CEO Overconfidence and Innovation *

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Abstract

Are CEOs' attitudes and beliefs linked to their firms' innovative performance? This paper uses Malmendier and Tate's measure of overconfidence, based on CEO stock-option exercise, to study the relationship between a CEO's "revealed beliefs" about future performance and standard measures of corporate innovation. We begin by developing a career concern model where CEOs innovate to provide evidence of their ability. The model predicts that overconfident CEOs, who underestimate the probability of failure, are more likely to pursue innovation, and that this effect is larger in more competitive industries. We test these predictions on a panel of large publicly traded firms for the years 1980 to 1994. We find a robust positive association between overconfidence and citation-weighted patent counts in both cross sectional and fixed-effect models. This effect is larger in more competitive industries. Our results suggest that overconfident CEOs are more likely to take their firms in a new technological direction.

Keywords: Innovation, R&D, CEO Overconfidence, Managerial Biases.

JEL Codes: D80, O31, O32, O33.

1 Introduction

Economic models typically assume that beliefs are on average correct. However, a large body of evidence from applied psychology shows that individuals routinely over-estimate their ability (Svenson, 1981). While much of this evidence comes from surveys and lab experiments, there is growing interest in measuring the impact of overconfidence in the field (DellaVigna, 2008). This paper uses a novel measure of CEO overconfidence developed by Malmendier and Tate (2005a, 2005b, 2008) to study the relationship between managerial overconfidence and corporate innovation.[1]

Prior research on managerial overconfidence finds that overconfident CEOs tend to destroy value through unprofitable mergers and sub-optimal investment behaviour (Malmandier and Tate 2005a, 2005b, 2008). These results raise the question of why companies hire and retain overconfident CEOs? While several theories suggest that overconfidence may generate value through greater exploration and risk-taking (Bernardo and Welch 2001, Goel and Thakor 2008), there is no empirical evidence of this effect from outside the lab.

We argue that for large-firm CEOs, overconfidence is associated with an increased propensity to innovate. To make this idea precise, we propose a simple career concern model where CEOs decide whether or not to innovate. Successful innovation is rewarded because it reveals new information about managerial ability. Conversely, failure causes the market to infer that a CEO lacks talent. Overconfident CEOs underestimate the likelihood of failure, and are therefore more likely to pursue innovation. This effect is larger in more competitive industries, where successful innovation reveals more information about CEO ability, leading to a large payoff that overconfident CEOs are eager to capture. This simple theory provides one answer to the puzzle posed by previous research: If the rewards from successful innovation are large, an overconfident CEO's increased propensity to innovate may offset the negative impacts of unprofitable mergers and sub-optimal investment behavior.

To test these predictions, we combine standard measures of innovation, based on US patent data, with a measure of CEO overconfidence developed in a series of papers by Malmendier and Tate (2005a, 2005b, 2008). The measure is constructed by using CEOs' personal investments to capture "revealed beliefs" about their firms' future performance. Specifically, CEOs are classified as overconfident if they hold highly in-the-money stock options after they are fully vested. We run panel data regressions on a sample of 290 firms and 627 CEOs during the period 1980 to 1994. This sample consists of large firms, primarily from manufacturing and

[1] Throughout this paper we follow the convention adopted by Malmendier and Tate (2008), and refer to self-serving attribution bias (i.e. over-estimating outcomes related to one's own abilities) as "overconfidence." We use the term "optimism" to refer to over-estimation of exogenous positive outcomes (e.g. growth in GDP).

technology industries, where we observe significant patenting.

Our main result shows that the arrival of an overconfident CEO is correlated with a 25 to 35 percent increase in citation-weighted patent counts (i.e. forward citations received by patents filed in a given year). The effect is larger if we assume that a CEO only becomes overconfident after failing to exercise in-the-money option grants, instead of treating overconfidence as a permanent trait. We consider several additional outcome variables, and find that overconfidence produces similar-sized effects for unweighted patent counts, R&D expenditures and citations per issued patent. Interacting overconfidence with industry-level measures of competition reveals that the overconfidence effect is larger when product market competition is more intense. These interactions provide support for our analytical framework, and also illustrate how industry characteristics may amplify (or mute) the impact of behavioral biases.

We extend these baseline results in several directions. First, we examine the link between overconfidence and two measures of innovative direction, based on the Hall, Jaffe and Trajtenberg (2001) measure of patent originality and a new measure based on self-citation rates. The results suggest that overconfidence leads to a change in direction, and not just an increase in R&D spending and productivity. Second, we show that the link between overconfidence and innovation is stronger for CEOs who are less constrained. Specifically, the overconfidence effect is larger when a CEO also holds the titles of Chairman and President, or the firm has greater cash flows. These two findings strengthen our preferred interpretation of the main results by showing that overconfidence is more salient when a CEO has greater flexibility to make changes in their firm's strategic direction. Finally, we examine trends in various innovation measures prior to hiring an overconfident CEO. While the match between firm and CEO remains (potentially) endogenous, these models reassuringly find no evidence that firms "treated" with an overconfident executive behave differently from controls beforehand.

Because we rely on indirect measures of patent value, and have no information on the opportunity cost of R&D, our results do not reveal whether innovations by an overconfident CEOs actually create value. In particular, these CEOs may over-invest in risky projects. Nevertheless, we find that overconfident CEOs have greater R&D productivity (i.e. citations per dollar of R&D invested). While this result is not conclusive, it strongly suggests that executive overconfidence can, under the right circumstances, provide benefits that offset the negative effects documented in previous research.

1.1 Related Literature

Psychologists provide a wealth of evidence that individuals over-estimate their own abilities. For example, most people believe they have above average driving skills (Svenson, 1981) and ability to remember trivia (Moore and Cain, 2007). CEOs and other high-ranking executives may be particularly susceptible to this bias, since overconfidence is stronger among highly skilled individuals (Camerer and Lovallo, 1999), and when the link between actions and outcomes is complex (Moore and Kim, 2003).

Given the uncertainty and complexity associated with research and development, we might expect overconfidence to play an important role in the innovation process. In fact, there have been many studies of entrepreneurial overconfidence (see Shane 2003, pg. 12 for a review). Much of this research invokes overconfidence to explain persistence in the face of long odds. For instance, Astebro (2003) and Lowe and Ziedonis (2006) ask whether overconfidence is needed to rationalize entrepreneurial behaviour. Our study departs from this tradition in two important ways. First, we consider the role of overconfidence at the opposite end of the firm-size distribution, among CEOs of large publicly traded companies. And second, instead of asking whether latent overconfidence is required to rationalize observed behaviour, we examine the correlation between a novel measure of overconfidence and firm-level innovative performance.

This paper contributes to an emerging literature at the intersection of industrial organization and behavioral economics (see Camerer and Malmendier (2007) for a survey), and builds upon three broad streams of prior research. First, our data and measure of overconfidence come from Malmendier and Tate (2005a, 2005b, 2008), who use it to study corporate finance. Their key insight is that a CEO's personal financial decisions — specifically, whether they exercise fully vested stock options that are highly in-the-money — can be used to infer beliefs about future performance. As described below, Malmendier and Tate do extensive work to validate this measure, and use it to show that overconfident CEOs are more sensitive to cash flows (Malmendier and Tate, 2005a) and more likely to do mergers and acquisitions (Malmendier and Tate, 2008). Closer to our work is the study by Hirshleifer et al. (2010), who independently look at the correlation between options- and press-based measures of overconfidence and various measures of risk taking, including patenting and stock-return volatility.

We also build on a long line of research that uses patents to measure corporate innovation. Pakes and Griliches (1980) were the first to estimate a patent production function, and their model was extended by and Hausman, Hall and Griliches (1984), and Blundell, Griffith and Van Reenen (1999). Within this literature, our work is closely related to papers that emphasize corporate governance and stock-based compensation, such as Lerner and Wulf (2006), who study the link between innovation and incentive compensation for R&D managers, or Aghion, Van Reenen and Zingales (2009), who examine the link between institutional shareholding and innovation.

