equity ownership, however, is an incomplete measure of the managers' equity-based incentives. It does not reflect option contracts and does not capture the sensitivity of manager wealth, *per se*, to stock price performance. In this paper, we use the price pay sensitivity of the top 3 executive's compensation package as a more nuanced measure of incentive alignment. This is measured as the sensitivity of managers' wealth to percent changes in his firm's stock price, and depends on the amount of shares he owns, the number of options he owns, and various properties of the options such as maturity and strike prices.[19]

We find that innovation magnitude has an inverted U-shape relationship with price pay sensitivity. Patenting initially increases with price pay sensitivity, consistent with the incentive-alignment effect, i.e. managers' incentives are aligned with those of shareholders. This can be related directly to Hall et. al (2000) finding that the event of a patent grant has a positive impact

[19] Palia (2001), Coles, Lemmon and Meschke (2007) and Brick, Palia and Wang (2005) use similar measures for CEO pay-performance sensitivity.

on a firm's financial value through changes in stock price. If manager's wealth portfolios are very sensitive to such price changes, then they would be more willing to increase the number of patents obtained by the firm since it will directly increase their wealth. However, for very large price pay sensitivities, patenting activity is dampened. The negative effect on patenting for higher values for price pay sensitivity is more consistent with the risk-aversion hypothesis. Managers, whose personal wealth is closely tied to the financial performance of the firm, become averse to investing in risky investments such as R&D.

This conclusion is also consistent with evidence presented in Coles, Daniel and Naveen (2006) that looks at the empirical relationship between CEO price pay sensitivity and specific firm policies. They find that high price pay sensitivity induces CEOs to take less risky decisions, such as more capital expenditures and less R&D. This effect however, is an order of magnitude smaller than the positive effect and occurs at extremely high levels of price pay sensitivity. Overall, if price pay sensitivity increases by 1 percent, patenting increases by percent. Thus, increasing the price pay sensitive of a managers' wealth portfolio can induce them to increase patenting activity. These effects are robust across specifications. We also include a third variable that measures the short-term incentives of the managers as captured by the share of bonus in total salary. We find that such short-term incentives have no impact on innovation.

In addition, we find that the innovation environment of the firm and other firm characteristics have significant impacts on the patenting behavior of firms. Higher input quality, as measured by the average quality of past patents, has a significant positive impact of current patenting. Also, a higher technology concentration leads to a greater number of patents. This supports the view that firms may have an advantage in innovating in a limited number of core technology areas rather than diversifying into new fields where the learning costs may be greater.

In addition, firms with a higher quality of past innovation which are concentrated in a small number of fields are more successful in generating current patents.

We also find that older and larger firms have a greater number of patents in our data, while the negative and significant quadratic terms on age suggests that there is an optimal age after which innovation declines. However, this result is not robust to alternative specifications. We also find that the interaction tern between age and size is positive and significant, implying that for our sample, large old firms are less successful in patenting than smaller and younger firms. Manager characteristics such as the tenure of the top 3 executives have no impact on patenting. Last, from column 1 we find that firms in a competitive industry generate more patents. This implies that firms in a competitive industry may be patenting more either to gain competitive advantage or building a patent thicket around its core innovations to prevent future litigation. However, this result is not robust to the alternative specifications in column 2 and 3.

The significance of the innovation environment of the firm in the success of patenting leads us to explore whether managers are influencing various facets of the innovation environment, which in turn generates more patents. On a related theme we also want to investigate the channels through which the managers are pursuing a prolific patenting strategy. For instance, are they increasing R&D expenditures to obtain more patents, are they using the existing R&D expenditures more efficiently so that they obtain more patents per R&D dollar spent, or are they slicing up the existing innovations into more 'thinner' patents, such that average patent quality for the firm suffers. If incentive pay could make managers undertake the former two strategies, it would be value enhancing for the firm in the long run and align the incentives of the owners and managers. However, if the incentive structure makes managers adopt the "cutting the salami thin" strategy then this is detrimental to long term firm value. Next we examine how these pay incentives have influenced the R&D expenditures of firms, the quality of patents they are producing and their core technology fields.

3.2: R&D Spending

R&D is a continuous variable and can usually be estimated using linear fixed effect models. For our sample 40 percent of the firms conduct no R&D, since some old economy manufacturing firms do not invest in R&D. For the econometrician observing the data from outside, this presents a unique challenge. One is always faced with the question about what these zeros represent. Do they represent the decision not to conduct R&D, or are these just zero dollars spent on R&D? Although we can use econometric tests to select one over the other, one should also draw from qualitative evidence about firm conduct. In this case we believe that the zeroes represent a decision not to conduct R&D. For most firms, a critical minimum amount of R&D is required before the firm can observe any innovation activity or accrue benefits from that research. Thus some firms may choose not to engage in R&D. In the data we find that the R&D magnitude is zero throughout our sample period for most firms who choose not to invest in R&D. Only in a handful of cases do firms switch between zero and positive R&D.

Suppose R&D decisions are a two-step process. In this case, in the first stage the managers decide whether the firm should engage in R&D at all, depending on its expected future benefits for the managers from investing in R&D. The second level decision would involve determining the optimal amount of R&D that would maximize the present discounted value of top 3 executive's benefit function subject to various institutional constraints. In this context, both unobserved heterogeneity and selection issues are a problem. A number of studies have addressed selection issues and unobserved heterogeneity under conditions of strict exogeneity of explanatory variables (Kyriazidou, 1997; Verbeek and Nijman, 1992) and with endogenous regressors (Vella and Verbeek, 1999; Wooldridge, 2002; Fernandez-Val and Vella, 2007). Using methodology developed in the above studies, we first test whether selection is a concern for our specification.

