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Non-executive employee stock options and corporate innovation ☆

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ABSTRACT

We provide empirical evidence on the positive effect of non-executive employee stock options on corporate innovation. The positive effect is more pronounced when employees are more important for innovation, when free-riding among employees is weaker, when options are granted broadly to most employees, when the average expiration period of options is longer, and when employee stock ownership is lower. Further analysis reveals that employee stock options foster innovation mainly through the risk-taking incentive, rather than the performance-based incentive created by stock options.

Most great ideas for enhancing corporate growth and profits aren't discovered in the lab late at night, or in the isolation of the executive suite. They come from the people who daily fight the company's battles, who serve the customers, explore new markets and fend off the competition. In other words, the employees.

The Wall Street Journal (*August 23, 2010*) – *“Who Has Innovative Ideas? Employees.”*

1. Introduction

Innovation has become an increasingly important corporate strategy that boosts the long-term growth and enhances the competitiveness of a firm. Innovation is about people. Innovation arises when active, motivated, and engaged people generate ideas and convert them into new products, services, or business models. In recent years, most companies have changed the innovation process by replacing centralized corporate research and development (R&D) laboratories with divisional laboratories (Lerner and Wulf, 2007), making rank-and-file employees increasingly important innovators in corporations.[1] What can motivate non-executive employees to be

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[1] Anecdotal evidence in Harden, Kruse, and Blasi (2008, p. 4) supports the view that non-executive employees are highly important

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more innovative? In this paper, we examine the role of stock options, a key component of employee compensation, in engaging rank-and-file employees in innovative activities. We document a positive incentive effect of non-executive employee stock options on corporate innovation.[2]

Holmstrom (1989) points out that corporate innovation, unlike conventional investments in tangible assets, involves a high probability of failure due to its dependence on various unpredictable conditions. As a result, the standard incentive schemes based on the pay-for-performance principle are insufficient in encouraging innovations. Instead, the model of Manso (2011) and the experimental study of Ederer and Manso (2013) show that incentive schemes that tolerate early failure and reward long-term success lead to better innovation performance.

Building on prior literature, we expect non-executive employee stock options to have a positive effect on corporate innovation for four reasons. First, innovation requires risk-taking (Holmstrom, 1989). Non-executive employee stock options positively relate employee wealth to stock return volatility, incentivizing employees to take more risk in the innovation process. Second, rewards for long-term success and tolerance for early failure are crucial for innovation success (Manso, 2011). The asymmetric payoff structure of stock options not only rewards employees with unlimited upside potential when innovation succeeds and stock prices increase, but also protects them with limited downside loss when innovation fails and stock prices fall. Third, innovation projects are long-term, multi-stage, and labor-intensive (Holmstrom, 1989). Employee stock options normally have a long vesting period and a long average time to expiration.[3] To exercise their options, employees have to stay with their firms until options become exercisable (Core and Guay, 2001). Therefore, the deferral feature of employee stock options can effectively direct employees' attention to the firm's long-term success and encourage employees' long-term human capital investment in innovation (Rajan and Zingales, 2000). Finally, innovation takes teamwork.[4] The laboratory experiment of Ederer (2009) reveals that innovation success and performance are greatest when innovators receive a *group* incentive scheme that rewards long-term *joint* success. Non-executive employee stock options, as a group incentive scheme with value determined by employees' joint effort, can enhance cooperation between employees, induce mutual monitoring among co-workers (Baker, Jensen, and Murphy, 1988; Hochberg and Lindsey, 2010), and encourage information sharing and social learning between innovators, leading to greater innovation success.[5]

Using a large panel of US firms covered by the National Bureau of Economic Research (NBER) Patent and Citation Database, we document that non-executive employee stock options foster corporate innovation. Specifically, we follow Hochberg and Lindsey (2010) and define non-executive employees as all employees except the top five executives in a firm. We estimate the Black-Scholes value of non-executive employee stock options using data retrieved from the Investors Responsibility Research Center (IRRC) Dilution Database and ExecuComp. Our main results are that the value of non-executive stock options per employee is positively associated with the quantity and quality of innovation output, measured by the number of patents and the number of patent citations, respectively. The association is both economically and statistically significant. We then perform a variety of checks to ensure that our main results are robust to alternative model specifications and variable definitions. Furthermore, we use a number of tests to address the problem of omitted variables that are potentially related to firms' financial constraints, corporate governance, and industry geographic clustering, all of which could drive both innovation and employee stock options.

The findings that non-executive employee stock options and innovation are positively correlated, however, by themselves, do not establish a causal influence of employee stock options on innovation output. It is plausible that causation runs from innovation to employee stock options for at least two reasons. First, innovative firms may use stock options to sort and retain certain types of employees (e.g., Core and Guay, 2001). Second, successful innovative firms may be able to treat non-executive employees well by granting them more options without angering shareholders (e.g., Ittner, Lambert, and Larcker, 2003; Kroumova and Sesil, 2006).[6] Hence, the causal relation between non-executive employee stock options and innovation can be bidirectional, and the two directions of causality are not necessarily mutually exclusive.

To alleviate the concern about reverse causality, we control for several variables that capture innovative firms' incentive to use stock options to sort or retain employees.

(*footnote continued*)
innovators in a firm: "*Whirlpool credits their successful product innovations not to a couple of departments, such as engineering or marketing. Instead, they contribute their success to the 61,000 employees who have the ability to contribute and develop product, service, or processes innovations*."

[2] Companies widely recognize the positive effect of employee stock options on corporate innovation. For instance, Cisco Systems, Inc., the world leader in communication and information technology, stated in its high-tech policy guide (January 2005) that "*Employee stock options fuel innovation and the entrepreneurial spirit*." *Google*, one of the most innovative companies according to *Business Week*'s annual survey in 2010, describes its innovation policy as "*Our commitment to innovation depends on everyone being comfortable sharing ideas and opinions. Every employee is a hands-on contributor, and everyone wears several hats.*" In the meantime, according to the *New York Times* (November 12, 2007), *Google*'s current and former employees collectively held vested stock options that were worth roughly $2.1 billion as of November 2007.

[3] The vesting period of stock options refers to the amount of time it takes for options to become fully exercisable. The survey of National Center for Employee Ownership (2001) reveals that vesting periods of employee stock options generally range between one and seven years. Four years is the most common.

[4] Dougherty (1992) and Van de Ven (1986) show that team-based work increases the quantity and quality of innovation.

[5] Henderson and Cockburn (1994) show that the sharing of information and experiences among R&D workers positively affects firms' innovation performance.

[6] We thank the referee for pointing out this reverse causality. For example, General Electric grants options to lower-level employees with above-average performance evaluations, but only when the entire firm has performed well (Core and Guay, 2001).

In addition, we control for historical average innovation measures to explicitly account for past innovation success. Our main results are unaffected. Finally, we follow Hochberg and Lindsey (2010) and perform two-stage least squares (2SLS) regressions using a geographic instrumental variable, i.e., stock options granted to employees of *non-innovative* firms that are geographically proximate but are from *other* industries.[7] The main results still hold, suggesting a causal effect of per-employee value of stock options on innovation, although we cannot completely rule out endogeneity as a potential confounding factor.

We then partition our sample in several ways to examine how the positive effect of employee stock options on innovation varies across firms. We find that the effect of employee options is stronger (1) when rank-and-file employees are more important for innovation, i.e., the KLD employee treatment index or per-employee R&D expenditure is higher, (2) when free-riding problems are less severe among non-executive employees, i.e., the number of employees is smaller or the per-employee growth opportunities are higher, (3) when firms have broad-based (as opposed to targeted) non-executive option plans, which have been shown by previous studies (e.g., Hochberg and Lindsey, 2010) to enhance cooperation and mutual monitoring among employees, (4) when the average expiration period of stock options is longer, and (5) when employee stock ownership, which has been shown by Bova, Kolev, Thomas, and Zhang (2014) to discourage corporate risk-taking, is lower. These results further support our arguments for the positive effect of employee options on innovation.

Employee stock options can create both performance-based (delta) and risk-taking (vega) incentives for rank-and-file employees. To examine which incentive is more important in driving our results, we compute the employee option delta (the sensitivity of option value to stock price) and vega (the sensitivity of option value to stock volatility) arising from non-executive stock options. Our regression analysis reveals that the positive effect of employee options on innovation is driven by option vega rather than delta. Further analyses are performed to alleviate the concern that this result is driven by successful innovative firms granting more new options to employees. Additionally, we show that the strength of the risk-taking incentive relative to the performance-based incentive, measured as employee options' vega-to-delta ratio, is associated with better innovation outcomes. Finally, we find that the positive effect of vega on innovation mainly arises from firms with employee options that are not deep in the money, consistent with the notion that deep-in-the-money options weaken risk-taking incentives (Lewellen, 2006). In sum, these findings suggest that the positive effect of employee stock options on innovation mainly results from the risk-taking incentive of option vega, instead of the performance-based incentive of option delta.

Our paper contributes to the extant literature in two ways. First, while previous studies mainly emphasize the role of executives and the importance of managerial incentives in innovation,[8] our work focuses on non-executive employees who have become increasingly important innovators since the 1980s. To the best of our knowledge, we are among the first to show how rank-and-file employees and their compensation influence corporate innovation using a large-scale analysis. Our results shed light on the positive role of rank-and-file employees, as important stakeholders, in firm value creation via innovation. Second, our findings offer a new explanation for the theoretically puzzling occurrence of broad-based stock option plans in corporate America (Kedia and Rajgopal, 2009). We demonstrate that an important function of broad-based option plans is to foster innovation. By doing so, our analysis also discovers a specific channel through which non-executive stock options affect firm performance, and hence complements the findings of Hochberg and Lindsey (2010) who show a causal and positive impact of broad-based option programs on firm performance.

The remainder of the paper proceeds as follows. Section 2 provides additional discussion of the literature and hypotheses. We discuss our sample and variables in Section 3. We present our main empirical results in Section 4 and report additional results in Section 5. Section 6 concludes.

2. Related literature

By examining the impact of non-executive employee options on corporate innovation, we bring together two different strands of literature.

First, our paper contributes to the literature on corporate innovation. Motivated by Holmstrom (1989) and Manso (2011), empirical studies have identified various factors that affect managerial incentives for innovation. For instance, Tian and Wang (2014) find that Initial Public Offering (IPO) firms backed by more failure-tolerant venture capitalists exhibit higher innovation productivity. He and Tian (2013) show that analyst coverage has a negative impact on innovation because analysts exert too much pressure on managers to meet short-term goals. Aghion, Van Reenen, and Zingales (2013) find that higher institutional ownership ensures Chief Executive Officers (CEOs) a secure job and hence helps overcome CEOs' myopia and promotes innovation productivity. Chang, Hilary, Kang, and Zhang (2013) show that conservative accounting, which fosters the early recognition of losses, reduces the tolerance for early failures and impedes innovation. Chemmanur and Tian (2011) document that firm-level anti-takeover provisions protect managers against short-term pressures from the corporate control market, encouraging them to focus on long-term valu-enhancing innovative activities. However, Atanassov (2013) uses the enactments of state-level anti-takeover laws to show that hostile takeovers monitor and discipline top managers, leading to better innovation outcomes. Fan and White (2003) and Armour and Cumming (2008) show that “forgiving” personal bankruptcy laws encourage entrepreneurship and innovation. Francis, Hasan, and Sharma (2011) show that golden parachutes and stock options of executives enhance

[7] We discuss the pros and cons of this instrument in Section 4.2.3.