Finally, our paper adds to a small literature that uses asymmetric beliefs to model the innovation process. For instance, in Klepper and Thompson (2007, 2010), asymmetric beliefs about the potential of a new technology lead to spin-outs, whereby entrepreneurs leave incumbent firms to work on a new idea.

2 A Model of Overconfidence and Innovation

Aghion, Van Reenen and Zingales (2009) extend the Holmstrom (1982) career concern model by allowing innovation to serve as an indicator of managerial ability. This section builds on their framework by introducing managerial overconfidence.

Consider a CEO whose ability $\theta \in \{0, \overline{\theta}\}$, where $\overline{\theta} > 0$, is unknown to the market (M) and to the CEO (C). The market and CEO have different prior beliefs about CEO ability, denoted by Pr_M and Pr_C respectively. Specifically, we assume that

$$\frac{1}{2} = \Pr_M(\theta{=}\overline{\theta}) < \Pr_C(\theta{=}\overline{\theta}) = \frac{1}{2}(1+o).$$

where $o \in (0,1]$ is a parameter that measures CEO overconfidence. Since $o > 0$, the overconfident CEO believes that the market underestimates his expected talent. This belief structure is common knowledge.[2]

The model has two periods, $t = 1, 2$. In period 1, the CEO decides whether to stay the present course, or try for an innovation $i \in \{0,1\}$. One might think of this as an observable choice between taking the firm in a new direction, which leads to a broad increase in exploration, versus sticking with an established strategy. If the CEO does not innovate ($i = 0$), the firm's second period revenue is $y_0 = 0$ and no information is revealed about the CEO's ability. If the CEO does innovate ($i = 1$), he incurs an innovation cost I, and the second period revenue $y_1 \in \{0,1\}$ provides information about θ. Specifically, we assume that

$$E[y_1|\theta = \overline{\theta}] = p > E[y_1|\theta = 0] = \alpha p$$

where $\alpha \equiv 1 - \pi$, and $\pi \in [0,1)$ is an index of product market competition. Thus, high ability CEOs are more likely to succeed, and the link between CEO ability and performance is stronger when competition is more intense. The term α can be interpreted as a reduced form of an un-modeled race in which a patent is awarded to the best idea in a technology field. The greater the degree of competition, the less likely are low ability CEOs to find innovations that distinguish them from competitors.[3]

[2] See Galasso (2010) for a discussion of the role of common priors in economic models.

[3] Consider this simple rent seeking game that Baye and Hoppe (2003) show is equivalent to a classic patent race model. Two players H (high ability) and L (low ability) exert effort, x sustaining marginal costs c_H and c_L with $c_H < c_L$. The probability that each player obtains the patent is $x_i/(x_i + x_j)$. It is possible to show that

The timing of the game is as follows: (i) the CEO chooses whether to pay I and innovate; (ii) y is realized and the market updates its assessment of the CEO's talent; (iii) the CEO decides whether to leave the firm based on the comparison between his expected period 2 income and his outside option. Following Holmstrom (1982), we assume the CEO operates in a fully competitive labor market, so his second period income if he stays with the firm is equal to the market's perception of his ability (conditional on the information acquired in period one). The CEO's outside option is to reallocate to another sector. As in Aghion, Van Reenen and Zingales (2009), we assume that CEO ability is sector specific, so compensation after relocating is independent of ability and equal to $\underline{w} = \overline{\theta}/2 - \delta$ where δ is a switching cost.

We solve the model by backward induction. If the CEO decides to innovate, market beliefs follow Bayes' rule. Thus, the CEO's period 2 income within the firm equals

$$w_2(y_1) = \overline{\theta}\ \mathrm{Pr}_M\left(\theta = \overline{\theta}|y_1\right) = \overline{\theta}\ \left(\frac{y_1}{1+\alpha} + \frac{(1-y_1)(1-p)}{2-p-\alpha p}\right) \tag{1}$$

We assume that $w_2(1) > \underline{w} > w_2(0)$, so a CEO will leave the firm in period 2 if their attempted innovation was unsuccessful. In period 1, a CEO will try to innovate if the expected net benefits $E[w_2(y_1)|o] - I$ exceed their known second-period payoff without innovation $w_2(y_0) = \overline{\theta}/2$. The expected benefits of innovation are given by

$$\begin{aligned} E[w_2(y_1)|o] = & \left[\frac{1}{2}(1+o)p + \frac{1}{2}(1-o)\alpha p\right]\frac{\overline{\theta}}{1+\alpha} \\ & + \left[\frac{1}{2}(1+o)(1-p) + \frac{1}{2}(1-o)(1-\alpha p)\right]\underline{w} \end{aligned} \tag{2}$$

The first term in (2) is $w_2(1)$ times the probability of success, and the second term is the outside payoff $\underline{w}$ times the probability of failure. Both probabilities reflect the CEO's optimistic beliefs. In equilibrium, the CEO will choose to innovate if and only if costs are not too large, specifically: $I \leq \widehat{I} \equiv E[w_2(y_1)|o] - \overline{\theta}/2$. This condition yields two testable implications. The first prediction relates to the direct effect of CEO overconfidence. Because

$$\frac{\partial \widehat{I}}{\partial o} = \frac{p}{2}(1-\alpha)\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right) > 0$$

innovation takes place at higher cost-levels (i.e. the probability of innovation is higher) when the CEO is overconfident. We can write this result as:

the presence of a third player with marginal cost $c_M \in [c_H, c_L]$ reduces the probability of winning the race for both players but has a stronger impact on the low ability player than on the high ability player.

Implication 1 *Overconfident CEOs are more likely to innovate than non-overconfident CEOs.*

Second, the model suggests a link between product market competition and innovation. The cross-partial derivative

$$\frac{\partial^2 \widehat{I}}{\partial o \partial \alpha} = -\frac{p}{2}\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right) - \frac{p}{2}\frac{\overline{\theta}(1-\alpha)}{(1+\alpha)^2} < 0$$

and the fact that $\alpha = 1 - \pi$ imply that overconfidence and competition are complements in the CEO's decision to innovate, or formally, $\partial^2 \widehat{I}/\partial o \partial \pi > 0$.

Implication 2 *The impact of CEO overconfidence on innovation increases with the level of product market competition.*

Intuitively, competition reduces the chance of success, and hence the expected benefits of innovation, but less so for overconfident CEOs who believe they have high ability.[4] More generally, Implication 2 shows that industry characteristics (in this case, the level of competition) may amplify or mute the impact of managerial biases.

2.1 Discussion

This section discusses several of our simplifying assumptions. First, we assume that CEOs can influence corporate innovation. Though we do not emphasize specific mechanisms, a CEO might influence patent-based innovation measures in several ways. For example, CEOs could change the compensation schemes of R&D executives, which can significantly alter innovation output as documented in Lerner and Wulf (2007). CEOs with strong beliefs about innovation may attract employees with similar beliefs through labour market sorting, as in Van den Steen (2005). CEOs could also instigate a broad shift in the technology strategy. For instance, Lou Gerstner, the CEO of IBM from 1993 to 2002, generated a large increase in patenting with three strategic moves (Kanellos and Spooner, 2002). First, Gerstner expanded IBM's research from a narrow focus on hardware to exploration in areas such as software and supercomputers. Second, he placed greater fiscal responsibility on the R&D department by setting precise goals,

[4]Increasing π has two effects: the first-order impact is a reduced probability of successful innovation, which outweighs a second-order increase in the CEO's expected payoff conditional on success. The size of the first effect declines with overconfidence (and in the limit where $o = 1$, vanishes completely), while the second effect is not influenced by overconfidence. The first effect is consistent with the results of Carmer and Lovallo (1999) showing that overconfident subjects discount the negative threat created by an increase in the level of competition.

cutting waste, and rewarding successful innovators. And third, Gerstner increased efforts to exploit the company's patents, generating a substantial increase in licensing revenue.