Each year the manager decides whether to apply invest in R&D or not (y_{it}), depending on whether it gives her positive net benefits. The latent unobserved variable is net benefit stream for the manager from patenting (y^*_{it}). Thus the decision is modeled as:

$$y^*_{it} = x'_{it}\varphi + u_{it}, \quad \text{where } i = 1,...n \text{ and } t = 1,.......T_i$$
$$y_{it} = 1 \quad \text{if } y^*_{it} > 0, \text{ and 0 otherwise} \tag{2}$$

where: u_{it} is the error term independent of x_{it}, which represents the vector of covariates and comprise top 3 executive characteristics, firm attributes and industry characteristics. Although this is a panel specification[20], testing for sample selection, and consistent estimation of the two-stage model requires that we estimate a cross-section probit equation for each year between 1993 and 2005 (Wooldridge, 1995, 2002) with a R&D dummy[21] for the dependent variable. We use age, age square, firm size, industry concentration, long-term debt, lagged patent dummy[22] showing past patenting activity, lagged mean adjusted innovation quality, current tenure of the top 3 executives, a dummy for whether the CEO is new, and industry dummies as explanatory variables in the probit regression. We present the results of a random effects panel probit model in Table 3, column (1), to show how various factors affect the decision to engage in R&D.

We find that only pay sensitivity affect the probability of engaging in R&D. Greater pay sensitivity makes manager more inclined to invest in research activities. We also find that higher managerial tenure increases the probability of R&D spending and better aligns the managers' actions with a firm's long-tern goals. In addition, a new CEO (joined in the last 6 months) is

[20] Following Chamberlain's approach (1980, 1982) we could have used the panel specification, but it would require certain linearity assumptions that may not be warranted for our specification.
[21] R&D dummy = 1 if the firm engages in positive R&D for that year.
[22] This dummy=1 if the firm has patented in the past year.

much more likely to invest in R&D. Firms with past innovation experience are more likely to invest in research, as a larger firms. Older firms are less likely to do research, and more leveraged firms tend to do no research. Last, greater industry concentration seems to induce a firm to engage in R&D. We derive the inverse Mills ratio[23] (IMR) for each firm *i* for *t* years (from our year by year probit model) and use it to test for sample selection in the second stage.

To test whether selection issues are a problem in our specification we estimate equation (4) below (without the IMR term) using a fixed effects panel data model that accounts for time-invariant heterogeneity and has robust S.E. This test was first proposed by Nijman and Verbeek (1992) and later modified by Wooldridge (1995). However, the estimates for the other coefficients are inconsistent as shown in Wooldridge (2002), and thus results are not presented. We find that selection is a significant concern for the R&D specification, since the inverse Mills ratio is significant in all specifications. This validates our earlier assertion that R&D should be treated as a two-step process.

The second stage is then observed, conditional on participation in research activities.[24] Here we investigate the factors that influence the magnitude of R&D spending given that the firm has decided to engage in research. The dependent variable is log of positive R&D spending (in 2000 dollars) and the estimation equation is given by:

$$\ln RD_{it} = \alpha + \sum_{k=1}^{4} \beta_4 Exec\_pay_{it} + \sum_{l=1}^{L} \gamma_l Firm_{it} + \sum_{m=1}^{M} \delta_m Innov_{it} \sum_{p=1}^{P} \phi_p Ind_{jt} + \rho IMR_{it} + \varepsilon_{it} \qquad (4)$$

[23] The inverse Mill's ratio captures the non-selection hazard, and is given by $\phi\left(x_{it}^{'}\beta\right)/\Phi\left(x_{it}^{'}\beta\right)$, where φ(.) and Φ(.) denote the PDF and CDF of the standard normal distribution respectively.

[24] The exclusion restrictions are satisfied since there are 3 variables in the selection model that are excluded from the levels equation since we believe that these affect only the decision to conduct R&D and the level of expenditure.

To account for selection effect, we include inverse Mills ratio (IMR_{it}) that is calculated based on the probit equation of the first stage[25]. Following Wooldridge (2002), we estimate the above equation using a pooled OLS model, and correct the errors for heteroscedasticity, and for the inclusion of the estimated inverse Mills ratio. We find that the coefficient on the inverse Mills ratio is negative and significant (-0.564) indicating the presence of selection.[26] Hence, a two-stage model is warranted instead of a tobit specification. Results are presented in Table 3, column (2). As a robustness check we present results from a panel data tobit model in column (3).

From both specifications, we find that the incentive pay characteristics of managers have a significant impact on R&D expenditures, conditional on firms engaging in R&D. We find that controlling for firm characteristics and the innovation environment in the firm, greater executive holdings decreases R&D expenditure. This may imply that as managers own more shares they become entrenched and invest less in R&D, since the returns from such expenditures may be long term and given the short tenure of most managers, it may not be in their best interest. Again, increasing the shareholdings of managers may not serve to enhance the innovation capabilities of a firm. The price pay sensitivity on the other hand, may be a better incentive mechanism for increasing R&D expenditures. We find that the relationship between R&D and price pay sensitivity is non-monotonic. R&D initially increases with price pay sensitivity and then declines at very high levels of price pay sensitivity. However, the negative quadratic term is small and economically insignificant. Thus overall, increasing the price pay sensitivity of managers, portfolios increases R&D spending. Last, we find that increasing manager salaries has a small positive impct on R&D expenditures, although the result is not robust across specifications.

[25] For calculation of the inverse Mills ratio see Wooldridge (2002) and Fernandez-Val and Vella (2007).

[26] To capture the time-varying nature of selection we included the interaction between the IMR and year dummies – however in all specifications the interactions were insignificant showing that the selection effect does not vary with time. Thus the interactions have been dropped from the final model.

We also find that that the innovation environment of the firm and other firm attributes impact R&D expenditures. Firms with higher quality past patent portfolio invest more in research (column 3) showing that firms build on their past innovation successes. Technology class concentration is also positively related to R&D expenditures. Firms which keep to their core technology areas invest more in research. This implies that if firms want to gain expertise in a narrow number of areas it may require greater R&D expenditures since it may be more difficult to generate inventions in a set a narrow over-researched areas. Whether this is a strategy that also generates better quality innovation is explored later in the paper.