[8] We review the literature in greater detail in Section 2.

innovation. Hirshleifer, Low, and Teoh (2012) find that overconfident CEOs can better exploit innovative growth opportunities and generate greater innovation success.

We focus on the role of rank-and-file employees in innovation, which is still an underexplored topic in the literature. By doing so, our study complements Acharya, Baghai, and Subramanian (2009, 2014) who find that stringent labor laws and wrongful discharge laws that do not punish employees for short-term failures foster innovations, and Baccara and Razin (2009) who argue that an innovation bonus to employees could guarantee that innovation takes place.

The second strand of literature focuses on the economic functions of stock options, which are granted to non-executive employees on a large-scale basis. A few studies reveal various motives for firms to grant stock options to non-executive employees. For instance, employee stock options can be used by cash-constrained firms as a substitute for cash wages (Core and Guay, 2001; Yermack, 1995). Employee stock options are tax deductible and hence are able to generate substantial non-debt tax shields (Graham, Lang, and Shackelford, 2004; Babenko and Tserlukevich, 2009). Firms also use non-executive options to sort and retain certain types of employees. By assuming that employees have heterogeneous beliefs, Oyer and Schaefer (2005) posit that employee stock options attract optimistic and productive employees who value their firm's stock options more than the market price.

However, the incentive effect of non-executive stock options is still under debate. Oyer (2004) refers to non-executive stock options as “incentives that have no incentive effects.” Because stock options granted to rank-and-file employees reward them for joint performance improvements, free-riding stemming from an individual worker's inability to substantially affect option value herself may dominate the positive incentive effect. In contrast, Hochberg and Lindsey (2010) find that the pay-for-performance sensitivity created by employee stock options reinforces the mutual monitoring and cooperation among rank-and-file employees, resulting in better firm operating performance. Our paper adds to this literature by showing that non-executive stock options incentivize rank-and-file employees to innovate.

Moreover, the convexity of the wealth-performance relation, a distinct feature of stock options, promotes risk-taking incentives (Murphy, 2003). This feature has received extensive attention in studies on the relation between executive compensation and risk-taking (e.g., Smith and Stulz, 1985; Guay, 1999; Coles, Daniel, and Naveen, 2006; Low, 2009). However, few studies examine this feature in the framework of non-executive employee compensation. In a paper contemporaneous to ours, Bova, Kolev, Thomas, and Zhang (2014) show that employees who hold stocks of their own company have strong incentives to reduce corporate risk because they are risk-averse and have their human capital closely tied to their employer's fortune. Our study, however, shows that when employees hold stock options instead, their risk-taking incentives increase. This feature, together with other features of non-executive stock options, namely, failure tolerance, encouraging long-term perspectives, and promoting team-based work, makes non-executive employee stock options an effective stimulator for innovation.

3. Data, variables, and summary statistics

3.1. Data and sample

We obtain data on employee stock options from the Investors Responsibility Research Center (IRRC) Dilution Database, which covers Standard and Poor's (S&P) 1,500 firms between 1997 and 2005. This data set contains firm-level information on options granted to all employees, including year-end outstanding option grants, the weighted average exercise price and weighted average contractual life of options outstanding, and other characteristics of employee option portfolios. To separate non-executive employee options from executive options, we match the IRRC data with the data from Compustat ExecuComp database. ExecuComp provides information on options outstanding for top executives in a firm. Financial data are from the Compustat Industrial Annual files. Data on stock prices and returns are retrieved from the Center for Research in Security Prices (CRSP) files.

To measure the quantity and quality of innovation output, we use data from the NBER Patent and Citation Database, which provides detailed information on all U.S. patents granted by the U.S. Patent and Trademark Office between 1976 and 2006. There is, on average, a two-year lag between the date when inventors file for patents (the application date) and the date when patents are granted. Since the latest year in the NBER data set is 2006, patents applied for in 2004 and 2005 may not be completely covered by the database as it only includes patents eventually granted. As suggested by Hall, Jaffe, and Trajtenberg (2001), we end our sample period in 2003 to address this issue.[9]

Following Hirshleifer, Low, and Teoh (2012), we exclude firms in any four-digit Standard Industrial Classification (SIC) industries that have no patents between 1976 and 2006 and firms in financial and utility industries (SIC codes: 6000–6999 and 4900–4999, respectively). Also excluded are firms with missing values for non-executive and executive options and for variables employed in the regressions. These restrictions result in a final sample that consists of 1,394 firms (5,640 firm-years) between 1998 and 2003. Our sample starts in 1998 because we use the one-year lagged value of non-executive employee stock options when predicting innovation output. Appendix A tabulates the sample construction in greater detail.

3.2. Measuring innovation output

Our first measure of innovation output is the number of patents applied for by a firm in a given year (*Patents*). Patent counts, however, imperfectly capture innovation

[9] We use the patent application year rather than the grant year to merge the NBER and IRRC databases since Hall, Jaffe, and Trajtenberg (2001) suggest that the application date, as compared to the grant date, is closer to the actual time of inventions.

success because patents vary drastically in their technological and economic significance (Hirshleifer, Low, and Teoh, 2012). We therefore follow Hall, Jaffe, and Trajtenberg (2001, 2005) and use forward citations of a patent to measure its quality (importance).[10] The raw citation counts suffer from truncation bias due to the finite length of the sample. As patents receive citations from other patents over a long period of time, patents in the later years of the sample have less time to accumulate citations. We use two methods to deal with this truncation bias. First, we adjust each patent's raw citation counts by multiplying it with the weighting index of Hall, Jaffe, and Trajtenberg (2001, 2005) provided in the NBER database. The weighting index is derived from a quasi-structural model, where the shape of the citation-lag distribution is econometrically estimated. *Qcitations* is then the sum of the adjusted citations across all patents applied for during each firm-year. Second, we adjust the raw citation counts using the fixed-effect approach, which involves scaling the raw citation counts by the average citation counts of all patents applied for in the same year and in the same technology class. The fixed-effect approach accounts for the differing propensity of patents in different years and in different technology classes to cite other patents.[11] We use *Tcitations* to denote the sum of the adjusted citations during each firm-year under this alternative adjustment approach.

3.3. Measuring non-executive employee stock options

Firms do not explicitly disclose information regarding options granted to non-executive employees. We follow the methodology of Hochberg and Lindsey (2010) when computing the Black-Scholes value of non-executive employee stock options. Specifically, we first use data from the IRRC database to estimate the Black-Scholes value of outstanding options held by all employees.[12] We then estimate the Black-Scholes value of outstanding options held by the top five executives based on the information provided by ExecuComp. Finally, the Black-Scholes value of non-executive employee options is equal to the difference between the value of options for all employees and the value of options for the top five executives. To mitigate heteroskedasticity, we scale the Black-Scholes value of non-executive employee options using the number of non-executive employees. The resulting measure (*EmpOpt*), the per-employee value of non-executive stock options, is the key variable of our interest in the regressions.

3.4. Control variables

To isolate the effect of non-executive employee stock options on innovation output, we control for an array of firm characteristics that have been documented as important determinants of innovation by previous studies. The first control variable is R&D expenses scaled by total assets (*R&D/Assets*), which serves as an important input to innovation, apart from human capital and the efforts and creativity of managers and employees (Atanassov, 2013). Hall and Ziedonis (2001) argue that large firms and capital-intensive firms generate more patents and citations. We thus use the natural log of total assets (*Ln* (*Assets*)) to control for firm size. Our results are robust to the use of net sales or the number of employees as proxies for firm size. We use the log of the net Property, Plant, and Equipment (*PPE*) scaled by the number of employees (*Ln* (*PPE/#employees*)) to account for capital intensity. The log of the net sales scaled by the number of employees (*Ln* (*Sales/#employees*)) is included to proxy for labor productivity and quality as higher labor productivity may lead to higher innovation productivity. Return on assets (*ROA*) is included to capture operating profitability and the buy-and-hold stock return computed over the fiscal year (*Stock return*) is included to capture stock performance. Also included are *Sales growth* and the market-to-book ratio (*M/B*) as proxies for growth opportunities. The cash-to-assets ratio (*Cash/Assets*) and the leverage ratio (*Leverage*) are added to account for the effects of cash holdings and capital structure on innovation. To control for the effect of a firm's life cycle on its innovation ability, we employ the natural log of firm age, *Ln*(*Firm age*), which is the number of years elapsed since a firm enters the CRSP database.

Additionally, given that Chan, Lakonishok, and Sougiannis (2001) document that R&D investments are positively associated with stock return volatility, we include the standard deviation of daily stock returns over the fiscal year (*Stock volatility*) as an additional control. Aghion, Bloom, Blundell, Griffith, and Howitt (2005) find an inverted U-shape relation between product market competition and innovation. Accordingly, similar to Atanassov (2013) and Chemmanur and Tian (2011), we include as control variables the three-digit SIC Herfindahl index (*Herfindahl*) and its squared term (*Herfindahl*^{2}).

Finally, Francis, Hasan, and Sharma (2011) show that stock options granted to corporate executives have a positive effect on innovation output. Thus, we control for the average value of stock options across the top five executives, *ExeOpt*. All variables are winsorized at the 1% level at both tails of their distributions. Except for *Stock return* and *Stock volatility*, which are measured between year $t-1$ and t, all control variables are measured at $t-1$ in the regressions. Dollar values are converted into 2000

[10] We include self-citations since Hall, Jaffe, and Trajtenberg (2005) find that self-citations are more valuable than external citations. They argue that self-citations, which come from subsequent patents, reflect strong competitive advantages, less need of technology acquisitions, and lower risk of rapid entry.

[11] See Atanassov (2013) and Hirshleifer, Low, and Teoh (2012) for detailed discussions on the advantages and disadvantages of this approach.

[12] When calculating the value of non-executive stock options and related incentive measures, we do not use the Black-Scholes inputs in the IRRC database because they are company-supplied inputs and can be biased if firms want to avoid reporting large earnings expenses associated with stock options. Following Hayes, Lemmon, and Qiu (2012), we compute annualized volatility of the past 36 months' monthly stock returns and the dividend yield using the CRSP and Compustat. Risk-free rates are retrieved from the Federal Reserve files. All option values are measured at the fiscal year-end. Similar to Hochberg and Lindsey (2010), we treat all options as exercisable when calculating their average life to expiration.

constant dollars using the Gross Domestic Product (GDP) deflator.

3.5. Descriptive statistics

Columns 1–3 of Table 1 respectively report means, medians, and standard deviations of the variables used for the whole sample. We divide firms into two subsamples according to the median value of options per non-executive employee (*EmpOpt*) each year, and report mean values of the variables in columns 4 and 5 for high and low *EmpOpt* firms separately. We test the mean differences of variables between the two subsamples and report the levels of significance in column 5. Similar inferences are drawn using the *Wilcoxon-Mann-Whitney* test (untabulated) on the differences in median values between the two subsamples.