In our stylized model, the players' beliefs should converge over longer time-horizons, thereby weakening the link between overconfidence and innovation. However, Yildiz (2004) shows that the conditions for complete learning become extremely onerous when the signal space — in our model, the binary variable y_1 — grows more complex. In practice, CEOs can send a large variety of signals to the market, making it reasonable to assume that beliefs about ability need not converge during a typical CEOs tenure.[5]

We consider several extensions to our baseline model in an on-line Appendix. First, building on Malmendier and Tate (2005), we add a budget constraint to the model, and assume that a CEO must finance innovation efforts using either internal funds (cash) or external finance (debt). This extended model shows that innovation by overconfident CEOs is more sensitive to cash flow than innovation by non-overconfident CEOs. Intuitively, because overconfident CEOs accept a larger range of projects, their budget constraints are more likely to be binding. Therefore, a marginal increase in cash-flow tends to have a greater impact on the investment decisions of biased CEOs. A second set of extensions show that our results do not depend on not depend on specific assumptions about how to model the CEO's outside option (e.g. we consider non-sector specific ability, as in Aghion, Van Reenen and Zingales (2009), and also drop the switching cost δ). Finally, we generalize our set-up and show how our main results still hold under alternative assumptions about the interplay between competition and innovation.

Of course, our stylized career concerns model omits many factors that might influence either a firms innovation strategy or the market's assessment of CEO ability. Since CEOs may respond to all of these forces, we now turn to the data and use a novel measure of CEO overconfidence to evaluate the main predictions of the model.

3 Data and Methods

We begin with a panel of 450 large publicly traded U.S. firms between 1980 and 1994. These data are described in Hall and Liebman (1998) and Malmendier and Tate (2008). Each firm in the sample appeared at least four times on a *Forbes* magazine list of the largest U.S. companies. These data provide a very detailed picture of CEO's stock option holdings, which Malmendier and Tate (2008) use to construct the measure of CEO overconfidence described below.

[5]One obvious way to expand the signal space of our model is to assume that the CEO's initial beliefs are unknown to the market. This leads to a two-dimensional career concern model, similar to the one studied in Koszegi and Li (2008). Their results suggest that overconfidence may increase innovation in this more complicated setting.

We use the Compustat firm identifier (GVKEY) to merge this panel of large publicly traded firms to the NBER US patent data file. The NBER patent data are described in Hall et al. (2001), and provide detailed information on all U.S. patents during our sample period, including application and grant years, citations to other patents, and assignee codes that can be used to identify the owner. To match U.S. patent assignee codes with Compustat firms, we started with the name-matching tool of Bessen (2009) and then searched by hand for variations on the names in our panel. After dropping firms in the Finance, Insurance and Real Estate sector (one-digit SIC code 6), which has a very low rate of patenting, we arrive at an estimation sample with 290 firms, 3,648 firm-years and 627 individual CEOs, covering the period 1980 to 1994.[6] Table 1 provides summary statistics for this sample.

Our primary measure of innovation is a citation-weighted count of U.S. patents. Patent citations identify prior knowledge upon which a patent builds and delimit the scope of the property rights awarded to the inventor. A patent examiner who is an expert in the technology area is responsible for insuring that all appropriate patents have been cited. Because of this important legal function of patent cites, the economics of innovation literature has often employed the number of forward-citations received by a patent as an indirect measure of patent value (Pakes and Griliches, 1980; Hall et al., 2005; Harhoff et al., 1999; Aghion et al., 2009, inter alia).[7] Since citation counts are inherently truncated, we weight each patent by the truncation-adjusted citation count field contained in the NBER patent data file (see Hall et al., 2001, for details).

We match patents to firm-year observations according to their filing date, which approximates the date of invention, since the patent system provides incentives to file quickly. While filing dates may anticipate a CEO's ultimate payoff from innovation, we view this as a reasonable choice given the evidence that lags from application to grant are short on average (1.89 years in our data), citations peak roughly two years after a patent is granted (Mehta, Rysman and Simcoe 2010), and Tobin's q is correlated with the *future* citations of a firm's current patent stock (Hall, Jaffe and Trajtenberg 2005), suggesting that cites are a lagging indicator of value.[8]

Ideally, we would like to identify patents that are attributable the actions of a particular CEO. Unfortunately, we have no information on when specific research investments were initi-

[6]Retaining firms from the FIRE sector does not change the main results.

[7]A number of studies have been conducted to validate the use of patent cites. Harhoff et al. (1999) show that the price at which a patentee was willing to sell a patent is highly correlated with the citations received by the patent. Highly cited patents have been shown to be more frequently litigated (Lanjouw and Schankerman, 2001), more frequently traded among firms (Serrano, 2010) and to boost market value (Hall et al., 2005).

[8]While it may take a long time to for a patented innovation to be embedded into products and to generate profits there is evidence that markets react very quickly to patent awards (Hall, Jaffe and Trajtenberg, 2005).

ated, and we know of no research that tries to measure the average time lag between starting a research project and issuance of the first related patent.[9] Moreover, if R&D investments are staged, it may be impossible to partition "responsibility" for a given patent between CEOs who make complementary investment decisions at different stages of the research process. Nevertheless, it is reasonable to think that a new CEO might quickly influence research at all stages of the development process, through both investment decisions, and by changing the firm's strategic priorities. And a virtue of linking patents to CEOs based on the patent's filing date is that we know the overconfident CEO was responsible for the final decision to incur the application costs.

We also consider several additional innovation metrics. First, we de-compose our primary citation-weghted patent measure into an unweighted patent count, and the average number of citations per patent (excluding self cites). Second, we use the research and development expenditures (Compustat item 46) as a measure of innovation inputs. Since firms are not required to account for their R&D expenditures, this variable has many missing values, even after we interpolate over any gaps of three years or less. Finally, in a series of extensions, we examine changes in originality (i.e. dispersion of citations across technology areas) and in the share of self-citations. Table 1 shows that the distribution of innovative activity in our sample is highly skewed. While the median firm-year observation consists of a single patent that receives 6 citations, the sample mean is much higher, at 28 patents and 489 cites.

To measure competition, we use a Lerner index, as in Aghion et al. (2009). Specifically, we calculate the median gross margin of all firms in the Compustat database with the same two-digit SIC code as a focal firm. Our baseline model allows this competition measure to vary over time. However, we also consider robustness tests that use a time-invariant Lerner index, or a dummy for firms whose average gross margin over the entire sample period falls above the median of all firms in the estimation sample.

In our regressions we condition on size and the capital-labor ratio, as suggested by literature on patent production functions (see inter alia Aghion et al., 2009; and Hall and Ziedonis, 2001). At the CEO level, we control for age and tenure (and their squared terms) to capture experience and career concern incentives of the top executives. We also include control variables for the effects of CEO stock ownership and options holding. Our main Compustat items are sales (item 1); a capital-labor ratio constructed from the book value of total assets (item 6) and the number of employees (item 29); and a deflated R&D stock. To construct the R&D stock,

[9]We expect that in some industries (e.g. software) the time from initial idea to patent application may be quite short, and in others (e.g. pharmaceuticals) quite long. However, such measurements would be quite difficult if the research process is cumulative and chaotic, with overlapping projects and opportunistic patent applications, rather than an orderly "linear" process that proceeds from investment to outcome.

we follow the method described in Hall (1990), depreciating all reported R&D activity at a rate of 15 percent over a ten year period. As in Malmedier and Tate (2005a, 2005b, 2008), we construct a measure of cash-flow adding Compustat earnings before extraordinary items (item 18) and depreciation (item 14). We also have several CEO-level control variables used in Malmendier and Tate (2008), including age, job tenure, and a set of dummies categorizing their educational background as finance or technical. CEOs with a "finance" background received a degree in accounting, finance, business (including MBA) or economics. CEOs with a "technical" background received a degree in engineering, physics, chemistry, mathematics, operations research, biology or applied sciences.