Other firm attributes such as age and size also matter. Older firms do less R&D, while larger firms do more. However large older firms do more R&D than smaller younger firms. Also, firms with a large amount of cash tend to invest more in R&D. Interestingly, executive tenure has a positive impact on R&D. Thus managers that have stayed in the firm longer invest more in research. More years in a firm implies greater entrenchment for the manager, which may make him want to preserve the status quo. However, we find evidence contrary to this entrenchment hypothesis. One possible explanation could be that as managers stay at a firm longer it mitigates the myopic decision problem faced by managers with a short tenure. Long-term managers may take a long-term view of the firm’s planning horizon and may invest more in longer horizon growth strategies such as investing in R&D. In conclusion, the findings on the effect of incentive alignment contracts on R&D and patenting may imply that increasing managerial holdings will not increase innovation. Rather, increasing the price pay sensitivity on a manager’s portfolio may achieve the long term goal of increasing R&D and innovation for a firm. It may discourage managers from following the “cutting the salami thin” strategy, and may induce managers to produce better quality patents. We investigate this idea in the next section.

3.3: Patent Quality

Patent quality, as measure by citations, are an indicator of the ‘importance’ of a patent, and as such, provides a way of understanding the vast heterogeneity in the value of patents. Patents with a greater amount of citations are considered more ‘valuable; and have a significant link to the private, social and market valuation of a firm (Griliches, 1981, Griliches et. al, 1991, Hall et. al. 2004; Harhoff et. al, 1999, Trajtenberg, 1990). Hall et. al. (2004) find that the market valuation of a firm increases by 3 percent for every additional citation. Thus as the price pay sensitivity of managers increase, they should follow innovation strategies that would potentially yield higher values patents with more citations.

We use four metrics to measure patent quality: the log of the average and the aggregate adjusted and unadjusted quality of a firm’s patent portfolio[27], since neither one by themselves may be sufficient to capture true innovation quality. In an environment where firms are getting more patents than in previous years, total citations to a firm’s portfolio of patents may increase simply because the number of patents obtained by the firm is increasing, or because there are more citing patents in the particular technology class. Thus an increase in total number of citations may not be a true indicator of quality increase. Mean quality however, may be a better metric. This would increase if and only if the rate of increase in citations is greater than the rate of increase in the number of patents. Hence we use both measures to assess whether the increase in patenting due better alignment of the managers’ and owners’ incentives serves the firm in the longer term by increasing underlying innovation quality, or whether the increase in patenting is a short-term mechanism aimed at pleasing the market.

[27] Average adjusted quality is measured by the mean number of citations (purged of field effects) that each firm/assignee receives. Aggregate adjusted quality is the total number of citations (purged of field effects) that each firm/assignee receives. When we purge the citations of field effects, this in essence controls for technology class fixed effects. The unadjusted numbers are the raw citation numbers.

Quality, as explained earlier, is measured by the number of backward citations received by a patent (a count variable), purging these of technology and year effects and using the means and totals of these variables (by firm) make them continuous. However, we cannot use a linear fixed effects model in this case since again there is a substantial proportion of zeros in the data that invalidate OLS assumptions. Most patents never get cited. When measured in levels all quality variables are bounded by zero on the lower end of the distribution. Although we are only interested in the positive citation numbers, discarding the zeroes would bias our results. Thus we estimate a random effects tobit model to account for the left-censored data (at zero, in this case) similar to the patent specification. Results are presented in Tables 4. [28]

We find very similar results for average and aggregate patent quality and thus, we shall discuss the results for the average unadjusted patent quality from columns (1a). Similar to the innovation magnitude and R&D results we find that quality increases as the price pay sensitivity increases. If better quality patents increase the stock prices of the firm by a larger amount then managers will tend to invest in producing better quality patents as their price pay sensitivity increases, as such action increases their personal wealth. This result confirms out finding about patents and R&D and show that price pay sensitivity can align managers' incentives with those of shareholders and induce managers to invest in R&D and produce better quality and increase number of patents and not "cut the salami too thin". In addition, there is no negative effect of risk-aversion at very high levels of price pay sensitivity. Managerial holdings and short-term monetary incentives have no influence of patent quality.

[28] However, this does not allow one to correct errors for clustering and heteroscedasticity. As a robustness check we use a random effects GLS model[28] with clustered and robust standard errors when estimating the average quality specification, as well as a censored normal, and the results are stable across all specifications. For the aggregate quality equation there may be an autocorrelation component in the data and hence we use a linear AR(1) panel data model in this case and results are largely unchanged.

We also find that as firms age they suffer a decline in patent quality, a result that can be contrasted with firms obtaining a higher number of patents as they age, while reducing their R&D expenditures. This may hint at the fact that for older firms patents are used more as a strategic tool rather than embodying fundamental innovations. Larger firms appear to have higher quality patents while industry concentration has no impact. Manager characteristics such as the tenure of the top 3 executives have no impact on patent quality. We also find that higher R&D leads to better quality patents. Interestingly, we find that technology class concentration is also positively related to quality showing that firms who stick to their core areas of expertise produce better quality innovation. Thus for shareholders trying to increase both the quality and magnitude of innovations, the effect of incentive pay on managerial decision about diversifying into broader technology fields versus concentrating in core expertise may be of importance. We explore this idea further in the next section.