For our corporate innovation measures, an average firm in our sample applies for roughly 14 patents and receives 46 raw citations for its patents every year. The average citations of patents adjusted based on the weighting scheme of Hall, Jaffe, and Trajtenberg (2001, 2005) (*Qcitations*) and on the year and technology class fixed-effect method (*Tcitations*) are around 144 and 15, respectively. The distributions of patent and citation counts are highly skewed. Untabulated statistics reveal that approximately 52% (58%) of firms apply for no patents (receive no citations) in a given year, thus the median number of patent (citation) counts is zero.

The distribution of *EmpOpt* shows positive skewness as well. On average, each non-executive employee holds about \$50,200 worth of stock options, while the median non-executive employee has roughly \$8,500 worth of stock options. In contrast, options held by an average executive are worth \$7.6 million, 152 times more valuable than those held by an average non-executive employee. However, the total value of options held by all non-executive employees is, on average, 7.5 times as large as the value of options held by all top five executives,

Table 1
Summary statistics.

The sample consists of 5,640 firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. The high (low) *EmpOpt* subsample contains firms with above (below) median values of *EmpOpt* in each year. *EmpOpt* is value of non-executive stock options per employee. *ExeOpt* is average value of stock options across the top five executives. *Qcitations* and *Tcitations* are patent citations adjusted using the weighting index of Hall, Jaffe, and Trajtenberg (2001, 2005) and the method of time-technology class fixed effect, respectively. *Assets* is book value of total assets. *PPE/#employees* is net Property, Plant, and Equipment (*PPE*) scaled by the number of employees. *Sales/#employees* is net sales scaled by the number of employees. *ROA* is Earnings Before Interest, Taxes, and Depreciation and Amortization (EBITDA) over *Assets*. *Sales growth* is change in net sales scaled by lagged net sales. Market-to-book ratio (*M/B*) is (*Assets*+Market value of equity−Book value of equity)/*Assets*. *Cash/Assets* is cash-to-assets ratio. *Leverage* is (Short-term debt+Long-term debt)/*Assets*. *Firm age* is the number of years elapsed since a firm enters the CRSP database. *R&D/Assets* is R&D expenses scaled by book value of total assets. *Stock return* is buy-and-hold stock returns computed over the fiscal year. *Stock volatility* is standard deviation of daily stock returns over the fiscal year. *Herfindahl* index is computed based on the three-digit SIC code. All variables are winsorized at the 1% level at both tails of the distribution. Dollar values are converted into 2000 constant dollars using the GDP deflator. *T*-tests are conducted to test for differences in mean values between the high and low *EmpOpt* subsamples. The symbols ***, **, and * indicate that subsample means are significantly different from each other at the 1%, 5%, and 10% levels, respectively.

	Whole sample $N=5{,}640$			High *EmpOpt* $N=2{,}819$	Low *EmpOpt* $N=2{,}821$
	Mean (1)	Median (2)	SD (3)	Mean (4)	Mean (5)
Number of patents (raw)	13.5	0	28.2	16.7	10.3***
Number of citations (raw)	45.7	0	135.0	62.3	29.0***
Qcitations	143.5	0	346.8	189.9	97.3***
Tcitations	14.9	0	32.4	18.9	10.9***
Options per employee (*EmpOpt*) in \$1,000	50.2	8.5	119.0	97.1	3.3***
Options per executive (*ExeOpt*) in \$1,000	7,639	2,716	13,092	11,348	3,933***
Total employee options in \$millions	287.5	55.5	956.1	502.6	72.6***
Total executive options in \$millions	38.2	13.6	65.5	56.7	19.7***
Assets (\$millions)	4,910	1,277	10,006	4,937	4,884
Number of employees (in 1,000)	17.9	6.1	27.5	11.5	24.3***
Firm age (years)	23.4	17.0	17.9	18.4	28.3***
R&D/Assets	0.04	0.01	0.06	0.06	0.01***
PPE/#employees (in \$1,000)	149.7	46.9	412.9	215.7	83.7***
Sales/#employees (in \$1,000)	322.6	224.0	354.7	414.9	230.4***
ROA	0.10	0.10	0.11	0.10	0.10
M/B	2.30	1.66	1.97	3.06	1.54***
Sales growth	0.13	0.07	0.36	0.19	0.07***
Leverage	0.22	0.23	0.17	0.18	0.27***
Cash/Assets	0.14	0.05	0.18	0.21	0.06***
Stock volatility	0.03	0.03	0.01	0.04	0.03***
Stock return	0.13	0.05	0.58	0.15	0.11**
Herfindahl index	0.18	0.12	0.16	0.14	0.21***

suggesting that more stock options are held by non-executive employees as a whole, rather than by the top five corporate executives.

Firms in the high *EmpOpt* subsample, relative to low *EmpOpt* firms, are significantly more innovative in terms of the numbers of patents and citations, raw and adjusted. By looking at the mean differences in firm characteristics between the two subsamples, we find that firms with more non-executive employee stock options are younger and have fewer employees, greater growth opportunities, higher capital intensity and labor quality, lower leverage, more cash holdings, and higher but more volatile stock returns. In addition, they make more R&D investments and operate in more competitive industries than their low *EmpOpt* counterparts. Although interesting, these unconditional relations require more refined multivariate tests, which we turn to next.

4. Main results

4.1. The baseline model

We examine the effect of non-executive stock options per employee on a firm's innovation output using the baseline model as follows:

$$Ln(1+Innovation_{i,t}) = \alpha + \beta Ln(1+EmpOpt_{i,t-1}) + \gamma X_{i,t-1} + \delta Industry_{i,t} + \theta Year_t + \varepsilon_{i,t}, \tag{1}$$

where $Innovation_{i,t}$ refers to our innovation measures (*Patents*, *Qcitations*, and *Tcitations*) of firm i in year t. The key explanatory variable is *EmpOpt*, measured at the end of year $t-1$. To reduce skewness of our innovation measures, *EmpOpt*, and *ExeOpt*, we use the log of one plus these variables in the regression analyses. X represents the set of control variables defined in Section 3.4. We also include two-digit SIC industry and year fixed effects in the model.[13] The standard errors of the estimated coefficients allow for clustering of observations by firm but our conclusions are not affected if we allow clustering by both firm and year.

Table 2 reports the results of our baseline regressions in Eq. (1). We find that $Ln(1+EmpOpt)$ is positively and significantly associated with all three measures of innovations, $Ln(1+Patents)$, $Ln(1+Qcitations)$, and $Ln(1+Tcitations)$ with t-statistics of 3.5, 3.5, and 3.7, respectively. Economically, increasing *EmpOpt* from its 25th percentile ($2,722) to the 75th percentile ($33,812) increases the values of *Patents*, *Qcitations*, and *Tcitations* by almost 96%, 141%, and 105% from their respective means.[14] Untabulated statistics show that the mean Variance Inflation Factor (VIF) is below 2, suggesting that multicollinearity is not an issue in our setting.

We find that the value of executive stock options, $Ln(1+ExeOpt)$, also has positive effects on innovation, but the coefficients are statistically insignificant (t-statistics are 0.3, 0.9, and 0.6, respectively, in columns 1–3). In terms of economic significance, increasing *ExeOpt* from its 25th percentile ($858,634) to the 75th percentile ($7,625,985) increases the values of *Patents*, *Qcitations*, and *Tcitations* by 1%, 6%, and 3% from their respective means. Similar results (untabulated) are obtained if we use the value of options held by CEOs, instead of top five executives.[15] Collectively, these results indicate that non-executive employee stock options are more strongly related to innovation than executive options.

The coefficients of other control variables are generally consistent with prior literature. For example, we find that firms with larger R&D expenditures are associated with higher innovation productivity. Larger and older firms have more patents and citations. Firms with lower leverage and firms with higher *M/B*, stock return volatility, and stock performance have more innovation output.

We perform a number of additional tests to ensure that our main results are robust to alternative model specifications and variable definitions. For the sake of brevity, we only tabulate the coefficients of key variables in Appendix B. In particular, none of the following has a major effect on our results: (a) running negative binomial regressions (instead of Ordinary Least Squares (OLS) regressions) to address the issue that patent and citation counts are non-negative and discrete;[16] (b) defining non-executive employee options using the calibration method of Oyer and Schaefer (2005) to mitigate the concern that our definition of non-executive employees may wrongly include executives other than the top five;[17] (c) scaling

[13] Both our innovation measures and *EmpOpt* are highly persistent variables, therefore, we include industry fixed effects rather than firm fixed effects in the regressions. The first-order autocorrelations for $Ln(1+Patents)$, $Ln(1+Qcitations)$, $Ln(1+Tcitations)$, and $Ln(1+EmpOpt)$ are 0.95, 0.88, 0.91, and 0.87, respectively. Zhou (2001) points out that the persistence of key variables can reduce the signal-to-noise ratio and lower the power of panel data estimators.

[14] Because $d[Ln(1+y)]/d[Ln(1+x)] = [(1+x)/(1+y)]\ dy/dx$, $dy = d[Ln(1+y)]/d[Ln(1+x)] \times [(1+y)/(1+x)]dx$. For example, when quantifying the effect of the change in *EmpOpt* (dx) on the change in *Patents* (dy), we increase *EmpOpt* from its 25th percentile ($2,722) to the 75th percentile ($33,812), so $dx = \$31,090$. The change in *Patents* (dy) from its (*footnote continued*) mean value (13.5) is then equal to $0.078 \times [(1+13.5)/(1+2{,}722)] \times 31{,}090 = 12.9$, which amounts to 96% of the mean value of *Patents*.

[15] More specifically, the coefficients of the value of CEO options are 0.004, 0.010, and 0.004, respectively, in columns 1–3. The corresponding t-statistics are 1.0, 1.6, and 1.0. When investigating the effect of CEO compensation on innovation over the period of 1992–2006, Francis, Hasan, and Sharma (2011) consider the value of CEOs' newly granted options and CEOs' vested and unvested options. They use the number of patents and the number of citations per patent to measure innovation output. We are able to replicate their results using our sample and their regression models. More importantly, after augmenting their models by including the value of non-executive employee stock options, we find that the coefficients on employee stock options are all significant at the 1% level. These results are available upon request.

[16] For this test, the dependent variables are the numbers of patents and adjusted citations, rather than their log values. In addition, to control for the time-invariant firm characteristics that can be correlated with innovation output, we use a mean scaling approach (Aghion, Van Reenen, and Zingales, 2013), which involves including the pre-sample average of patents and citations between 1976 and 1997 in the negative binomial model, and obtain similar results.

[17] Specifically, we assume that the high-level management other than the top five receives an average option grant one-tenth as large as that received by the average executive in the second through fifth compensation ranks. But unlike Oyer and Schaefer (2005) who assume that the number of these high-level managers is 10% of the total number of employees, we follow Kumar, Page, and Spalt (2011) by assuming that the number of high-level managers in a firm can be approximated by the

Table 2
Effects of non-executive stock options per employee on innovation output.