3.1 Measuring Overconfidence

Our measures of CEO overconfidence build on a series of papers by Malmendier and Tate. These papers use CEOs' personal investment decisions to construct a proxy for overconfidence, or systematic over-estimation of the returns to holding stock in their own firm. The key idea behind this measurement strategy is to focus on the decision to exercise executive stock options. These options give the holder a right to purchase stock in their own company, usually at the prevailing price on the date of the option grant. They typically have a ten year life, and are fully exercisable after a four year vesting period. At exercise, the shares are almost always immediately sold.

While investors may hold ordinary options because the right to delay a stock purchase has positive value, executive stock options have several unique features that create strong incentives for exercise, so long as they are fully vested (and in the money). In particular, executive stock options are non-tradable, and CEOs cannot legally hedge their risk by short-selling shares in their own firm. Moreover, most CEOs are highly exposed to idiosyncratic risk associated with their own firm through equity compensation, stock holdings and firm-specific human capital. Consequently, standard models of decision-making under uncertainty (e.g. Hall and Murphy, 2002) indicate that a risk-averse CEO should exercise vested executive options before expiration as long as the stock price is sufficiently high. Nevertheless, many of the CEOs in our sample fail to exercise their executive options, often repeatedly. Malmendier and Tate use this behavior as an indicator of CEO overconfidence, or systematic over-estimation of expected returns from holding the stock.

While there are other potential explanations for a CEO's decision to hold fully vested executive options, Malmendier and Tate (2008) provide strong evidence for the overconfidence interpretation. In particular, their research shows that failure to exercise in-the-money executive options is positively associated with value-destroying merger and acquisition activity, and a relatively high sensitivity of investments to cash flows. These findings are consistent with the idea that overconfident CEOs believe they can make good investments, but perceive the market price of debt financing as too high. Malmendier and Tate also find that CEOs do not earn abnormal returns from holding their executive options, relative to a benchmark case of exercising the options and investing the proceeds in an S&P 500 stock index. This suggests that "late" exercise does not reflect inside information about the future prospects of the company.[10] After considering a variety of other interpretations (e.g. board pressure, risk-tolerance, taxes and procrastination) Malmendier and Tate (2008) argue that the broad pattern of results is most consistent with the idea that CEOs who fail to exercise their fully vested and in the money executive options are systematically over-estimating the future performance of their own firm, i.e. they are overconfident. We build on the measurement strategy of Malmendier and Tate (2008) to construct two proxies for CEO overconfidence:

Holder67 This indicator variable is identical to the Holder67 variable in Malmendier and Tate (2008). To construct this variable, they examine all fully vested CEO option packages five years before expiration. The variable Holder 67 equals one for any CEO that fails to exercise an executive option after their stock price has risen by at least 67 percent. This 67 percent exercise threshold is calibrated using the Hall and Murphy (2002) framework, assuming that two-thirds of CEO wealth is tied to company stock. Under this framework, failing to exercise an option that is 67 percent in the money implies a constant relative risk-aversion parameter of three. This measure treats overconfidence as an absorbing state: once a CEO becomes overconfident, they will never change back. While a CEO may switch from "rational" to overconfident within our sample, it is a rare event; most retain their initial classification throughout the sample period.

In our estimation sample, Holder67 classifies roughly half of all CEOs as overconfident. However, a large proportion of all CEOs are not classified, either because they served a short tenure (so there was no opportunity to exercise a fully vested option package), or because their stock price did not appreciate by 67 percent. Moreover, Holder67 is only defined for CEOs who have been with a company for at least four years. Thus, our estimation sample contains 1,344 observations where Holder67 is defined. One can think of Holder67 as identifying CEOs who become overconfident following a 67 percent increase in the stock price of their firm. Our second measure is motivated by the idea that overconfidence may be a permanent trait.

Overconfidence This measure is a CEO fixed effect that equals one for all CEOs where Holder67 equals one, and zero for all CEOs where Holder67 equals zero. In practical terms,

[10] A literal reading of our stylized model suggests that CEOs are waiting for uncertain innovation outcomes to be revealed. A more encompassing view is that CEO option-holding reflects a broad divergence of opinion regarding the firm's overall prospects.

Overconfidence is simply the maximum value of Holder67 for a given CEO. This is useful for models where we wish to exploit within-firm variation associated with the arrival of an overconfident CEO, as opposed to a cross-sectional difference between firms. While Overconfidence is defined for 2,230 observations in our sample, there are still 1,418 observations where it is undefined because of a short tenure or a stock that did not appreciate by at least 67 percent. Our main results are robust to re-classifying these missing CEOs as non-onverconfident, though we have no justification for doing so.

Our data have some limitations relative those in Malmendeir and Tate (2008). For example, while they show that the choice of a particular cut-off does not affect the main results, we only observe the Holder67 dummy, and cannot use the detailed option-holdings to construct alternative exercise thresholds.

3.2 Methods

Our main econometric models focus on the relationship between count-based measures of innovative activity Y_{it} at firm i in period t, and measures of CEO overconfidence O_{it}. We typically model the conditional expectation of innovative activity as

$$E[Y_{it}] = \exp(\alpha O_{it} + x_{it-1}\beta + \gamma_i + \lambda_t) \tag{3}$$

where x_{it-1} is a vector of control variables (lagged one period to account for obvious forms of simultaneity), γ_i is a firm-specific idiosyncratic effect, and λ_t is a vector of time-period effects. Equation (3) uses the log-link formulation because of the non-negative and highly skewed nature of our count-based dependent variables.[11] We allow for arbitrary heteroskedasticity and autocorrelation (i.e. clustering standard errors).[12]

When x includes measures of the firm's R&D stock, equation (3) can be interpreted as a "knowledge production function" that translates past research investments into new inventions. In that formulation, α indicates whether firms led by overconfident CEOs receive more cite-weighted patents per dollar of R&D expenditure, so it is a measure of efficiency. We also estimate models that omit the R&D stock from x, in which case α measures the combined impact of changes in R&D stocks and inventive efficiency.

Our identification comes primarily from changes in innovative performance across CEOs within a firm. We do not have an instrument for CEO overconfidence, or a canonical difference-

[11] Wooldridge (1999) emphasizes that Poisson quasi maximum-likelihood estimation will yield consistent estimates as long as the conditional mean is correctly specified, making it equally appropriate for positive and continuously-valued variables, such as R&D.

[12] Our results are robust to clustering standard errors at the level of two-digit SIC codes, firms or CEOs.

in-differences set-up where "treated" firms exogenously switch to overconfident CEOs at a point in time. The controls x_{it-1} and firm effects γ_i therefore play an important role in our analysis, though we perform several robustness checks designed to placate endogeneity concerns.

The main method that we use to introduce the firm-specific effects γ_i in equation (3) is the "mean scaling" estimator of Blundell et al. (1999). This method uses pre-sample data on the dependent variable to construct a mean, which then enters the estimation directly (analogously to x_{it}) to account for initial conditions. We use ten years of pre-sample data, though Blundell et al. (1999) show that the approach performs well even with relatively short pre-sample periods. While a conditional fixed effects model, such as the fixed-effects Poisson estimator of Hausman et al. (1984), isolates the within-firm variation, it also assumes that x_{it} is strictly exogenous (i.e. uncorrelated with past, present and future shocks to y_{it}). This strict exogeneity assumption would be false if, for example, an unobserved shock in the value of firm's technology causes firms to increase both current R&D and future patenting efforts. The mean-scaling estimator relaxes the strict exogeneity assumption and provides consistent estimates under the weaker assumption of predetermined x_{it}, as long as the first-moments of the data are stable.