3.4: Diversification versus Concentration

From previous discussion we observed that firms that concentrate on a narrow range on core technologies have a higher number of patents and better quality innovations. Thus shareholders may want to induce managers to follow a strategy of concentration rather than diversification. In Table 5 we report the results. In column (1) we use a random effects tobit model since the concentration index is theoretically bound between 0 and 10000. In column (2) we use a linear fixed effects model with standard errors clustered at the industry level. We find that similar all the earlier specifications, a better tool to incentivize managers to take decisions to maximize shareholder value is the price pay sensitivity of a manager’s portfolio. We find that price pay sensitivity has a very significant effect of technology concentration. As price pay sensitivity increases firms get more concentrated in terms of their core technology classes, implying that managers take decisions to innovate in the core areas of expertise. From the previous discussions we know that increasing the number and quality of patents increases the manager's wealth as the price pay sensitivity increases, since a patent grant leads to a positive stock price increase. We also know that concentrating on core technology classes increases both quantity and quality of patents. Thus one channel that managers may pursue to enhance the innovation metrics of a firm is to stick to the core technology areas.

We also find that the relation between pay price sensitivity and technology concentration is non-monotonic. At high levels of price pay sensitivity, technology concentration decreases, i.e. firms tend to broaden their technology fields. Such diversification may be a result of the manager's risk aversion at high levels of price pay sensitivity. They may want to explore newer technology areas in the hopes of increasing their patent portfolio. However, this effect is economically small and overall increasing price pay sensitivity makes firms more concentrated in their core technology areas. Interestingly, from column (1) we find that as managerial holdings increase the firm's technology portfolio becomes more diverse. This may be one of the reasons why innovation magnitude suffers as managerial holding increases, since we know that greater diversity leads to a lower number of patents. However, this result is not robust to the specification in column (2). Last, short-term cash incentives have no impact of the technology concentration of the firm.

We also find that greater R&D increases the technological concentration of the firm, and older and larger firms are more concentrated in their technology portfolio. Last we find that greater market competition leads to more diversification. Viewed together all the results suggest that price pay sensitivity of the managerial portfolio has a significant influence in shaping a firm's innovation strategy. Increased sensitivity leads to more R&D, a greater focus on the firm's core technological areas, and thus yields a larger number of high quality patents. Managerial holdings, on the other hand, lead to managerial entrenchment and a reduction in R&D expenditures and innovation magnitude. Short-term monetary incentives do not influence innovation strategies.

4. Attempts at Solving Endogeneity

One may also be concerned about endogeneity in our specifications. We have argued that the reason top 3 managers want to influence a firm's innovation performance is because it has a direct impact on their compensation packages. This implies that past innovation performance should directly impact current compensation packages. This feedback effect is not accounted for in the specifications. In addition, there may be some exogenous unobservables that may impact both innovation and managerial compensation. For example, more innovative firms may choose top managers who can provide leadership in newer innovation strategies. This selection issue is not controlled for in our specifications. Thus we attempt to solve these using an instrumental variable technique.

We use a strategy similar to that used by Lerner and Wulf (2007). In their paper they argue that for their data set the compensation of the CEO and the Human Resource manager have little to do with the firm's innovation. Rather it is the compensation of the R&D managers that drive patenting. However, there is a close link between the compensation structures of all the top managers, including the R&D heads. Thus they use the compensation of the non-R&D managers as instruments for the R&D manager's compensation. Aghion et. al.(2009) however, show that top managers such as CEO's, impact their firm's innovation. We combine the flavor of both papers and argue that while the top managers such as CEOs, CFOs and Presidents should influence the innovation strategies of a firm, the next level of managers, such as the head of HR, the marketing manager, or the advertising manager should have little impact on innovation.

However, the compensation structures of the top managers should be highly correlated. This allows us to use the compensation of the fourth and fifth top executive (by salary) as instruments for the top 3 executive compensation. The fourth and fifth top executive is a majority of companies is some combination of the marketing manager, advertising and sales manager of HR head.

Results are presented in Table 6A and B. In Table 6A, column (1) we estimate an identical specification to that in Table 2, except that we substitute the top 3 managerial compensation variables with those of the fourth and fifth managers. We find that the compensation of managers who comprise this fourth and fifth ranks, such as the advertising and marketing managers have no impact on patenting. However their compensation packages are fairly correlated with those of the top 3 managers and this makes the former ideal instruments, as seen in columns (2) – (5) which display the first stage models for the instrumental varoiable regressions. In Table 6B we present the results for the second stage model where we use the predicted compensation variables for the top 3 managers. Column (1) is estimated using a fixed effects instrumental variable model with the log of patent counts as the dependent variable. Column (2) is estimated using a manual two stage least squares, where this second stage equation is estimated using a fixed effects negative binomial model with patent counts as the dependent variable. Comparing column (1) and (2) with the same columns in Table 2, we find that the signs and significant is similar for the pay sensitivity compensation variables, which displays an inverted U-shape with respect to patenting activity. The holdings variable is strongly negative in Table 6B while it was negative only in column (2) in Table 2. The fact that we get similar signs and significance on the compensation variables shows that endogeneity may not be a big problem for our results.

Conclusion

This paper investigates how whether aligning manager and owner incentives can improve the innovation performance of firms. We find that price pay sensitivity, i.e. the sensitivity of managers' wealth to percent changes in his firm's stock price is the most important incentive mechanism that aligns managers' and shareholders' goals. We find that innovation magnitude, R&D and technology concentration have an inverted U-shape relationship with price pay sensitivity. All these variables first increase with price pay sensitivity, and then decrease at very high levels of price pay sensitivity. However, the quadratic term is economically insignificant is all cases and the overall impact is a positive one. Only patent quality has a positive linear relationship with pay sensitivity. Managerial holdings often have a negative impact on the innovation strategies of a firm and short-term monetary incentives have no impact.

We find that innovation magnitude has an inverted U-shape relationship with price pay sensitivity. Patenting initially increases with price pay sensitivity, consistent with the incentive-alignment effect, i.e. managers' incentives are aligned with those of shareholders. This can be related directly to Hall et. al (2000) finding that the event of a patent grant has a positive impact on a firm's financial value through changes in stock price. If manager's wealth portfolios are very sensitive to such price changes, then they would be more willing to increase the number of patents obtained by the firm since it will directly increase their wealth. However, for very large price pay sensitivities, patenting activity is dampened. Managerial holdings lead to entrenchment and have a negative effect on patenting. We find similar results for R&D.