The sample consists of 5,640 firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. *EmpOpt* is value of non-executive stock options per employee. *ExeOpt* is average value of stock options across the top five executives. *Patents* is the number of patents applied for. *Qcitations* and *Tcitations* are patent citations adjusted using the weighting index of Hall, Jaffe, and Trajtenberg (2001, 2005) and the method of time-technology class fixed effect, respectively. *Assets* is book value of total assets. *PPE/#employees* is net Property, Plant, and Equipment (*PPE*) scaled by the number of employees. *Sales/#employees* is net sales scaled by the number of employees. *ROA* is EBITDA/*Assets*. *Sales growth* is change in net sales scaled by lagged net sales. *M/B* is (*Assets*+Market value of equity−Book value of equity)/*Assets*. *Cash/Assets* is cash-to-assets ratio. *Leverage* is (Short-term debt+Long-term debt)/*Assets*. *Firm age* is the number of years elapsed since a firm enters the CRSP database. *R&D/Assets* is R&D expenses scaled by book value of total assets. *Stock return* is buy-and-hold stock returns computed over the fiscal year. *Stock volatility* is standard deviation of daily stock returns over the fiscal year. *Herfindahl* index is computed based on the three-digit SIC code. Constant terms are included but not reported. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Ln(1+*Patents*) OLS (1)	*Ln*(1+*Qcitations*) OLS (2)	*Ln*(1+*Tcitations*) OLS (3)
Ln(1+ *EmpOpt*)	0.078***	0.123***	0.086***
	(3.5)	(3.5)	(3.7)
Ln(1+ *ExeOpt*)	0.001	0.007	0.003
	(0.3)	(0.9)	(0.6)
R&D/Assets	6.184***	9.976***	6.079***
	(8.6)	(8.3)	(8.0)
Ln(*Assets*)	0.537***	0.775***	0.547***
	(19.0)	(17.7)	(18.4)
Ln(*Firm age*)	0.121***	0.164**	0.111**
	(2.7)	(2.4)	(2.4)
Ln(*PPE/#employees*)	−0.029	−0.033	−0.028
	(−0.7)	(−0.5)	(−0.6)
Ln(*Sales/#employees*)	−0.074	−0.104	−0.084
	(−1.5)	(−1.3)	(−1.6)
ROA	1.127***	1.821***	1.089***
	(4.3)	(4.1)	(3.8)
M/B	0.037***	0.073***	0.047***
	(2.6)	(2.9)	(2.9)
Sales growth	−0.216***	−0.318***	−0.220***
	(−4.5)	(−3.9)	(−4.5)
Leverage	−0.488**	−0.773**	−0.515**
	(−2.5)	(−2.5)	(−2.5)
Cash/Assets	0.126	0.054	−0.005
	(0.6)	(0.2)	(−0.0)
Stock volatility	4.257**	8.390***	5.562***
	(2.2)	(2.6)	(2.6)
Stock return	0.099***	0.201***	0.122***
	(3.8)	(4.1)	(4.1)
Herfindahl	0.219	0.505	0.124
	(0.4)	(0.6)	(0.2)
Herfindahl^2	−0.027	−0.022	0.140
	(−0.1)	(−0.0)	(0.2)
Industry and year fixed effects	Y	Y	Y
N/*R*-squared	5,640/0.53	5,640/0.50	5,640/0.49

total value of non-executive stock options by market capitalization;[18] (*d*) using the value of newly granted (rather than total) non-executive stock options; (*e*) replacing $EmptOpt_{t-1}$ by $EmptOpt_{t-2}$ in Eq. (1) to account for the possibility that it may take more than one year for option incentives to take effect; (*f*) excluding self-citations when defining *Qcitations* and *Tcitations*; (*g*) excluding firm-years with zero patents and citations; (*h*) using as dependent variable, the average citations per patent (rather than total citations) that measure the average importance of patents; (*i*) excluding firms engaging in mergers and acquisitions (identified using the Securities Data Company Mergers & Acquisitions (SDC M&A) database) in the previous two years, to address the concern that firms may acquire patents and citations through takeovers rather than via in-house innovation activities incentivized by stock options; (*j*) excluding the period of the technology boom (1998–2000), to avoid the effect of the aggressive

(*footnote continued*)
square root of the total number of employees. Kumar, Page, and Spalt (2011) argue that the linear estimation of Oyer and Schaefer (2005) is likely to overstate the number of executives in large firms.

[18] Alternatively, we measure employee incentives using the total number of non-executive stock options scaled by the number of shares outstanding. Our results remain qualitatively the same.

use of non-executive employee stock options by new-economy firms during this period (Ittner, Lambert, and Larcker, 2003; Murphy, 2003).

4.2. Endogeneity issues

Although we document a strongly positive association between non-executive employee stock options and innovation output, the results are potentially subject to two types of endogeneity. The first type is omitted variable bias. While we have controlled for a standard set of variables that have been shown by previous studies to affect innovation, the relation that we observe may be spurious if our model omits any variables that affect both corporate innovation and the value of non-executive stock options. The other possible endogeneity issue is reverse causality running from innovation to employee options. In both cases, the coefficient estimates from the OLS regressions are biased and inconsistent. To address these endogeneity issues, our first strategy is to explicitly describe issues related to potential omitted variables and reverse causality that we can think of, and design specific tests to address them. We tabulate the results in Table 3. While all control variables in Eq. (1) are still included in the new tests, we only report the coefficients of $Ln(1+EmpOpt)$ and the newly added variables for brevity. In our second strategy, we use the instrumental variable approach to mitigate any remaining endogeneity concerns. The results of the instrumental variable approach are tabulated in Table 4.

4.2.1. Potential omitted variables

The use of stock options for employee compensation can potentially alleviate firms' financial constraints through two channels, i.e., saving cash when options are granted (Core and Guay, 2001) and generating substantial cash inflows from the proceeds and associated tax benefits when the options are exercised (Babenko, Lemmon, and Tserlukevich, 2011). Thus, to the extent that innovative firms are financially constrained because of pressing investment needs for innovation, they may pay non-executive employees with stock options instead of cash, leading to a positive relation between employee options and innovation output. While we have included cash holdings in Eq. (1), to further mitigate the concern that financial constraints may drive our findings, we augment our baseline model by including as additional control variables Hadlock and Pierce's (2010) index of financial constraints, and the proceeds and tax benefits generated by option exercises.[19] The results, reported in Panel A of Table 3, suggest that the effect of financial constraints on innovation is significantly negative, while the impact of option proceeds and tax benefits on innovation is insignificant. More importantly, our main results still hold.

Corporate governance may affect both employee options and corporate innovation. On one hand, entrenched managers may dole out generous stock option packages to employees to buy a quiet life in poorly governed firms (Bertrand and Mullainathan, 2003). On the other hand, Chemmanur and Tian (2011) show that firms shielded with a larger number of anti-takeover provisions generate better innovative outcomes because anti-takeover provisions alleviate the short-term pressure on managers from the corporate control market. In addition, while institutional holdings reduce the demand for employee stock options as an incentive scheme (Eisenhardt, 1988), Graves (1988) finds that institutional investors negatively affect firm innovation in the computer industry due to their short-termism. To ensure our findings are not driven by corporate governance, we add to Eq. (1) a set of governance measures, including the governance index (*G-index*) compiled by Gompers, Ishii, and Metrick (2003), board size, and the level of institutional holdings. Panel B of Table 3 reveals that these additional controls do not affect our main results.[20]

Industry geographic clustering may contribute to the correlation between employee options and innovation. Engelberg, Ozoguz, and Wang (2010) show that firms in the same industry cluster exhibit significant correlation in firm fundamentals. Jaffe, Trajtenberg, and Henderson (1993) and Ellison, Glaeser, and Kerr (2010) provide evidence of knowledge spillovers within geographic clusters. Furthermore, Kedia and Rajgopal (2009) show that a firm's option grants to rank-and-file employees are positively affected by the option-granting behavior of other firms nearby as firms use stock options to attract and retain employees in tight labor markets. To the extent that the geographic clustering of option programs occurs in areas where innovation investments are correlated locally, the relation between employee stock options and innovation may just capture this geographic proximity effect. Although we have controlled for industry fixed effects in the main specification, to further address this concern, we conduct the following tests: (*a*) removing firms with their headquarters in Silicon Valley where high-technology firms have a strong propensity to grant stock options to their non-executive employees and excluding all firms located in industry clusters defined by Kedia and Rajgopal (2009);[21] (*b*) directly controlling for geographic fixed effects using two-digit ZIP codes. The

[19] Hadlock and Pierce's (2010) index is defined as $-0.737 \times Ln(Assets) + 0.043 \times Ln(Assets)^2 - 0.04 \times Firm\ \ age$. By construction, higher scores of Hadlock and Pierce's (2010) index indicate that firms are more financially constrained. They show that in various contexts, their index is a more reasonable measure of financial constraints than alterative measures, such as Kaplan and Zingales' (1997) index, Whited and Wu's (2006) constraint index, and the dividend payer indicator. In untabulated results, we also include the three alternative measures and find similar results. Option proceeds and tax benefits are defined according to Babenko, Lemmon, and Tserlukevich (2011) using the IRRC database.

[20] The coefficient of *G-index* is positive but insignificant. This may reflect a mixed effect of *G-index* on innovation productivity since Atanassov (2013) finds that firms create fewer patents and fewer citations of patents after the enactment of anti-takeover laws in certain states, highlighting the agency issue in the corporate innovative activities. Consistent with Atanassov (2013), board size has a negative and significant coefficient. However, the coefficient of institutional ownership is negative and insignificant in most regressions. This may be due to the mixed effect of institutional ownership on innovative outcomes since in addition to the negative effect of institutional investors' short-termism on innovations, Aghion, Van Reenen, and Zingales (2013) find that institutional owners can encourage innovation efficiency by reducing managers' career concern on risky projects.

[21] Following Gompers, Lerner, and Scharfstein (2005), we define Silicon Valley as the Alameda, San Mateo, and Santa Clara counties in California.

Table 3
Tests for omitted variables and reverse causality.