4 Results

Table 2 presents our first set of regression results, which show a robust positive association between CEO overconfidence and innovation. The dependent variable in all models is a cite-weighted patent count, or equivalently, a total forward citation count for issued patents applied for in year t. All models in Table 2 are estimated via Poisson, with robust standard errors to account for over dispersion. Columns (1) through (4) use the Overconfidence measure, while (5) and (6) consider the alternative Holder67 variable, which leads to a smaller estimation sample.

We begin in column (1) with a model that includes only firm, year and two-digit SIC code effects, along with the overconfidence measure. Exponentiating the coefficient of 0.39 suggests that overconfident CEOs obtain 48 percent more citation-weighted patents than their non-overconfident counterparts. Column (2) adds controls for lagged sales, the firm's capital to labor ratio, the CEO's age, age squared, tenure and tenure squared, and the levels of CEO stock ownership and vested option holdings.[13] This produces almost no change in the Overconfidence coefficient relative to the model containing only the pre-sample means of inventive output.

In columns (1) and (2), the Overconfidence coefficient α measures the combined impact of changes in efficiency (more output per dollar of R&D) and innovative intensity (greater

[13]Stock Ownership measures the percent of company stock held by the CEO at the beginning of the year, while Vested options equals the number of options exercisable in the first six months of the year normalized by total shares outstanding.

spending on innovation). In column (3) we add the log of each firm's R&D stock, so the model becomes a patent production function, where α measures the patenting premium of overconfident CEOs per dollar of lagged R&D spending. As expected, we observe a very robust positive correlation between past R&D and current patenting (see Hall et al., 2005). The coefficient on Overconfidence also declines by about 33 percent, to 0.24, indicating that Overconfident CEOs obtain 28 percent more cite-weighted patents per dollar of lagged R&D spending than their counterparts. This difference could reflect either a higher patent propensity among overconfident CEOs, or a change in the direction of innovative activity that leads to greater research productivity.[14]

Perhaps the results in column (3) are driven by overconfident CEOs' greater propensity for mergers and acquisitions? To address this concern, we collected data on M&A transactions by firms in our sample from the Thompson Financial SDC database and created a variable called M&A, which counts the number of completed deals for each firm-year.[15] Column (4) of Table 2 shows that acquisitions are associated with an increase in forward-citations per dollar of R&D. However, the overconfidence coefficient changes only marginally with the introduction of this control for M&A activity.

Columns (5) and (6) estimate the same model as (2) and (3) using the alternative Holder67 measure of overconfidence. Since Holder67 is only defined starting in the year when a CEO holds a fully vested executive stock option that has appreciated by 67 percent or more, the sample size declines sharply. However, the pattern of results is very similar. While the coefficient on overconfidence is slightly greater, it still falls by about 20 percent when we move to a production function model that includes the R&D stock.

For the unreported controls, we find that CEO tenure and age are inversely related to innovative output. In particular, the quadratic terms for both age and tenure are jointly significant at the 1 percent level, and indicate that innovation declines with age and tenure more steeply when CEOs are young and inexperienced (though the raw correlations between age tenure and citations are all below 0.05).[16] We take these results as support for the career concern model, since the incentives to innovate are lower for CEOs close to retirement.

Overall, the results in Table 2 document a strong positive association between overconfi-

[14]Results are similar if: (i) we replace the R&D stock with a stock of cite-weighted patents or with the stock of cites before the CEO takes office; (ii) we replace SIC code effects with fixed effects for the primary USPTO subcategory or fixed effects for the primary USPTO patent class (nclass).

[15]Following Malmendier and Tate (2008) we dropped the deals where the acquiring company obtains less than 51% of the target share and the deals in which the acquirer already owns more than 51% before the deal. We also dropped deals whose targets were small (i.e. sales less than 10% of average sales in our sample).

[16]The estimated marginal effect for tenure implies that an extra year as a CEO is associated with a reduction in innovation of 2 percent for CEOs with 4 years of tenure (25th percentile) compared to a reduction of 1 percent for CEOs with 13 years (75th percentile).

dence and innovation. The on-line Appendix shows that these findings are robust to a variety of measurement and empirical modeling strategies, including the use of conditional fixed effects. We take these results as support of the first prediction in the theoretical model.

4.1 Alternative Innovation Measures

Table 3 asks whether our baseline results are driven by greater output (more patents), greater input (more R&D), or greater impact (more cites). We find evidence of all three effects.

The first two columns in Table 3 use unweighted patent counts as the dependent variable. The results in column (1) suggest that overconfident CEOs file for about 20 percent more patents per dollar of lagged R&D stock than CEOs who are not overconfident. Adding fixed effects in column (2) causes the coefficients on sales and lagged R&D stock to fall, but has no noticeable effect on the Overconfidence coefficient.

The middle two columns examine the link between Overconfidence and R&D. We drop the lagged R&D stock in this specification, since we are focused on inputs, and rely on a conditional fixed effects estimator because missing data complicates the construction of pre-sample means. In column (3), we find that overconfident CEOs perform about 18 percent more R&D than a typical CEO. Adding firm effects reduces this effect slightly (to 17 percent).[17] Without more information on the profits generated by these R&D investments, or the opportunity cost of invested funds, we cannot say whether the increased expenditures are profit-maximizing. In particular, since Malmendier and Tate link overconfidence to excessive M&A activity and cash-flow sensitivity, one might expect these CEOs to over-invest. However, that interpretation is hard to reconcile with our finding that R&D investments by overconfident CEOs are more productive (i.e. generate more patents and citations per dollar). It is also worth noting that if the social returns to R&D exceed the private benefits, as many economists believe, then over-investment is generally desirable.

The last two columns in Table 3 examine the correlation between CEO overconfidence and citations per patent.[18] The results show a roughly twenty percent increase in the mean citation rate. Interestingly, there is little correlation between the average citation rate and the firm level controls of sales, capital-labor ratio and R&D stock. We find this last result especially intriguing, as it evokes a change in innovative direction or impact, as opposed to merely an increase in the amount of R&D or patenting by overconfident CEOs.

To further explore changes in the citation rate conditional on receiving a patent, we ran

[17] The results in Table (3) use linear interpolation (over gaps of three years or less) to replace missing values of R&D, but the results are robust to leaving those observations missing or treating them as zeroes.

[18] We set this variable to zero in firm-years where no patents were filed, but the results change very little if those observations are dropped.

a series of patent-level regressions. Specifically, we created a patent-year panel dataset that includes all patents filed by CEOs in our baseline model between 5 years before and 19 years after patent issuance. Our dependent variable is a count of citations received in a given calendar year. By moving to the patent level we can add technology-class fixed effects to control for unobserved heterogeneity in firms' technology portfolios, along with a combination of patent-age and citing-year effects to control for truncation (without using the Hall et al. (2001) adjustment factors) and time-trends in the baseline citation rate.

Column (1) in Table 4 shows that the average annual citation rate for a patent filed by an overconfident CEO is 3.7 percent higher than for a patent issued to a rational CEO in the same year and technology category. This model includes patent-age (since grant), application-year, and technology-class (subcat) by citing-year fixed effects. Columns (2) through (4) show that when firm effects are added to this model — so the comparison is to a patent issued to the same firm, in the same technology class, under a different (non-overconfident) CEO — the estimated impact of overconfidence on citations per year increases to roughly 12 percent. Column (2) estimates a model with firm, patent-age and citing-year effects.[19] Column (3) interacts the firm fixed-effects with a set of detailed technology codes, based on the primary 3-digit USPTO classification. Column (4) interacts a less detailed set of technology codes (the NBER subcat variable) with a full set of citing-year effects to capture the idea that certain technologies may become hot, and therefore highly cited, at different points in time.