Similar to the innovation magnitude and R&D results we find that quality increases as the price pay sensitivity increases. If better quality patents increase the stock prices of the firm by a larger amount then managers will tend to invest in producing better quality patents as their price pay sensitivity increases, as such action increases their personal wealth. This result confirms out finding about patents and R&D and show that price pay sensitivity can align managers' incentives with those of shareholders and induce managers to invest in R&D and produce better quality and increase number of patents and not "cut the salami too thin". In addition, there is no negative effect of risk-aversion at very high levels of price pay sensitivity. We also find that the relation between pay price sensitivity and technology concentration is non-monotonic. At high levels of price pay sensitivity, technology concentration decreases, i.e. firms tend to broaden their technology fields. Such diversification may be a result of the manager's risk aversion at high levels of price pay sensitivity.

We explain this behavior by drawing on Hall's (2004) finding that the event of a patent grant provides a positive shock to a firm's stock price. If manager's wealth portfolios are very sensitive to such price changes, then they would be more willing to increase the number of patents, produce better quality patents and invest more in R&D, which in turn increases the number and quality of patents, since it will directly increase their wealth. In addition, managers will concentrate more on core technology fields are this too increases the number and quality of patents while required less expenditure on R&D. Thus if share holders wish to align managerial incentives with the long-term goal of increasing the innovation potential of a firm, increasing the price pay sensitivity of a manager's wealth portfolio should achieve the goal.

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TABLE 1
Summary Statistics

	Mean	Median	SD	Min	Max
Dependent Variable					
Patent Count	38.297	3.000	164.633	0	4344
Log Patent Count	1.653	1.099	1.720	0	8.377
R&D Dummy	0.705	1.000	0.456	0	1.000
Log R&D Expenditure	2.580	2.808	2.274	-2.175	9.278
Log Average Adjusted Patent Quality	-11.800	-23.026	11.320	-23.026	2.548
Log Average Unadjusted Patent Quality	-10.412	-23.026	12.714	-23.026	5.832
Log Aggregate Adjusted Patent Quality	-10.417	-23.026	12.766	-23.026	8.683
Log Aggregate Unadjusted Patent Quality	-9.134	-23.026	14.054	-23.026	11.558
Log Technology Class Concentration	-0.517	-1.022	2.677	-3.219	10.434
Incentive Alignment					
Holdings (%) (Lag 1 Yr.)	3.136	0.414	7.177	0	45.148
Price Pay Sensitivity ($ '00 M) (Lag 1 Yr.)	0.402	0.101	1.185	0	9.778
Short-Term Incentive (Lag 1 Yr.)	34.619	36.456	19.895	0	89.109
Firm Innovation Environment					
Log Mean (Adjusted) Patent Quality (Lag 2 Yrs.)	-0.176	0	0.736	-5.033	2.849
Log Technology Class Concentration (Lag 2 Yr.)	-0.508	-1.022	2.708	-3.219	10.434
Past Patent Activity Dummy	0.980	1	0.141	0	1.000
Log (R&D Stock)(2000 M$)(Lag 2 Yrs.)	3.278	3.754	2.651	-4.472	10.392
Firm & Executive Characteristics					
Top 3 Executive Tenure (Lag 1 Yr.)	12.259	8.000	11.127	0	55.000
New CEO Dummy	0.221	0	0.415	0	1.000
Firm Age	37.498	35.000	21.316	1.000	126.000
Firm Size	7.099	7.027	2.023	0.000	13.713
Log Long Term Debt (Lag 2 Yrs.)	4.252	4.949	3.052	-5.394	12.962
Log Cash (Lag 2 Yrs.)	-0.480	-0.474	1.931	-10.366	6.514
Industry Characteristics					
Log Industry Concentration	6.240	6.213	0.818	0	9.002

Note: There are 8321 observations in the sample.

TABLE 2
Incentive Alignment and Innovation Magnitude

	(1)	(2)	(3)
Dependent Variable	Patent Count	Log (Patent Count)	
Model	FE Neg. Binom.	Linear FE	RE Tobit
Incentive Alignment			
Holdings (%) (Lag 1 Yr.)	0.001	-0.005*	-0.008***
	(0.002)	(0.003)	(0.003)
Price Pay Sensitivity ($ '00 M) (Lag 1 Yr.)	0.048**	0.067***	0.083**
	(0.023)	(0.024)	(0.036)
Price Pay Sensitivity Squared (Lag 1 Yr.)	-0.005**	-0.006**	-0.008**
	(0.002)	(0.003)	(0.004)
Short-Term Incentive (Lag 1 Yr.)	-0.001*	-0.00003	0.001
	(0.0004)	(0.0004)	(0.001)
Firm Innovation Environment			
Log Mean (Adjusted) Patent Quality (Lag 2 Yrs.)	0.117***	0.180***	0.135***
	(0.012)	(0.023)	(0.013)
Log Technology Class Concentration (Lag 2 Yr.)	0.075***	0.173***	0.321***
	(0.006)	(0.016)	(0.010)
Log Mean (Adjusted) Patent Quality * Log Tech. Class Conc. (Lag 2 Yrs.)	0.060***	0.074***	0.066***
	(0.004)	(0.010)	(0.006)
Firm & Executive Characteristics			
Top 3 Executive Tenure (Lag 1 Yr.)	0.0003	0.001	-0.001
	(0.001)	(0.001)	(0.001)
Firm Age	0.025***	0.036***	0.0002
	(0.004)	(0.009)	(0.005)
Firm Age Squared	-0.0001***	0.0001	-0.0002***
	(0.00004)	(0.0001)	(0.0001)
Firm Size	0.210***	0.166***	0.265***
	(0.016)	(0.032)	(0.019)
Firm Size * Firm Age	-0.002***	-0.001*	-0.001**
	(0.0003)	(0.0007)	(0.0004)
Industry Characteristics			
Industry Concentration	-0.123***	-0.045	-0.006
	(0.023)	(0.066)	(0.054)
Relevant Statistics			
Observations	8321	8236	8236
Number of Firms	1146	1146	1146
Chi-Sq Statistic/R-Square	2126.72	0.175	4893.95