The sample consists of firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. All regressions include the same control variables as those used in Table 2, but their coefficients are not tabulated. Hadlock and Pierce's (2010) index is $-0.737 \times Ln(Assets) + 0.043 \times Ln(Assets)^2 - 0.04 \times Firm\ age$. Option proceeds and tax benefits are defined using the IRRC Dilution Database. An industry cluster is defined as one if 10% of the industry's market value is located in the Metropolitan Statistical Area (MSA) and 10% of the market value of that MSA is accounted for by that industry. Geographic fixed effects are defined using two-digit ZIP code. Catholic-Protestant ratio is the number of Catholic adherents in a county divided by the number of Protestant adherents in that county. Religiosity is defined as the proportion of religious adherents in a county. Median abnormal stock returns are computed across all firms sharing the same two-digit ZIP code. Local beta is defined according to Kedia and Rajgopal (2009). Past innovation success is defined as the average number of patents or citations during 1993–1997, respectively. Other variable definitions are in the legend of Table 2. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	$Ln(1+Patents)$ (1)	$Ln(1+Qcitations)$ (2)	$Ln(1+Tcitations)$ (3)
Panel A: Controlling for financial constraints (N=5,106)			
$Ln(1+EmpOpt)$	0.076***	0.117***	0.082***
	(3.1)	(3.0)	(3.1)
Hadlock and Pierce's (2010) index	−0.276***	−0.376**	−0.213*
	(−2.6)	(−2.3)	(−1.9)
Ln[(Option proceeds + tax benefits)/#employees]	−0.005	−0.003	−0.004
	(−0.4)	(−0.1)	(−0.3)
Panel B: Controlling for corporate governance measures (N=4,647)			
$Ln(1+EmpOpt)$	0.060**	0.100**	0.069**
	(2.3)	(2.5)	(2.5)
G-index	0.017	0.019	0.011
	(1.3)	(0.9)	(0.8)
Board size	−0.024*	−0.040*	−0.029*
	(−1.7)	(−1.8)	(−1.9)
Institutional holdings	−0.241	−0.350	−0.285*
	(−1.5)	(−1.4)	(−1.7)
Panel C: Excluding firms in Silicon Valley and industry clusters (MSA level) (N=4,286)			
$Ln(1+EmpOpt)$	0.062***	0.086**	0.063***
	(2.7)	(2.4)	(2.7)
Panel D: Controlling for geographic fixed effects (two-digit ZIP code) (N=5,640)			
$Ln(1+EmpOpt)$	0.067***	0.104***	0.075***
	(3.0)	(3.0)	(3.2)
Panel E: Controlling for factors related to reverse causality (N=4,998)			
$Ln(1+EmpOpt)$	0.052***	0.051**	0.040**
	(3.3)	(2.0)	(2.5)
% Of population in the county with college education	−0.001	−0.000	0.001
	(−0.2)	(−0.0)	(0.2)
Religiosity	−0.301*	−0.280	−0.219
	(−1.8)	(−1.1)	(−1.3)
Catholic/Protestant	0.001	−0.010	−0.008
	(0.1)	(−0.5)	(−0.6)
Local median abnormal returns	−0.032	0.042	−0.047
	(−0.5)	(0.3)	(−0.6)
Local beta	0.009	0.008	0.013
	(0.6)	(0.3)	(0.7)
Past innovation success	0.734***	0.645***	0.709***
	(29.8)	(32.9)	(32.1)

results tabulated in Panels C and D, respectively, confirm that our main results are unaffected.

Finally in untabulated tests, we also control for a few variables that may affect non-executive employee options and firm innovation. They are the top five executives' stock ownership (Cai, Sevilir, Van Wesep, and Wang, 2010), CEO tenure, the option-based CEO overconfidence measure (Hirshleifer, Low, and Teoh, 2012), abnormal stock returns (Capital Asset Pricing Model (CAPM) adjusted) accumulated over the period $[t-3,\ t-1]$ as a proxy for management quality (Milbourn, 2003) or employee sentiment (Bergman and Jenter, 2007), labor expenses per employee measured at the three-digit SIC industry level, and the level of employee stock ownership in defined contribution pension plans, as obtained from the Internal Revenue Service (IRS) Form 5500 database. While the inclusion of these variables significantly reduces the number of observations owing to data availability, our main findings are unaffected.

4.2.2. *Tests for reverse causality*

The causal relation between non-executive employee options and innovation can be bidirectional. While our results suggest that employee stock options enhance firm innovation, innovative firms may grant stock options to employees for at least two purposes that are not directly related to innovation enhancement.

First, Core and Guay (2001) show that employee stock options can be used to attract and retain certain types

Table 4
Instrumental variable approach.
The sample consists of firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. *EmpOpt* is value of non-executive stock options per employee. *ExeOpt* is average value of stock options across the top five executives. *Patents* is the number of patents applied for. *Qcitations* and *Tcitations* are patent citations adjusted using the weighting index of Hall, Jaffe, and Trajtenberg (2001, 2005) and the method of time-technology class fixed effect, respectively. *EmpOpt_Other* is average value of annual grants of non-executive stock option per employee across all zero-citation firms that share the same two-digit ZIP code with the firm but do not belong to the firm's two-digit SIC industry. Column 1 reports the estimates of the first-stage regression and columns 2–4 report the estimates of the second-stage regressions using the 2SLS model. Other variable definitions are in the legend of Table 2. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	1st Stage	2nd Stage		
	Ln(1+ *EmpOpt*) (1)	*Ln*(1+*Patents*) (2)	*Ln*(1+*Qcitations*) (3)	*Ln*(1+*Tcitations*) (4)
Ln(1+ *EmpOpt*)	N/A	0.602**	1.031**	0.656**
		(2.3)	(2.5)	(2.4)
Ln(1+ *EmpOpt_Other*)	0.088***	N/A	N/A	N/A
	(5.2)			
Ln(1+ *ExeOpt*)	0.018***	−0.012*	−0.016	−0.012
	(4.1)	(−1.7)	(−1.4)	(−1.6)
R&D/Assets	4.262***	3.873***	6.000***	3.580**
	(8.4)	(2.8)	(2.6)	(2.5)
Ln(*Assets*)	0.001	0.491***	0.700***	0.502***
	(0.0)	(15.5)	(14.1)	(15.0)
Ln(*Firm age*)	−0.307***	0.313***	0.491***	0.316***
	(−9.0)	(3.2)	(3.2)	(3.1)
Ln(*PPE/#employees*)	0.396***	−0.172	−0.299*	−0.193
	(12.2)	(−1.6)	(−1.7)	(−1.6)
Ln(*Sales/#employees*)	0.601***	−0.362**	−0.610**	−0.399**
	(13.0)	(−2.2)	(−2.3)	(−2.3)
ROA	0.752**	0.718*	1.134*	0.646
	(2.4)	(1.9)	(1.8)	(1.6)
M/B	0.256***	−0.104	−0.171	−0.107
	(16.1)	(−1.5)	(−1.5)	(−1.4)
Sales growth	0.257***	−0.327***	−0.523***	−0.346***
	(4.0)	(−3.9)	(−3.8)	(−3.9)
Leverage	−0.605***	−0.219	−0.305	−0.232
	(−3.6)	(−0.8)	(−0.7)	(−0.8)
Cash/Assets	2.163***	−1.089*	−2.050**	−1.313**
	(13.0)	(−1.8)	(−2.1)	(−2.0)
Stock volatility	−0.199	5.860**	10.935***	7.034***
	(−0.1)	(2.4)	(2.8)	(2.8)
Stock return	−0.059**	0.137***	0.258***	0.157***
	(−2.1)	(4.2)	(4.3)	(4.3)
Herfindahl	−2.295***	0.816	1.635	0.815
	(−5.4)	(1.0)	(1.3)	(1.0)
Herfindahl^2	2.587***	−0.542	−1.073	−0.467
	(5.2)	(−0.6)	(−0.7)	(−0.5)
Industry and year fixed effects	Y	Y	Y	Y
Joint test of excluded instruments	$F(1,1346)=26.73$ Prob > F=0.00	N/A	N/A	N/A
N/*R*-squared	5,315/0.71	5,315	5,315	5,315

of employees. For example, innovative firms may grant options to more educated employees who may understand options better and be more willing to accept options as a form of compensation, to less risk-averse employees, or to employees with strong gambling preference because these employees may find options more in line with their risk attitude (Kumar, Page, and Spalt, 2011), or to employees who are more optimistic about their employers' prospects (Oyer and Schaefer, 2005). In addition, Oyer (2004) and Oyer and Schaefer (2005) point out that firms use stock options to retain employees by indexing their compensation to outside opportunities, which are positively correlated with their employers' stock price. Because US labor markets are geographically segmented, rank-and file employees' outside opportunities mainly come from other firms located in the same geographical area. Thus, Kedia and Rajgopal (2009) find that the retention role of employee options is more effective when a firm's stock price co-moves more with stock prices of other firms in the same region.

Second, innovative firms may treat employees well by rewarding them with stock options in recognition of superior performance arising from past innovation success. The survey study of Ittner, Lambert, and Larcker (2003) shows that the “rewarding” purpose is among the most important objectives of employee stock option plans. Kroumova and Sesil (2006) provide evidence that high-tech or new-economy firms with superior past performance are more likely to adopt and maintain broad-based employee stock option plans.

The two directions of causality are not mutually exclusive and may be at work simultaneously. To substantiate forward causality (employee options enhancing innovation) while accounting for reverse causality (innovative firms granting employees more options), we incorporate into Eq. (1) a set of additional variables that capture firms' sorting and retention motives behind the use of employee stock options and firms' past innovation success. Specifically, we include the percentage of the population in the local county with a college education as a proxy for rank-and-file employees' average education level. We control for the local religiosity, a proxy for employee risk aversion (Hilary and Hui, 2009) and the Catholic-Protestant ratio, a proxy for employee gambling propensity (Kumar, Page, and Spalt, 2011).[22] We add the median abnormal (CAPM adjusted) stock return across all firms sharing the same two-digit ZIP code, as a proxy for regional employee sentiment (Kedia and Rajgopal, 2009). Also included is Kedia and Rajgopal's (2009) local beta, which measures the extent of co-movement between a firm's stock price and stock prices of other firms in the same region.[23] Finally, we control for past innovation success measured using the pre-sample five-year average number of patents or citations during 1993–1997.[24] The results, reported in Panel E of Table 3, reveal that $Ln(1+EmpOpt)$ remains positive and significant, indicating that reverse causality arising from firms' sorting and retention motives and past innovation success is not the main driver of our results.

4.2.3. The instrumental variable approach

To further address endogeneity concerns, especially those not specifically identified previously, we employ an instrumental variable approach similar to that of Hochberg and Lindsey (2010). In particular, we use an instrumental variable that is correlated with option grants to non-executive employees but unrelated to innovation output. The instrument is defined as the average per-employee value of annual option grants to non-executive employees across all zero-citation firms that share the same two-digit ZIP code with the firm but do not belong to the firm's two-digit SIC industry, *EmpOpt_Other*. When constructing this instrument, we use firms in geographical proximity because Kedia and Rajgopal (2009) document a local similarity in the employee option grant policy. Therefore, our instrument satisfies the relevance criteria. Furthermore, we only include non-innovative (zero-citation) firms in other industries to avoid local knowledge spillovers among firms within the same industry geographic cluster (e.g., Jaffe, Trajtenberg, and Henderson, 1993) and among innovative firms across industries.[25] Thus, our instrument is likely to satisfy the exclusion criteria as well. Taken together, we expect *EmpOpt_Other* to affect a firm's innovation outcomes only through the resemblance of employee compensation policy in the neighborhood, rather than through knowledge spillovers within and across industries.

Results obtained using the instrumental variable approach in the framework of a two-stage least squares (2SLS) regression are reported in Table 4. The first-stage regression is presented in column 1. $Ln(1+EmpOpt\_Other)$ is significantly and positively related to $Ln(1+EmpOpt)$ (t-statistic$=5.2$). The instrument also passes the relevance test as the F-statistic from the joint test of excluded instruments is 27 and significant at the 1% level.

Columns 2–4 show the second stage of the 2SLS regressions for each of the three dependent variables. Similar to the OLS regressions, we find that employee stock options significantly and positively predict patent counts and adjusted citation counts. We also estimate the 2SLS model using the methods of limited information maximum likelihood (LIML) and generalized method of moments (GMM), and find that our results are unaffected by these alternative methods.