The results of the patent level analysis are consistent with the citations-per-patent findings in the last two columns of Table 3. Together, these results suggest that patents filed under overconfident CEOs achieve a greater impact. While we do not have direct evidence on the underlying mechanisms, one possibility is that overconfident executives take their firms in new directions, and are therefore more likely to generate foundational patents that receive many cites. Another possibility is that by pursuing a riskier innovation strategy, overconfident CEOs spread the distribution of research outcomes, and since they have an option to abandon projects that do not work out (i.e. by not filing for a patent, or not citing one that is granted) we observe only the increased weight at the upper end of the citation distribution. To further explore the latter possibility, the on-line Appendix presents results from a series of patent-level linear probability models, where the dependent variable is a dummy for cumulative forward citations greater than 5, 10, 20, 40 or 60 cites.[20] We find that patents filed under overconfident CEOs exhibit a statistically significant 3 percentage point increase in the probability of receiving 20 or

[19]Note that is it not possible to separately identify the application-year, citing-year and patent-age effects in a model with firm fixed-effects. This issue is discussed at length in Mehta , Rysman and Simcoe (2010).

[20]These thresholds correspond to the 25th, 50th, 75th, 90th and 95th percentile in the unconditional distribution of total citations.

more cites (and we find similar effects at the 40 and 60 cite thresholds). These results suggest that the distribution of research outcomes is more skewed under overconfident CEOs.

4.2 Overconfidence and Competition

Table 5 presents several results related to the second prediction of our model. Specifically, the model suggests that the association between overconfidence and innovation will be stronger when firms face more competition. To examine this relationship, we interact the Overconfidence indicator variable with several variations on the Lerner index, or gross margin, which we assume is inversely related to product market competition. All of these regressions use our baseline patent production function specification (see column (3) in Table 2).

Column (1) uses a time-varying Lerner index calculated as the median gross margin of all firms in a particular two-digit SIC code. In this specification, the main effect of Overconfidence is economically large and statistically significant. While the main effect of the Lerner index is negative (less competition yields less innovation), the effect is not statistically significant. To provide a sense of the effect size, we note that a one standard deviation change in the Lerner index (or an additional 5 points of gross margin) is associated with a roughly 3 percent change in cite-weighted patents per dollar of R&D stock. However, the slope of this relationship between competition and innovation is roughly an order of magnitude larger for overconfident CEOs. In particular, the interaction between Overconfidence and the Lerner index is large and statistically significant, as predicted by our model.

In column (2), we find a qualitatively similar pattern using the Holder67 measure of CEO overconfidence. The main effect of overconfidence is economically large and statistically significant. The main effect of competition is negligible. And the interaction is negative and significant. Once again, the interpretation is that the relationship between Overconfidence and citation-weighted patents is stronger for firms facing more competition.

Columns (3) and (4) return to our primary Overconfidence measure, but use different measures of competition. In column (3) we restrict the Lerner index to be constant over time, but continue to base the measure on the median gross margin of all Compustat firms in a two-digit SIC code. Note that we cannot estimate a main effect of competition in such a model, since the measure is collinear with industry effects. The results in column (3) are nevertheless very close to those in column (1).

Finally, column (4) measures competition using Lerner50, a dummy for firms in an industry with a time invariant Lerner index that is above the median of all firms in our data set. Thus, we rely on within-sample variation in competition, rather than variation in the entire Compustat dataset. Once again, we find that the relationship between innovation and overconfidence is stronger when competition is more intense.

4.3 Extensions and Robustness

4.3.1 Overconfidence and Innovative Direction

Next, we use a series of alternative outcome variables to explore the idea that overconfident CEOs do not simply increase the level of innovation, but rather cause a change in the direction pursued by the firms they manage. In columns (1) and (2) of Table 6, the outcome variable is an originality weighted patent count. Originality, as defined in Hall et al. (2001), is essentially one minus a Herfindahl of the concentration of a patent's backwards citations across classes. Thus, more original patents cite a more diverse array of prior art. The results in columns (1) and (2) show that originality weighted patent counts increase with CEO Overconfidence, and more so in industries with lower gross margins.

In columns (3) and (4), we use self-citations to construct a new measure called the Derivative Patent Share. We classify a patent as derivative if more than half of its backward citations are self-cites, i.e. the patent's reference list primarily cites other patents assigned to the same firm. We then calculate the proportion of all patents that are "derivative" for a given firm-year and use that proportion as our outcome variable. Column (3) shows that there is no meaningful relationship between Overconfidence and the derivative patent share in the pooled panel regressions. However, when Overconfidence is interacted with competition, we find that derivative patenting declines for overconfident CEOs, but increases for overconfident CEOs when there is little competition. This result suggests that overconfident CEOs in profitable industries increase innovation, but focus on familiar problems. Overconfident CEOs in highly competitive fields appear to try for new innovations, perhaps in an effort to escape from the levels of competition at their current product-market location.

4.3.2 CEO Autonomy and Cash Flow Sensitivity

To examine whether the impact of overconfidence is influenced by the degree of autonomy of the CEO, we introduce a dummy for CEOs who also hold the titles of Chairman and President. These titles are used in the corporate governance literature as proxies for centralized executive control over corporate decisions. Thus, we expect the impact of overconfidence to be stronger for CEOs who are also Chairman and President. The estimates in columns (1) and (2) of Table 7 confirm this prediction and show that the effects of overconfidence and Holder67 are roughly 42 percentage points larger when the CEO has multiple titles. This result complements the findings of Adams et al. (2005), who show that firms with powerful CEOs experience more variability in performance. In the absence of interaction with overconfidence, the CEO-Chairman variable has a positive coefficient (0.063) but it is not statistically significant (p-value 0.33). In the smaller sample where Holder67 is defined, CEO-Chairman also has a positive coefficient (0.122) and it is significant at the 10 percent level. Overall these results suggest that powerful CEOs are more likely to innovate, but that this effect is mainly driven by CEOs who are both overconfident and powerful. Because we only have one simple measure of CEO autonomy, we leave a more careful study of this topic for future research.

Table 6 also explores the sensitivity of R&D investments to cash flow, defined as Compustat earnings before extraordinary items (item18) plus depreciation (item 14). As stressed in Malmandier and Tate (2005, 2008), overconfident CEOs should prefer internal funds to external funds because they perceive their company to be undervalued by the market. Therefore, we expect R&D investments of overconfident CEOs to be more sensitive to cash flow. Columns (3) and (4) of Table 7 add a control for cash flow and its interaction with overconfidence. The main effect of cash-flow is statistically insignificant, suggesting that it has no impact on R&D investments for rational CEOs. But the positive and statistically significant interaction term shows that overconfident CEOs increase their R&D investments more when they experience greater positive cash flows, as expected.[21]

4.3.3 Endogeneity

Since overconfident CEOs are not randomly matched to firms, there is a concern that our results could be driven by companies that appoint overconfident CEOs in periods of successful innovation. To assuage this concern, we use a sub-sample of the full data set to conduct a within-firm analysis that identifies the Overconfidence effect purely from changes in innovative activity before and after CEO changes that create an increase in overconfidence. While this analysis does not solve the endogenous matching problem in the sense of having a valid instrumental variable for CEO overconfidence, it allows us us to use methods that are familiar from difference-in-differences estimation to ask whether firms were behaving differently in observable ways before selecting an overconfident CEO.[22]

We start this CEO switching analysis by identifying 28 cases where a CEO who was either

[21] We also explored the impact of cash flow on the productivity of R&D (i.e. citation weighted patent counts). We found that R&D productivity of overconfident CEOs is sensitive to cash flow only for the most cash constrained firms (those in the bottom quartile of our sample for the Kaplan and Zingales (1996) measure of internal resources).