Note: Specification in col. (1) is estimated using a panel data negative binomial model with industry fixed effects. Col. (2) is estimated using a linear fixed effects panel data model with robust standard errors clustered at the industry level. Col. (3) is estimated using a random effects panel data tobit model with industry fixed effects and censoring occurring when a the number of patents granted to a firm is 1 or less. There are 2732 censored observations. The sample for all the specifications is restricted to firms that have atleast 1 patent during our sample period. Table reports the coefficients (or unconditional marginal effects). The panel is unbalanced with minimum observations per group=2 and max=13. Range: 1993-2005. All specifications contain a constant and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

TABLE 3
Channels of Influence: RD Change

Dependent Variable	RD Dummy	Log(RD Expenditure)	
Model	(1) RE Probit	(2) OLS	(3) RE Tobit
Incentive Alignment			
Holdings (%) (Lag 1 Yr.)	-0.012	-0.023***	-0.008***
	(0.011)	(0.006)	(0.003)
Price Pay Sensitivity ($ '00 M) (Lag 1 Yr.)	0.293*	0.189*	0.105***
	(0.169)	(0.102)	(0.035)
Price Pay Sensitivity Squared (Lag 1 Yr.)	-0.023	-0.014	-0.011***
	(0.019)	(0.011)	(0.004)
Short-Term Incentive (Lag 1 Yr.)	0.001	0.003**	-0.001
	(0.003)	(0.001)	(0.001)
Firm Innovation Environment			
Log Mean (Adjusted) Patent Quality (Lag 2 Yrs.)	-0.004	0.036	0.030**
	(0.029)	(0.033)	(0.012)
Log Technology Class Concentration (Lag 2 Yrs.)		0.277***	0.034***
		(0.016)	(0.008)
Past Patent Activity Dummy	1.288**		
	(0.145)		
Firm & Executive Characteristics			
Top 3 Executive Tenure (Lag 1 Yr.)	0.008**	0.006*	0.004***
	(0.002)	(0.003)	(0.001)
New CEO Dummy	0.226***		
	(0.051)		
Firm Age	-0.004***	-0.032***	-0.006
	(0.001)	(0.007)	(0.007)
Firm Age Square		0.0002***	-0.0001
		(0.0001)	(0.0001)
Firm Size	0.315***	0.089**	0.689***
	(0.017)	(0.036)	(0.023)
Firm Age * Firm Size		0.002***	0.002**
		(0.001)	(0.001)
Log Cash (Lag 2 Yrs.)	-0.023	0.152***	0.029***
	(0.016)	(0.019)	(0.009)
Log Long Term Debt (Lag 2 Yrs.)	-0.091***		
	(0.011)		
Industry Characteristics			
Industry Concentration	0.204**	0.089	-0.041
	(0.091)	(0.132)	(0.054)
Relevant Statistics			
R-Square/ Chi-Sq Statistic		0.688	

Note: Col. (1): RE probit selection equation, dependent variable is the R&D dummy that equals 1 if RD>0. Col. (2): Selection corrected second stage using pooled OLS. S.E.s are robust and clustered by firm, and bootstrapped to correct for the inclusion of first stage estimates of the Mills ratio, which is negative and significant. Col. (3): RE tobit model with truncation occurring at RD=0. Unbalanced panel. Minimum obs =2 and max=13, total obs=8395, 1146 firms. Range: 1993-2005. All specifications contain a constant, industry and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

TABLE 4
Channels of Influence: Quality Change

Dependent Variable	Log (Average Patent Quality)		Log(Aggregate Patent Quality)	
	Unadjusted	Adjusted	Unadjusted	Adjusted
	(1a)	(1b)	(2a)	(2b)
Incentive Alignment				
Holdings (%) (Lag 1 Yr.)	-0.042	-0.037	-0.048	-0.044
	(0.044)	(0.039)	(0.046)	(0.041)
Price Pay Sensitivity ($ '00	0.985*	0.860*	1.084*	0.978*
M) (Lag 1 Yr.)	(0.620)	(0.561)	(0.664)	(0.598)
Price Pay Sensitivity	-0.081	-0.070	-0.089	-0.080
Squared (Lag 1 Yr.)	(0.068)	(0.060)	(0.071)	(0.063)
Short-Term Incentive (Lag 1	-0.005	-0.004	-0.004	-0.003
Yr.)	(0.011)	(0.010)	(0.011)	(0.010)
Firm Innovation Environment				
Log Technology Class	2.157***	1.900***	2.253***	2.303***
Concentration (Lag 2 Yrs.)	(0.137)	(0.121)	(0.144)	(0.129)
Log (R&D Stock)(2000	0.690***	0.627***	0.846***	0.773***
M$)(Lag 2 Yrs.)	(0.179)	(0.158)	(0.188)	(0.169)
Firm & Executive Characteristics				
Top 3 Executive Tenure (Lag 1	-0.005	-0.004	-0.005	-0.004
Yr.)	(0.024)	(0.021)	(0.025)	(0.022)
Firm Age	-0.435***	-0.389***	-0.462***	-0.413***
	(0.068)	(0.060)	(0.071)	(0.064)
Firm Age Square	0.004***	0.004***	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Firm Size	0.565*	0.485*	0.690**	0.623**
	(0.333)	(0.293)	(0.349)	(0.314)
Firm Age * Firm Size	0.006	0.005	0.006	0.005
	(0.007)	(0.007)	(0.008)	(0.007)
Industry Characteristics				
Industry Concentration	-0.813	-0.868	-0.864	-0.909
	(1.017)	(0.896)	(1.063)	(0.955)
Relevant Statistics				
Observations	8077	8077	8077	8077
Number of Firms	1204	1204	1204	1204
Chi-Sq Statistic	2923.65	2950.12	3208.26	3248.05