We take care in interpreting the 2SLS results as strong evidence for a causal effect of employee stock options on innovation because the instrument (*EmpOpt_Other*) is far from perfect.[26] For instance, to the extent that nearby non-innovative firms in other industries mimic an innovative firm's option-granting policy, *EmpOpt_Other* may reflect innovation output of the innovative firm. In addition, zero-citation firms can still be innovative if they choose not to patent their innovation output or their patents are not cited. As a result, *EmpOpt_Other* may be driven by innovation needs of these firms even though they have no patents and citations. To mitigate these concerns, we first remove firms that are innovation leaders in the local region from the second stage of the 2SLS regressions since the compensation policies of leading innovative firms in geographic proximity are more likely to be imitated.[27] The results (untabulated) show that the t-statistics on the coefficients of $Ln(1+EmpOpt)$ are 3.7, 3.0,

[22] The county-level religion data are collected from the American Religion Data Archive (ARDA). Since the county-level religion data are available only for years 1990 and 2000 in our sample period, following Hilary and Hui (2009), we linearly interpolate the religion data to obtain the values in the intermediate years. Religiosity is defined as the proportion of religious adherents in a county. Following the classification provided by ARDA, we categorize the churches into four main groups, including Catholics, Protestants, Orthodox, and others. We define the Catholic-Protestant ratio as the ratio of the number of Catholic adherents in the county to the number of Protestant adherents in the county.

[23] Local beta, β^{LOC}, is estimated using the equation, $R_{i,t}=\alpha_I+\beta^{LOC}R_t^{LOC}+\beta^{MKT}R_t^{MKT}+\beta^{IND}R_t^{IND}+\varepsilon_{i,t}$, where $R_{i,t}$ is a firm's monthly stock return, R^{LOC} is the monthly return of an equally weighted index in the stock's corresponding Metropolitan Statistical Area (MSA). To alleviate the concern of spurious correlations, we exclude the return of the corresponding stock when calculating R^{LOC}. R^{MKT} is the monthly return of the equally weighted CRSP market portfolio. R^{IND} is the monthly return of an equally weighted index of the stock's corresponding 49 Fama-French industries. We estimate the above equation using time-series regressions over three different periods, 1993–1997, 1998–2002, and 2003–2007 and using firms with at least 24 non-missing monthly return observations. Our results are robust to using two-digit SIC codes as industry classifications.

[24] Alternatively, in untabulated tests, we measure past innovation success as the rolling average number of patents or citations during the previous five years, i.e., from year $t-2$ to $t-6$, and obtain similar results. We also include additional controls for firm performance such as the historical average value of *ROA* or *Stock return* during the past five years, and find similar results.

[25] The results are qualitatively the same if we define industry using three-digit or four-digit SIC.

[26] We thank the referee for pointing out the potential issues regarding the instrument.

[27] Specifically, we define a firm as an innovation leader in the local region if its number of patents or citations is above the 75th percentile of the distribution in the local region each year. Similar results are obtained if we use the 80th or 90th percentile as alternative cutoffs.

and 3.1, respectively, in the second stage of the 2SLS regressions. Second, instead of defining non-innovative firms as those with zero-citations, we alternatively define them as firms in non-high-tech industries (Loughran and Ritter, 2004) or those in non-new-economy industries (Murphy, 2003). Similar results are obtained.

To summarize, while endogeneity is a perennial issue that no empirical test can entirely rule out, we conduct a battery of tests to alleviate endogeneity concerns, and find that our main conclusion holds. Although each test can be subject to criticism, the balance of evidence points to a causal relation going from non-executive employee stock options to innovation.

5. Further analysis

5.1. Cross-sectional heterogeneity in results

To further understand the channels through which non-executive employee stock options affect corporate innovation, we partition our sample in several ways to examine whether our results vary across firms. We report the results in Table 5 where the regressions include all the control variables in Table 2. Again, to save space, we only tabulate the coefficients of $Ln(1+EmpOpt)$ for different subsamples.

5.1.1. Importance of employees' input to innovation

Given that skills and efforts of employees are fundamental inputs to the innovation process, we expect that employee incentives provided by stock options have a stronger impact on the innovation productivity in firms where the input of rank-and-file employees is relatively more important. We use the employee treatment index in the KLD Database and per-employee R&D expenses to measure the importance of employees for innovation. Bae, Kang, and Wang (2011) argue that firms are more likely to adopt an employee friendly policy if they value employees' firm-specific human capital. Ouimet and Zarutskie (2014) point out that labor and human capital play increasingly important roles in production, especially in the R&D-intensive industries. Thus, employee treatment and per-employee R&D expenses should be positively related to employee importance in innovation.

In Panel A of Table 5, we partition the firms into two groups using the employee treatment index and per-employee R&D expenses.[28] We classify firms with employee treatment index equal to (greater than) zero or with R&D per-employee below (above) the sample median as having low (high) employee importance. We then re-estimate Eq. (1) for the two groups separately. The results show that the positive relation between employee options and innovation is more pronounced in firms with higher employee treatment index or higher R&D per employee, confirming our conjecture that the positive effect of employee stock options on innovation productivity is stronger if employee inputs are more important and valued. Among firms with low employee importance, the coefficients on employee options are not significantly different from zero and are much smaller in magnitude.

5.1.2. Free-riding among employees

Innovation projects involve various types of tasks and processes, and thus are rarely the task of one individual or a single department. Instead, the use of team-based work is a popular mechanism for enhancing innovation. While we have shown that employee stock options form a strong group-based incentive device to foster innovation, the power of this group incentive can be diluted if free-riding problems are severe among non-executive employees (Hochberg and Lindsey, 2010). Therefore, we expect that the positive impact of non-executive stock options on innovation is more pronounced for firms with a less severe free-riding problem. Hochberg and Lindsey (2010) argue that the extent of free-riding is smaller in firms with fewer employees since the overall firm success is more sensitive to the actions of individual workers, and in firms with higher per-employee growth opportunities where the ability of individual employees to influence the firm value is higher (Core and Guay, 2001). We thus partition firms into subsamples using the number of employees and per-employee growth opportunities as proxies for the extent of free-riding among employees.[29] Firms with above (below) median number of employees or below (above) median per-employee growth opportunities are defined as having high (low) risk of free-riding. The results, reported in Panel B of Table 5, indicate that the effect of employee options on innovation is indeed stronger among firms with low risk of free-riding problems. More importantly, the finding that our main results are contingent on the extent of free-riding suggests that employee stock options affect corporate innovation at least partially through a group effort channel.

5.1.3. Broad-based vs. targeted non-executive stock option plan

To foster innovation, stock options can be broadly granted to most if not all employees (typically more than 50% of all employees), or selectively targeted towards specific R&D workers or groups. Hochberg and Lindsey (2010) point out that broad-based non-executive option plans, as a group incentive that rewards joint success, may enhance cooperation and mutual monitoring among employees in firms for which knowledge sharing is important. Given the importance of cooperation and mutual monitoring in fostering innovation, we expect the effect of employee stock options on innovation to be stronger in firms that grant options broadly.

We follow Oyer and Schaefer (2005) and Hochberg and Lindsey (2010) when identifying broad-based stock option plans. Specifically, we exclude option grants to high-level management (including the top five executives) from the

[28] We follow Bae, Kang, and Wang (2011) and construct the employee treatment index ranging from zero to five. The employee treatment index covers the strength in five categories of employee relations, namely, union relations, cash profit-sharing, employee involvement, retirement benefits strength, and health and safety. A higher value of employee treatment index indicates better employee treatment. The median value of the index is zero.

[29] We follow Core and Guay (2001) and define per-employee growth opportunities as (market value of equity − book value of equity)/the number of employees.

Table 5
Cross-sectional differences in the effects of employee stock options on innovation.

The sample consists of firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. This table partitions firms into subsamples and re-estimates the regressions in Table 2 for different subsamples. *EmpOpt* is value of non-executive stock options per employee. Other variable definitions are in the legend of Table 2. All regressions include the same control variables as those used in Table 2, but their coefficients are not tabulated. In Panel A, a firm with an employee treatment index equal to (greater than) zero or with R&D per employee below (above) the sample median is classified as having low (high) employee importance. In Panel B, a firm is classified as having high (low) risk of free-riding if the number of employees is above (below) the sample median, or if growth opportunities per employee is below (above) the sample median. In Panel C, a firm is classified as having broad-based option plans (*Broad*) if the number of option grants to non-executives (excluding high-level management) over the total shares outstanding exceeds 0.5%, and targeted plans (*Targeted*) otherwise. In Panel D, a firm is classified as having long (short) option expiration period if its average stock option expiration period across all option plans is above (below) the sample median. In Panel E, a firm is classified as having low (high) employee stock ownership if the firm has zero (greater than zero) investment in its own stocks in the defined contribution plans. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	$Ln(1+Patents)$		$Ln(1+Qcitations)$		$Ln(1+Tcitations)$	
Panel A: Partitioning the sample based on importance of employee input						
	Low	High	Low	High	Low	High
Zero vs. positive KLD employee treatment index (N_{Low}=2,269; N_{High}=965)						
$Ln(1+ EmpOpt)$	0.042	0.140**	0.051	0.246**	0.047	0.160**
	(1.3)	(2.3)	(1.0)	(2.6)	(1.4)	(2.3)
Partitioning the sample according to per-employee R&D expenses (N_{Low}=2,821; N_{High}=2,819)						
$Ln(1+ EmpOpt)$	−0.001	0.102***	0.010	0.146**	0.006	0.114***
	(-0.0)	(2.9)	(0.4)	(2.6)	(0.4)	(2.9)
Panel B: Partitioning the sample based on the risk of free-riding						
	High	Low	High	Low	High	Low
Partitioning the sample according to the number of employees (N_{High}=2,807; N_{Low}=2,814)						
$Ln(1+ EmpOpt)$	0.035	0.068***	0.074	0.099**	0.049	0.072***
	(0.9)	(2.8)	(1.3)	(2.4)	(1.2)	(2.7)
Partitioning the sample according to per-employee growth opportunities (N_{High}=2,809; N_{Low}=2,812)						
$Ln(1+ EmpOpt)$	0.014	0.078**	0.035	0.110**	0.025	0.079**
	(0.5)	(2.5)	(0.8)	(2.3)	(0.9)	(2.3)
Panel C: Targeted vs. broad-based option plans ($N_{Targeted}$=1,201; N_{Broad}=4,234)						
	Targeted	Broad	Targeted	Broad	Targeted	Broad
$Ln(1+ EmpOpt)$	−0.002	0.061**	0.011	0.082*	0.021	0.059**
	(−0.1)	(2.3)	(0.2)	(1.9)	(0.6)	(2.1)
Panel D: Partitioning the sample according to the average stock option expiration period (N_{Short}=2,676; N_{Long}=2,769)						
	Short	Long	Short	Long	Short	Long
$Ln(1+ EmpOpt)$	0.037	0.079***	0.050	0.133***	0.032	0.098***
	(1.3)	(2.6)	(1.1)	(2.7)	(1.1)	(3.0)
Panel E: Positive vs. zero employee stock ownership (N_{High}=2,264; N_{Low}=2,022)						
	High	Low	High	Low	High	Low
$Ln(1+ EmpOpt)$	0.040	0.078**	0.052	0.138**	0.040	0.090**
	(1.2)	(2.1)	(1.0)	(2.4)	(1.2)	(2.2)

total grants to all employees using the calibration method described in Section 4.1, and obtain the residual grants to non-executive employees. We then classify option programs as broad-based (targeted) if the residual grants to non-executive employees are greater (less) than 0.5% of the number of shares outstanding.