[22] One might also worry that some firms are not "at risk" for selecting an overconfident CEO, or vice versa. Since we mainly rely on within-firm variation, our models should absorb time-invariant factors that influence the CEO selection process. However, our analysis remains vulnerable to time-varying omitted variables that drive both CEO selection and innovative performance; the switching analysis is meant to address this concern. We also tried to collect information on candidates who were passed over for the CEO position, but this proved challenging for two reasons: press coverage of losing candidates was minimal, and since these contenders are not in our data, we cannot use the stock-option measures to assess their overconfidence.

not-overconfident or unclassified was replaced by an overconfident CEO. In each case, we retained data for the four years preceding the switch and all subsequent years of data for the overconfident CEO. To obtain a control sample, we performed a similar exercise to identify 24 cases where a not-overconfident or unclassified CEO was replaced by a not-overconfident CEO. We use the resulting dataset to compare the change in innovation when a new CEO is overconfident to the change when the new CEO is not overconfident, which leads to the familiar difference-in-differences estimator. However, the main purpose of this regression is not to estimate the Overconfidence effect, but rather to test the hypothesis that the time-trend of the dependent variable was different at the treatment and control firms prior to the CEO switch. We estimate fixed-effects Poisson models to isolate within-firm variation, and we drop the firm-level controls which are unlikely to be strictly exogenous. Results for these regressions are reported in the on-line Appendix.

Figure 1 provides a look at the impact of a switch to an overconfident CEO on cite-weighted patents. Here, we allow the "treatment effect" to vary for each year, normalizing the coefficient for one year before the switch to zero. The figure shows that there is no discernible trend prior to the switch. In the year of the switch, there is a sharp increase, which doubles over the next two to four years, before levelling off.

While the analysis of CEO switching helps address concerns about endogenous matching, one might also be concerned about reverse causality. In particular, if an exogenous increase in innovation leads CEOs to become overconfident, and thus hold more options, overconfident CEOs are not affecting innovation; it is innovation that causes overconfidence. However, we have two pieces of evidence that help distinguish the direction of causality. First, columns (1) and (2) in Table 6 indicate that the correlation between overconfidence and innovation is stronger for CEOs that have greater autonomy. This correlation is difficult to reconcile with reverse causality. If increased innovation is causing a change in confidence, the results in Table 6 would imply that CEOs with less autonomy become overconfident *more easily* (i.e. at a lower innovation level) than CEOs with greater control. Second, to further investigate the direction of causality we split the overconfidence dummy into two separate dummy variables: Pre-Holder67 and Post-Holder67. Post-Holder67 is equal to one only after the CEO reveals his overconfidence for the first time.[23] Including both variables in our baseline regression, we find that only Post-Holder67 is statistically significant, thus suggesting that it is not an increase in patenting activity that induces CEOs to postpone option exercise.

[23] More precisely, the variable Post-Holder67 equals to 1 when Holder67 is equal to one and is equal to zero when Holder67 is equal to zero or when Holder67 is not defined. The variable Pre-Holder67 equals 1 for the rest of the CEO years.

4.3.4 Additional Robustness Checks

This section describes a variety of additional extensions and robustness checks that interested readers can find in the on-line Appendix. First, we show that our main results are robust to using a conditional fixed-effects specification. While the mean scaling estimator allows us to include pre-determined (but not strictly exogenous) firm-level covariates, it does not isolate the within-firm co-variation of overconfidence and innovation, as evidenced by the fact that we can include SIC effects. To isolate such variation, we use the fixed-effects Poisson estimator (Hausman et al., 1984) which is analogous to the familiar within group OLS estimator and assumes that all covariates are strictly exogenous. Despite eliminating all between-firm variation, we still find support for the two testable implications of our model: overconfidence is positively correlated with innovation and the correlation is stronger when product market competition is more intense.

A second series of extensions demonstrates that our main results are robust to including extra covariates and changing the model specification. In particular, the results are not affected when: (i) we control for investment opportunities (Tobin's Q); (ii) we allow for dynamics using a multiplicative feedback model that controls for the logarithm of lagged cite-weighted patent counts; (iii) we introduce industry specific time-trends by interacting the industry fixed effects with the calendar year, or; (iv) we use a negative binomial specification.

A third set of robustness checks considers an alternative measure of overconfidence. To strengthen the overconfidence interpretation of their results, Malmendier and Tate (2008) use business press coverage data to identify CEOs depicted as "optimistic" or "confident." We conduct a similar exercise using articles from the Wall Street Journal, New York Times, Business Week, Financial Times and Economist during the sample period. We find that this alternative overconfidence measure is positively correlated with citation-weighted patent counts, and that the correlation is stronger in more competitive industries.

Finally, we show that our results can be replicated using a different sample of firms in a later time-period. Our main analysis uses a dataset originally constructed by Hall and Liebman (1998) and Malmandier and Tate (2005a; 2005b; 2008). The main virtue of these data is the ability to create Holder67, a relatively precise measure of executive option-holding behavior. Their primary limitation is the small sample, which contains only 290 innovating firms. We used the larger S&P ExecuComp database, which reports information on executive compensation for S&P 1,500 companies from 1992 to 2009, to construct an alternative measure of vested-option-holding. Once again, we find support for the predictions of the model: the correlation between innovation and overconfidence is positive and significant and the coefficient on the interaction between the Lerner index and overconfidence is negative and significant.

5 Conclusions

In this paper we study the relationship between CEO overconfidence and innovation. We use a simple career concern model to show that CEO overconfidence can increase innovation. The model also predicts that the impact of overconfidence will be stronger when product market competition is more intense. We find strong empirical support for these predictions. In particular, overconfident CEOs obtain more cite-weighted patents, and this effect increases with product market competition.

We interpret these findings as evidence that overconfident CEOs are more likely to initiate a significant change in their firm's innovation strategy. More broadly, our results suggest that applying tools from behavioral economics to questions in the field of innovation may yield novel insights into the determinants of R&D investments and patenting. Our findings also complement those of Aghion et al. (2009), who show that institutional ownership encourages innovation by reducing the likelihood that a CEO is dismissed after a decline in profits. Our results show that overconfidence encourages innovation by reducing a CEO's internal beliefs about the likelihood of failure.

Although we show that overconfident CEOs obtain more patents and citations per dollar of R&D, these results do not imply that overconfident CEOs make optimal, or even profitable, R&D investments. Since we use indirect measures of innovation value, and have no information on the opportunity cost of funds, we cannot rule out over-investment or poor project selection. Nevertheless, the greater research productivity of overconfident CEOs may offset the negative impacts of executive overconfidence found in previous research. And if the social returns to innovation exceed its private benefits, over-investment in corporate R&D would be a desirable outcome.

References

Adams, R. B., H. Almeida, and D. Ferreira (2005). Powerful CEOs and Their Impact on Corporate Performance. *Review of Financial Studies 18*, 1408–1432.

Aghion, P., J. Van Reenen, and L. Zingales (2009). Innovation and Institutional Ownership. *NBER Working Paper 14769*.

Astebro, T. (2003). The Return to Independent Invention: Evidence of Risk Seeking, Extreme Optimism or Skewness-Loving. *The Economic Journal 113*, 226–239.

Baye, M. R. and H. C. Hoppe (2003). The strategic equivalence of rent-seeking, innovation, and patent-race games. *Games and Economic Behavior 44*(2), 217–226.

Bernardo, A. E. and I. Welch (2001). On the Evolution of Overconfidence and Entrepreneurs. *Journal of Economics & Management Strategy 10*(3), 301–330.

Bessen, J. (2009). Tool for Matching Assignee Names. Technical report, NBER Patent Data Project.

Bloom, N., M. Schankerman, and J. Van Reenen (2005). Identifying Technology Spillovers and Product Market Rivalry. CEPR Discussion Papers 4912, C.E.P.R. Discussion Papers.