Note: We estimate each equation using a random effects panel data tobit model, with censoring occurring when a the number of citations =0. There are 3947 censored observations. Column (1a) and (2a) use the raw average and aggregate patent quality while (1b) and (2b) use the adjusted average and total patent quality. The adjusted variables are purged of patent-class fixed effects. Table reports the coefficients (or unconditional marginal effects). The panel is unbalanced with minimum observations per group=2 and max=13. Range: 1993-2005. All specifications contain a constant, industry and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

TABLE 5
Diversification v/s Concentration
Dependent Variable: Log Technology Class Concentration

	(1)	(2)
Model	RE Tobit	Linear FE
Incentive Alignment		
Holdings (%) (Lag 1 Yr.)	-0.009***	-0.006
	(0.003)	(0.006)
Price Pay Sensitivity ($ '00 M) (Lag 1 Yr.)	0.187***	0.141**
	(0.047)	(0.063)
Price Pay Sensitivity Squared (Lag 1 Yr.)	-0.013***	-0.010*
	(0.005)	(0.005)
Short-Term Incentive (Lag 1 Yr.)	0.0001	-0.001
	(0.0008)	(0.001)
Firm Innovation Environment		
Log (R&D Stock)(2000 M$)(Lag 2 Yrs.)	0.250***	0.085*
	(0.017)	(0.044)
Firm & Executive Characteristics		
Top 3 Executive Tenure (Lag 1 Yr.)	0.001	0.002
	(0.002)	(0.003)
Firm Age	0.014**	0.060**
	(0.007)	(0.024)
Firm Age Squared	0.0001	0.0001
	(0.0001)	(0.0002)
Firm Size	0.067***	0.047
	(0.022)	(0.050)
Firm Age * Firm Size	0.0002	-0.001
	(0.001)	(0.001)
Industry Characteristics		
Industry Concentration	-0.139**	-0.242*
	(0.071)	(0.149)
Relevant Statistics		
Observations	8222	8222
Number of Firms	1146	1146
Chi-Square/ R Square	1643.79	0.103

Note: We estimate column (1) the equation using a fixed effects panel data tobit model with industry fixed effects since the concentration index is bounded between 0 and 10000. However, for a positive number of patents, there is no censoring at the lower tail, and only 20 obs. are top censored. Column (2) uses a panel data fixed effects models with standard errors clustered by industry code. The panel is unbalanced with minimum observations per group=2 and max=13. Range: 1993-2005. All specifications contain a constant and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

TABLE 6A
Instrument Validity

	(1)	(2)	(3)	(4)	(5)
Dependent Variable	Patent Count	Holdings (%) (Lag 1 Yr.)	Pay Sen. (Lag 1 Yr.)	Pay Sen. Sq. (Lag 1 Yr.)	Sal./Bonus (Lag 1 Yr.)
Incentive Alignment					
Top 4 & 5 Holdings (%) (Lag 1 Yr.)	-0.020	0.205***	-0.157***	-0.949***	0.101
	(0.014)	(0.072)	(0.014)	(0.130)	(0.193)
Top 4 & 5 Price Pay Sensitivity ($ '00 M) (Lag 1 Yr.)	0.133	0.327	2.150***	7.408***	13.370***
	(0.102)	(0.739)	(0.143)	(1.341)	(1.988)
Top 4 & 5 Price Pay Sensitivity Squared (Lag 1 Yr.)	-0.007	-0.312	-0.272***	3.018***	-6.941***
	(0.054)	(0.427)	(0.082)	(0.776)	(1.149)
Top 4 & 5 Short-Term Incentive (Lag 1 Yr.)	-0.001	-0.002	0.002**	-0.001	0.842***
	(0.001)	(0.003)	(0.0005)	(0.005)	(0.008)
Firm Innovation Environment					
Log Mean (Adjusted) Patent Quality (Lag 2 Yrs.)	0.122***	-0.023	-0.006	-0.175	-0.127
	(0.014)	(0.067)	(0.013)	(0.119)	(0.177)
Log Technology Class Concentration (Lag 2 Yr.)	0.075***	0.140***	0.017**	0.152*	-0.283**
	(0.006)	(0.050)	(0.010)	(0.092)	(0.136)
Log Mean (Adj) Pat. Quality * Log Tech. Conc (Lag 2 Yrs)	0.062***	-0.008	-0.006	-0.009	0.069
	(0.005)	(0.027)	(0.005)	(0.049)	(0.073)
Log Patent Count (Lag 1 Yr.)		-0.218*	-0.023	-0.188	0.186
		(0.085)	(0.017)	(0.155)	(0.230)
Firm & Executive Characteristics					
Top 3 Executive Tenure (Lag 1 Yr.)	-0.0003	0.061***	0.011***	0.048***	-0.056***
	(0.001)	(0.007)	(0.001)	(0.013)	(0.019)
Firm Age	0.017***	-0.505***	-0.008	0.065	0.192*
	(0.004)	(0.035)	(0.007)	(0.063)	(0.094)
Firm Age Squared	-0.00003	0.003***	0.0002**	0.0001	0.0001
	(0.0001)	(0.0003)	(0.0001)	(0.001)	(0.001)
Firm Size	0.206***	-0.291***	0.050***	0.401***	0.118
	(0.017)	(0.079)	(0.015)	(0.144)	(0.214)
Firm Size * Firm Age	-0.002	0.005**	-0.001**	-0.006**	0.002
	(0.0003)	(0.002)	(0.0003)	(0.003)	(0.005)
Industry Characteristics					
Industry Concentration	-0.161***	0.831***	0.132**	0.743*	0.284
	(0.027)	(0.259)	(0.050)	(0.460)	(0.698)
Relevant Statistics					
Observations	6928	6978	6978	6978	6978
Number of Firms	1084	1133	1133	1133	1133
Chi-Sq Statistic/R-Square	1866.57	0.174	0.202	0.119	0.723