We separately estimate Eq. (1) for firms with targeted and broad-based option plans and report the results in Panel C of Table 5. The coefficients of $Ln(1+EmpOpt)$ are highly positive and significant for firms with broad-based option plans, but are much smaller and statistically insignificant for firms with targeted option plans. This finding is consistent with the notion that broad-based option plans promote joint success, encourage cooperation and mutual monitoring among rank-and-file employees, and alleviate free-riding incentives, leading to greater innovation productivity.

5.1.4. Average stock option expiration period

Due to the delayed feedback nature of innovation activities, Manso (2011) argues that the optimal incentive contract for innovations must provide the agent with long-term incentives. Therefore, we expect the positive effect of employee stock options on innovative outcomes to be stronger if non-executive employee options have a longer average expiration period.

To explore this possibility, we split our sample into two groups based on the median length of the average expiration period across all stock options in a firm.[30] The regression results for the two subsamples, tabulated in Panel D of Table 5,

[30] The median and mean values of average expiration periods for our sample are 6.9 and 6.7 years, respectively.

are consistent with our expectation. The effect of *Ln* (1+*EmpOpt*) on innovation output is more evident in firms of which stock options have a longer expiration period, indicating that long expiration periods of employee stock options induce long-term commitment by employees, prevent employees' myopic behaviors, and thus enhance innovation efficiency.

5.1.5. Employee stock ownership

Employees bear substantial amounts of undiversified risk by holding employer stocks, especially when they already invest large amounts of human-capital into the firm (Poterba, 2003; Berk, Stanton, and Zechner, 2010). Consistent with this view, Faleye, Mehrotra, and Morck (2006) and Bova, Kolev, Thomas, and Zhang (2014) find that firms with large employee ownership have strong incentives to reduce firm risk. Given the importance of risk-taking incentives in corporate innovative activities, we expect the incentive effect of employee stock options on innovation to be stronger in firms with lower employee ownership where employees' risk aversion is lower.

We hence divide our sample based on whether firms have investments in their own stocks for their employees in the defined contribution pension plans reported in the IRS Form 5500 and estimate Eq. (1) for both subsamples. The results are reported in Panel E of Table 5. Consistent with our expectation, the positive effect of employee options on innovation is more evident in firms that have no investments in their own stocks for their employees, suggesting that employee stock options are more effective in promoting risk-taking when employees are less risk-averse.

5.2. Employee option delta and vega

In this subsection, we examine whether the value of non-executive employee stock options affects innovation through the performance-based effect of option delta, or via the risk-taking incentive of option vega. The theoretical work of Baccara and Razin (2009) shows that the choice of employees to convert an innovative idea into product or to keep the idea to themselves without implementing and maintain the routine work depends on the right incentives given to them, since the effort to innovate is costly and associated with high probability of failure. On one hand, non-executive employee stock options, as an important form of equity-based compensation, tie employees' welfare to shareholders' wealth, or stock prices. By managing the *slope* of the relation between non-executive employee compensation and stock price using stock options, shareholders can induce rank-and-file employees to exert efforts that increase equity value (Guay, 1999). To the extent that innovation projects are value-enhancing, non-executive stock options may foster innovation through this performance-based mechanism. On the other hand, stock options also link employees' wealth positively to the volatility of equity value, increasing the *convexity* of the relation between employee compensation and stock price, and thus encouraging employees' risk-taking incentives (Murphy, 2003; Low, 2009). As innovation requires risk-taking, non-executive stock options may enhance innovation through the risk-taking mechanism.

To break down the incentive effects of employee stock options, we compute employee stock options' delta and vega, i.e., the slope and convexity, respectively, of the relation between the value of employee options and stock price. We define non-executive employee option delta (*EmpDelta*) as the dollar change in non-executive option values for a 1% change in stock price, deflated by the number of non-executive employees. Non-executive employee option vega (*EmpVega*) is the dollar change in non-executive option value for a 1% change in stock return volatility, deflated by the number of non-executive employees.[31] We then use *Ln*(1+*EmpDelta*) and *Ln*(1+*EmpVega*) to replace *Ln*(1+*EmpOpt*) in Eq. (1) and perform the regression analysis. In the meantime, we also replace *Ln*(1+*ExeOpt*) with the average delta and vega of the top five executives' stock-based compensation, which are denoted as *Ln*(1+*ExeDelta*) and *Ln*(1+*ExeVega*), respectively. Other control variables are the same as those reported in Table 2.

Table 6 presents the regression results. Non-executive employee option delta, *Ln*(1+*EmpDelta*), has a positive but statistically insignificant effect on patents and citations. In contrast, the effect of employee option vega, *Ln* (1+*EmpVega*), is positive and statistically significant with *t*-statistics of 4.4, 4.2, and 3.9, respectively. Turning to economic significance, increasing *EmpVega* from its 25th percentile ($31.1) to the 75th percentile ($242.5) increases the values of *Patents*, *Qcitations*, and *Tcitations* by almost 68%, 102%, and 64% from their respective means. Taken together, the horse race between employee option delta and vega reveals that it is the convexity, rather than the slope, of the relation between employee options and stock prices that drives the effect of employee options on corporate innovation. Although a high delta can encourage employees to work hard, it exposes employees to more risk and leads to too little risk-taking (Hirshleifer and Suh, 1992; Guay, 1999). In contrast, a high vega helps offset the aversion to risk that arises due to the increased delta, providing employees with incentives to take on greater risk in the innovation process.

Furthermore, consistent with Francis, Hasan, and Sharma (2011), we find that executive delta has no significant effect on innovation output. While coefficients of executive vega are all positive in our regressions, they are statistically insignificant (*t*-statistics are 0.9, 1.5, and 1.1, respectively).[32] In terms of economic significance, increasing *ExeVega* from its 25th percentile ($7,796) to the 75th percentile ($56,999) increases the values of *Patents*, *Qcitations*, and *Tcitations* by roughly 5%, 11%, and 5% from their respective means.

While we argue that employee option vega enhances innovation by encouraging employee risk-taking, it is plausible that causation can go in reverse from innovation to vega. Other things being equal, vega is highest for at-the-money options and converges to zero on both tails (far out of the money and deep in the money). If innovative and successful firms reward non-executive employees for innovation success

[31] Similar results are obtained if we compute employee delta using all forms of employee stock-based compensation, including stock options and stock holdings in the defined contribution pension plans.

[32] Similar results (untabulated) are obtained if we use delta and vega of CEOs' compensation portfolio, rather than those of all top five executives.

Table 6
Effects of employee incentives on innovation output.
The sample consists of 5,640 firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. *EmpDelta* (*ExeDelta*) is the average sensitivity of the value of non-executives' (the top five executives') stock options to a 1% change in stock price. *EmpVega* (*ExeVega*) is the average sensitivity of the value of non-executives' (the top five executives') stock options (stock-based compensation) to a 1% change in stock return volatility. *Patents* is the number of patents applied for. *Qcitations* and *Tcitations* are patent citations adjusted using the weighting index of Hall, Jaffe, and Trajtenberg (2001, 2005) and the method of time-technology class fixed effect, respectively. Other variables are defined in the legend of Table 2. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Ln(1+*Patents*) OLS (1)	*Ln*(1+*Qcitations*) OLS (2)	*Ln*(1+*Tcitations*) OLS (3)
Ln(1+ *EmpDelta*)	0.013	0.019	0.025
	(0.5)	(0.4)	(0.8)
Ln(1+ *EmpVega*)	0.096***	0.154***	0.091***
	(4.4)	(4.2)	(3.9)
Ln(1+ *ExeDelta*)	−0.000	−0.006	0.000
	(−0.0)	(−0.5)	(0.0)
Ln(1+ *ExeVega*)	0.007	0.017	0.008
	(0.9)	(1.5)	(1.1)
R&D/Assets	5.599***	9.029***	5.489***
	(8.1)	(7.7)	(7.4)
Ln(*Assets*)	0.525***	0.758***	0.534***
	(18.6)	(17.2)	(17.9)
Ln(*Firm age*)	0.118***	0.158**	0.108**
	(2.7)	(2.4)	(2.4)
Ln(*PPE/#employees*)	−0.002	0.009	−0.001
	(−0.0)	(0.1)	(−0.0)
Ln(*Sales/#employees*)	−0.098**	−0.145*	−0.108**
	(−2.0)	(−1.9)	(−2.1)
ROA	1.085***	1.754***	1.042***
	(4.2)	(4.0)	(3.7)
M/B	0.045***	0.087***	0.054***
	(3.2)	(3.5)	(3.4)
Sales growth	−0.184***	−0.270***	−0.188***
	(−4.0)	(−3.4)	(−3.9)
Leverage	−0.524***	−0.844***	−0.550***
	(−2.7)	(−2.7)	(−2.7)
Cash/Assets	0.010	−0.133	−0.123
	(0.0)	(−0.4)	(−0.5)
Stock volatility	4.070**	8.181**	5.402**
	(2.1)	(2.6)	(2.6)
Stock return	0.105***	0.211***	0.128***
	(4.1)	(4.4)	(4.4)
Herfindahl	0.077	0.264	−0.024
	(0.2)	(0.4)	(-0.0)
Herfindahl^2	0.276	0.468	0.452
	(0.5)	(0.6)	(0.8)
Industry and year fixed effects	Y	Y	Y
N/*R*-squared	5,640/0.55	5,640/0.51	5,640/0.50

by granting stock options frequently, employee stock options of innovative firms would then have a high vega caused by recently granted options that are normally at the money. Although we have included *ROA* and *Sales growth* in the regressions to account for firm profitability and success, we conduct several tests to further mitigate this concern.

First, in Panel A of Table 7, we augment the model in Table 6 by adding the average number of options that are newly granted to non-executive employees in year $t-1$. Other explanatory variables are still included but not tabulated. The results reveal that employee option vega continues to be significantly associated with our innovation measures. The economic significance of the coefficients on *Ln*(1+*EmpVega*) is similar to that in Table 6.

Second, to verify whether the incentive effect of vega derives solely from the newly granted options to employees, we decompose employee option vega into vega of options granted in year $t-1$ (*EmpVega_New*) and vega of options granted in years prior to $t-1$ (*EmpVega_Old*). Employee option delta is also decomposed accordingly. We then re-estimate the models in Table 6 using the components of option delta and vega. The results reported in Panel B of Table 7 reveal that both components of employee option vega have a positive effect on innovation, suggesting that the relation between vega and innovation is not driven solely by newly granted options.[33] Note that the significant effect of vega of newly granted

[33] The *Wald* test suggests that the coefficients on the two components of vega are not statistically different from each other with *F*-statistics of 0.9, 2.4, and 2.1, respectively, in columns 1–3.

Table 7
Further analysis on effects of employee option delta and vega on innovation.