Note: Col. (1) estimated using a panel data negative binomial model with industry fixed effects. Shows that instruments have no effect on patenting. Col. (2)-(5) show the first stage regressions for the IV model, where the dependent variables are the compensation measures for the top 3 managers. These are estimated using a linear fixed effects model. The sample for all the specifications is restricted to firms that have at least 1 patent during our sample period. The panel is unbalanced with minimum observations per group=2 and max=13. Range: 1993-2005. All specifications contain a constant and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

TABLE 6B
Corrections for Endogeneity

	(1)	(2)
Dependent Variable	Patent Count	Log Patent Count
Model	FE Neg Bin	FE Linear
Incentive Alignment		
Predicted Holdings (%) (Lag 1 Yr.)	-0.024	-0.907***
	(0.024)	(0.221)
Predicted Price Pay Sensitivity ($ '00 M)	0.211***	0.759*
(Lag 1 Yr.)	(0.075)	(0.386)
Predicted Price Pay Sensitivity Squared	-0.058**	-0.101*
(Lag 1 Yr.)	(0.026)	(0.051)
Predicted Short-Term Incentive (Lag 1 Yr.)	-0.001	-0.003
	(0.001)	(0.004)
Firm Innovation Environment		
Log Mean (Adjusted) Patent Quality (Lag	0.125***	0.141**
2 Yrs.)	(0.015)	(0.061)
Log Technology Class Concentration	0.096***	0.236***
(Lag 2 Yr.)	(0.007)	(0.044)
Log Mean (Adjusted) Patent Quality *	0.056***	0.066***
Log Tech. Class Conc. (Lag 2 Yrs.)	(0.005)	(0.021)
Firm & Executive Characteristics		
Top 3 Executive Tenure (Lag 1 Yr.)	0.001	0.052***
	(0.001)	(0.015)
Firm Age	0.033***	-0.494***
	(0.011)	(0.116)
Firm Age Squared	0.0001	0.003***
	(0.0001)	(0.001)
Firm Size	0.166***	0.121
	(0.041)	(0.101)
Firm Size * Firm Age	-0.005***	-0.003*
	(0.001)	(0.001)
Industry Characteristics		
Industry Concentration	-0.113***	-0.719**
	(0.036)	(0.301)
Relevant Statistics		
Observations	5734	6978
Number of Firms	947	1133
Chi-Sq Statistic/R-Square	1603.12	0.122

Note: Col. (1) estimated using a panel data negative binomial model with industry fixed effects (manual 2SLS: bootstrapped SE). Col. (2) estimated using a linear FE model (Second stage of IV regression). The sample for all the specifications is restricted to firms that have atleast 1 patent during our sample period. Table reports the coefficients (or unconditional marginal effects). The panel is unbalanced with minimum observations per group=2 and max=13. Range: 1993-2005. All specifications contain a constant and year fixed effects. '***', '**' & '*' denotes significance at 1, 5 and 10 percent respectively.

Appendix: Incentive Alignment Measures

Managerial *Holdings* = number of shares of the firm held by the Top 3 Executives/total shares outstanding

Top 3 *price pay sensitivity* (or *delta*)= Top 3 Equity *delta* + Top 3 Option *delta* (or Equity *delta* if Option *delta* is missing)[29]

Top 3 Equity *delta* $= [\partial(\text{equity value}) / \partial(\text{stock price})]$ * stock price * 0.01

$=$ number of shares outstanding * stock price * 0.01

Top 3 Option *delta* = $\sum_{j=1}^{N} [\partial(\text{option value}_j) / \partial(\text{stock price})]$ * stock price * 0.01

Equity value is the number of shares outstanding multiplied by the stock price. We use the fiscal year end stock price reported by Execucomp, and if missing, we obtain it from Compustat. Option value is calculated using the Black-Scholes (1973) formula for European call options for every option grant *j* awarded to the top 3 executives, accounting for dividends according to Merton (1973). Thus, we require five inputs in addition to the stock price, namely: the options' exercise price and time to maturity, stock return volatility, the firm's dividend yield and the risk free rate. We follow Core and Guay's (2002) methodology to estimate option values, which involves using information from the firm's most recent proxy statement (available from Execucomp). For new option grants in a particular year, the exercise price and time to maturity are disclosed in the proxy statement. For options granted in previous years, we do the following: 1) We estimate the exercise price as the difference between the stock price and the average realizable value per option.[30] 2) The time to maturity of unexercisable option grants is the time to maturity of the most recent fiscal year's grant minus one year while the time to maturity of exercisable option grants is the time to maturity of unexercisable option grants minus three years. If no new grants were made in the most recent fiscal year, the time to maturity for unexercisable and exercisable option grants are nine and six years, respectively. Finally, we measure stock return volatility as the annualized standard deviation of monthly returns for the previous 60 months, reported by ExecuComp. If this is missing, it is calculated using CRSP data.[31] The dividend yield is the firm's average dividend yield over the past 3 years, reported by Execucomp. We use risk free rates (yields on U.S. Treasuries) corresponding to the time to maturity of the options. CEO *delta* is calculated in 2003 dollars. Please see Core and Guay (2002) for more details.

[29] There are 279 firm-year observations for which there is insufficient information to calculate the CEO's option *delta* and *vega*.

[30] Realizable value is the value realized by the CEO if the stock price is greater than the exercise price and the option is exercised. This is reported in Execucomp separately for exercisable and unexercisable options.

[31] Our findings are unchanged if we use the standard deviation of daily returns for the previous 252 trading days.