The sample consists of firm-years jointly covered in the IRRC Dilution Database, ExecuComp, and the NBER Patent and Citation Database between 1998 and 2003. All regressions include the same control variables as those used in Table 6, but their coefficients are not tabulated. *#New option grants/#non-executive employees* is the average number of stock options that are newly granted to non-executive employees. *EmpDelta_New* (*EmpDelta_Old*) is the average sensitivity of the value of non-executive stock options granted in year $t-1$ (in years prior to $t-1$) to a 1% change in stock price. *EmpVega_New* (*EmpVega_Old*) is the average sensitivity of the value of non-executive stock options granted in year $t-1$ (in years prior to $t-1$) to a 1% change in stock return volatility. *Moneyness* is defined as stock price divided by the weighted average strike price of outstanding options. In Panel D, a firm is classified as having deep-in-the-money (other) options if the moneyness of its option portfolio is above (below) the 75th percentile of the sample. Other variable definitions are in the legends of Table 2 and Table 6. The *t*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Ln(1+*Patents*) (1)		*Ln*(1+*Qcitations*) (2)		*Ln*(1+*Tcitations*) (3)	
Panel A: Controlling for the number of newly granted options per employee (*N*=4,437)						
Ln(1+ *EmpDelta*)	−0.006		−0.004		0.008	
	(−0.2)		(−0.1)		(0.2)	
Ln(1+ *EmpVega*)	0.085***		0.133***		0.079***	
	(3.5)		(3.2)		(3.0)	
Ln(1+ *#New option grants/#non-executive employees*)	0.047		0.050		0.045	
	(1.4)		(0.9)		(1.3)	
Panel B: Decomposing employee delta and vega into new and old components (*N*=4,437)						
Ln(1+ *EmpDelta_New*)	−0.041		−0.130		−0.065	
	(−0.6)		(−1.1)		(−0.8)	
Ln(1+ *EmpDelta_Old*)	0.018		0.046		0.031	
	(0.7)		(1.0)		(1.0)	
Ln(1+ *EmpVega_New*)	0.137**		0.281**		0.177**	
	(2.0)		(2.3)		(2.2)	
Ln(1+ *EmpVega_Old*)	0.066***		0.077**		0.049**	
	(3.7)		(2.5)		(2.6)	
Panel C: Using the vega-to-delta ratio (*N*=5,431)						
Ln[(1+ *EmpVega*)/(1+*EmpDelta*)]	0.062***		0.104***		0.054**	
	(2.7)		(2.6)		(2.2)	
Ln[(1+ *ExeVega*)/(1+*ExeDelta*)]	0.004		0.012		0.004	
	(0.6)		(1.2)		(0.7)	
Panel D: Partitioning sample according to average moneyness of stock options ($N_{Deep\text{-}in}$=1,412; N_{Other}=4,233)						
	Deep-in	*Other*	*Deep-in*	*Other*	*Deep-in*	*Other*
Ln(1+ *EmpDelta*)	0.070	−0.020	0.147*	−0.056	0.102*	−0.019
	(1.4)	(−0.5)	(1.7)	(−0.8)	(1.9)	(−0.4)
Ln(1+ *EmpVega*)	0.028	0.129***	0.020	0.230***	0.029	0.126**
	(0.9)	(2.9)	(0.4)	(3.0)	(0.9)	(2.5)

options on innovation is also consistent with the incentive effect of vega. To the extent that over time, employee incentives may deviate from the optimal level, either because of the shift in the optimal level or because of the changes in the incentives provided by employees' total compensation, firms may actively manage new option grants to employees in response to the deviation (Core and Guay, 1999). Consistent with the results in Table 6, we find that neither component of employee option delta has a significant effect on innovation.

Third, we follow Grant, Markarian, and Parbonetti (2009) and Cassell, Huang, Manuel Sanchez, and Stuart (2012) by employing the ratio of vega to delta incentives, a parsimonious measure that accommodates both types of equity incentives. Intuitively, the vega-to-delta ratio captures the vega incentives per unit of delta incentives or the strength of the risk-taking incentive relative to the performance-based incentive. In addition, this measure is also independent of the magnitude of the employee option compensation. We replace *Ln*(1+*EmpDelta*) and *Ln*(1+*EmpVega*) with *Ln*[(1+*EmpVega*)/(1+*EmpDelta*)] in the regressions in Table 6, and treat executive incentive measures in the same way. The results reported in Panel C of Table 7 indicate that *Ln*[(1+*EmpVega*)/(1+*EmpDelta*)] has a significantly positive effect on our innovation measures, implying that the relative strength of the risk-taking incentive is associated with better innovation outcomes.

Finally, Lewellen (2006) suggests that stock options that are deep in the money can make option holders' wealth sensitive to stock price movements (i.e., options also increase delta), and thus reduce their risk-taking incentives. In Panel D of Table 7, we investigate the effect of option moneyness on the risk-taking incentives induced by employee option vega. Specifically, we partition the sample into two subsamples of firms based on the average moneyness of employee stock options, which is equal to the stock price divided by the weighted average strike price of outstanding options. We define options that are deep in the money as those with moneyness above the 75^{th} percentile of its distribution (the corresponding moneyness cutoff is 1.68).[34] We then estimate the effect of vega on innovation for firms with employee options that are or are not, on average, deep in the money and report the results in Panel D of Table 7. We find that the positive effect of employee vega on innovation mainly arises from firms with employee options that are not deep in the money.

Taken together, these results in Table 7 further support our argument that the positive effect of employee stock options on innovation comes from the risk-taking incentive of option vega rather than the performance-based incentive created by option delta. We also find that the relation between vega and innovation is not driven solely by successful innovative firms granting more options to employees, although we cannot completely rule out this reverse causality. Finally, our findings suggest that more stock options should be granted to non-executive employees, rather than to executives, in order to fuel corporate innovation.

6. Summary and conclusion

Innovation has become a core strategy to enhance a firm's competitiveness in the new millennium. As such, how to design an appropriate incentive mechanism to foster innovation productivity constitutes a challenge to firms' innovation practice. Despite abundant literature on various factors that spur or impede innovations, few studies examine the role of employees and employees' incentive scheme in the innovation process. Our paper fills this gap.

Using a large sample of firms covered by the NBER Patent and Citation Database, the IRRC Dilution Database, and ExecuComp between 1998 and 2003, we document a positive effect of non-executive employee stock options on innovation output, which is measured using the numbers of patents and patent citations, after we control for the R&D expenditure in the regressions. These results are robust to a variety of tests on model specifications, variable definitions, and endogeneity issues. Moreover, we find that the positive effect of non-executive options on innovation is more pronounced in firms where employees' input to innovation is more important, in firms where free-riding among employees is weaker, in firms with broad-based option plans, in firms where options have a longer average expiration period, and in firms with lower employee stock ownership. Additional analysis reveals that non-executive employee stock options foster innovation through enhancing employees' risk-taking incentives (option vega).

Collectively, our findings highlight the role of rank-and-file employees as important innovators, and thus enrich the stakeholder theory of corporate finance. Furthermore, our findings complement Hochberg and Lindsey (2010) by identifying a new channel through which non-executive employee stock options exert a beneficial influence on firm success.

[34] Similarly, Malmendier and Tate (2005) use 1.67 as cutoff to define CEO stock options that are deep in the money.

Appendix A. Sample construction

This table contains the observation counts for the sample at different stages of construction. We start from all firms reported in the IRRC Dilution Database during 1997 to 2005 and merge it with Compustat, CRSP, and ExecuComp. The combined data set is then merged with the NBER Patent and Citation Database. For the ExecuComp data, we remove firms with unidentified CEOs, negative CEO tenure, missing total compensation (ExecuComp data item *tdc*1), or zero total compensation. Also excluded are firms with less than two top executives in a given year (Spalt, 2013). For the NBER Patent and Citation data, we exclude firms in industries that have no patent in any year in the entire database.

Order	Selection criteria	Data source	Period	Number of observations
(1)	Remove observations with missing values on employee stock option variables.	IRRC Dilution Database	1997–2005	12,674
(2)	Remove firms without stock prices at year-end from Compustat, 36 months of stock return data from CRSP to calculate stock return volatility, or other Black-Scholes (BS) formula inputs.	IRRC Dilution Database, Compustat, and CRSP	1997–2005	12,384
(3)	Merge with ExecuComp and remove observations of error and firms with less than two top executives in a given year.	IRRC Dilution Database, Compustat, CRSP, and ExecuComp	1997–2005	12,260
(4)	Merge with NBER Patent and Citation Database and remove firms with missing values for the lagged non-executive options.	IRRC Dilution Database, Compustat, CRSP, ExecuComp, and NBER Patent and Citation Database	1998–2003	7,386
(5)	Drop financial firms and utilities and firm-years with missing values for dependent variables.	IRRC Dilution Database, Compustat, CRSP, ExecuComp, and NBER Patent and Citation Database	1998–2003	5,781
(6)	Remove firms with missing value for control variables used in regressions.	IRRC Dilution Database, Compustat, CRSP, ExecuComp, and NBER Patent and Citation Database	1998–2003	5,640

Appendix B. Robustness checks on alternative model specifications and variable definitions

All regressions include the same control variables as those used in Table 2, but the coefficients on these variables are not tabulated. Detailed variable definitions are in the legend of Table 2. The *t*- or *z*-statistics in parentheses are calculated from the Huber/White/Sandwich heteroskedastic-consistent errors, which are also corrected for correlation across observations for a given firm. The symbols ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

(*a*): Negative binomial regressions without log-transforming dependent variables (N=5,640)			
	Patents	*Qcitations*	*Tcitations*
Ln(1+*EmpOpt*)	0.077**	0.095**	0.082*
	(2.1)	(2.0)	(1.7)
(*b*): Using Oyer and Schaefer's (2005) calibrated value of non-executive stock options per employee, *EmpOpt_OS* (N=5,640)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt_OS*)	0.024***	0.036***	0.027***
	(2.9)	(2.8)	(3.2)
(*c*): Scaling total value of non-executive stock options by market capitalization, *EmpOpt_MC* (N=5,640)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt_MC*)	0.065**	0.101**	0.067**
	(2.4)	(2.3)	(2.3)
(*d*): Using the value of newly granted non-executive stock options, *EmpOpt_New* (N=4,437)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt_New*)	0.077***	0.115***	0.089***
	(2.7)	(2.6)	(3.0)
(*e*): Replacing $EmptOpt_{t-1}$ by $EmptOpt_{t-2}$ (N=4,245)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
$Ln(1+EmpOpt_{t-2})$	0.056**	0.087**	0.062**
	(2.2)	(2.3)	(2.4)
(*f*): Excluding self-citations when defining *Qcitations* and *Tcitations* (N=5,640)			
		Ln(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt*)		0.085***	0.063***
		(2.6)	(2.9)
(*g*): Excluding firm-years with zero patents and citations (N_{Patent}=2,732; $N_{Citation}$=2,342)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt*)	0.086***	0.147***	0.121***
	(3.3)	(4.1)	(3.9)
(*h*): Using average citations per patent as dependent variables (N=5,640)			
		$Ln(1+\overline{Qcitations})$	$Ln(1+\overline{Tcitations})$
Ln(1+*EmpOpt*)		0.031**	0.012**
		(2.0)	(2.0)
(*i*): Excluding firms engaging in mergers and acquisitions in the previous two years (N=1,793)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt*)	0.087***	0.114**	0.085***
	(3.1)	(2.5)	(2.8)
(*j*): Excluding the period of technology boom (1998–2000) (N=3,063)			
	Ln(1+*Patents*)	*Ln*(1+*Qcitations*)	*Ln*(1+*Tcitations*)
Ln(1+*EmpOpt*)	0.079***	0.119***	0.079***
	(3.0)	(2.9)	(2.7)

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