Blundell, R., R. Griffith, and J. van Reenen (1999). Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms. *Review of Economic Studies 66*(3), 529–54.

Camerer, C. and D. Lovallo (1999). Overconfidence and Excess Entry: An Experimental Approach. *American Economic Review 89*(1), 306–318.

Camerer, C. and U. Malmendier (2007). *Behavioral Economics and its Applications*, Chapter Behavioral Economics of Organizations. Princeton University Press.

De Meza, D. and C. Southey (1996). The borrowers curse: Optimism finance and entrepreneurship. *the Economic Journal 106*, 375–386.

DellaVigna, S. (2008). Psychology and Economics: Evidence from The Field. *Journal of Economic Literature 47*(2), 315–372.

Galasso, A. (2010). Over-confidence may reduce bargaining delay. *Journal of Economic Behavior and Organization 76*, 716–733.

Goel, A. M. and A. V. Thakor (2008). Overconfidence, CEO Selection, and Corporate Governance. *Journal of Finance 63*(6), 2737–2784.

Hall, B. H. (1990). The Manufacturing Sector Master File: 1959-1987. *NBER Working Paper No. 3366*.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2001). The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools. Working Paper 8498, National Bureau of Economic Research.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2005). Market Value and Patent Citations. *RAND Journal of Economics 36*, 16–38.

Hall, B. H. and R. H. Ziedonis (2001). The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995. *RAND Journal of Economics 32*(1), 101–128.

Hall, B. J. and J. B. Liebman (1998). Are CEOs Really Paid Like Bureaucrats? *The Quarterly Journal of Economics 113*(3), 653–691.

Hall, B. J. and K. J. Murphy (2002). Stock options for undiversified executives. *Journal of Accounting and Economics 33*(1), 3–42.

Harhoff, D., F. Narin, F. M. Scherer, and K. Vopel (1999). Citation frequency and the value of patented inventions. *Review of Economics and Statistics 81*(3), 511–515.

Hausman, J., B. Hall, and Z. Griliches (1984). Econometric Models for Count Data with an Application to the Patents-R&D Relationship. *Econometrica 52*(4), 909–938.

Hirshleifer, D. A., S. H. Teoh, and A. Low (2010). Are Overconfident CEOs Better Innovators? *SSRN Working Paper*.

Holmstrom, B. (1999). Managerial Incentive Problems: A Dynamic Perspective. *Review of Economic Studies 66*(1), 169–82.

Kanellos, M. and J. Spooner (2002). Ibm's outsider: A look back at lou. *CNET News February*.

Kaplan, S. and L. Zingales (1997). Do investment-cash flow sensitivities provide useful measures of financing constraints? *Quarterly Journal of Economics 112*, 169–215.

Klepper, S. and P. Thompson (2007). *Perspectives on Innovation*, Chapter Spinoff Entry in High-Tech Industries: Motives and Consequences (chapter6), pp. 187–218. Cambridge University Press.

Klepper, S. and P. Thompson (2010). Disagreement and Intra-industry spinoffs. *International Journal of Industrial Organization forthcoming.*

Koszegi, B. and W. Li (2008). Drive and Talent. *Journal of the European Economic Association 6*, 210–236.

Lanjouw, J. and M. Schankerman (2001). Characteristics of patent litigation: a window on competition. *RAND Journal of Economics 32*, 129–151.

Lerner, J. and J. Wulf (2007). Innovation and Incentives: evidence from corporate R&D. *Review of Economics and Statistics 89*, 634–644.

Lowe, R. A. and A. A. Ziedonis (2006). Overoptimism and the Performance of Entrepreneurial Firms. *Management Science 52*, 173–186.

Malmendier, U. and G. Tate (2005a). CEO Overconfidence and Corporate Investment. *Journal of Finance 60*(6), 2661–2700.

Malmendier, U. and G. Tate (2005b). Does Overconfidence Affect Corporate Investment? CEO Overconfidence Measures Revisited. *European Financial Management 11*(5), 649–659.

Malmendier, U. and G. Tate (2008). Who makes acquisitions? CEO overconfidence and the market's reaction. *Journal of Financial Economics 89*(1), 20–43.

Mehta, A., M. Rysman, and T. Simcoe (2010). Identifying the Age Profile of Patent Citations: New Estimates of Knowledge Diffusion. *Journal of Applied Econometrics*.

Moore, D. and T.-G. Kim (2003). Myopic Social Prediction and the Solo Comparison Paradox. *Journal of Personality and Social Psychology 85*, 1121–1135.

Moore, D. A. and D. M. Cain (2007). Overconfidence and underconfidence: When and why people underestimate (and overestimate) the competition. *Organizational Behavior and Human Decision Processes 103*(2), 197–213.

Pakes, A. and Z. Griliches (1980). Patents and R&D at the firm level: A first report. *Economics Letters 5*(4), 377–381.

Serrano, C. (2010). The dynamics of the transfer and renewal of patents. *RAND Journal of Economics*.

Shane, S. (2003). *A general theory of entrepreneurship: the individual-opportunity nexus.* Edward Elgar.

Svenson, O. (1981). Are we all less risky and more skillful than our fellow drivers? *Acta Psychologica 47*(2), 143–148.

VandenSteen, E. (2005). Organizational Beliefs and Managerial Vision. *Journal of Law, Economics, and Organization 21*(1), 256–283.

Wooldridge, J. M. (1999). Distribution-free estimation of some nonlinear panel data models. *Journal of Econometrics 90*(1), 77–97.

Yildiz, M. (2004). Waiting to Persuade? *Quarterly Journal of Economics 119*, 223–249.

Tables and Figures

Table 1: Summary Statistics

	Mean	Median	Min	Max	S.D.	Obs.
Total Cites	489.01	6.00	0.00	32,509	1,747	3648
Total Patents	27.79	1.00	0.00	1,221	81.29	3648
Cites per Patent	8.62	4.00	0.00	240	13.32	3648
log(R&D Expense)	3.80	3.92	0.00	8.73	1.94	1864
Overconfidence	0.58	1.00	0.00	1.00	0.49	2441
Holder67	0.49	0.00	0.00	1.00	0.50	1533
Lerner Index	0.11	0.09	0.03	0.22	0.05	3648
CEO Chairman	0.38	0.00	0.00	1.00	0.49	3640
log(Cash Flow)	5.31	5.33	-5.45	13.92	1.51	3624
log(Sales)	7.85	7.75	2.95	11.81	1.12	3641
log(Employees)	2.68	2.72	-2.23	6.78	1.29	3627
log(Capital/Labor)	4.29	4.01	0.09	7.47	1.35	3637
Stock Ownership	0.02	0.00	0.00	0.95	0.07	3648
Vested Options	0.26	0.00	0.00	786.00	13.10	3648
Total Firms			290			
Total CEOs			627			
Overconfident			168			
Not-overconfident			136			
Unclassified			323			

Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Overconfidence is the maximum value for Holder67 for a given CEO. Lerner Index is the median gross profit margin of all Compustat firms in a 2-digit SIC code. Cash Flow equals Compustat earnings before extraordinary items (item 18) plus depreciation (item 14). CEO Chairman is a dummy equal to one if a CEO also holds the titles of Chairman and President.

Table 2: Overconfidence and Innovation

Poisson Panel Regressions

Unit of Observation = Firm-Year

Dependent Variable = Total Cites

	(1)	(2)	(3)	(4)	(5)	(6)
Overconfidence	0.389**	0.357**	0.241**	0.228**		
	(0.12)	(0.15)	(0.12)	(0.11)		
Holder67					0.543***	0.407***
					(0.14)	(0.11)
ln(Sales)		0.412***	0.201*	0.186	0.410***	0.054
		(0.12)	(0.10)	(0.12)	(0.12)	(0.13)
ln(Capital/Labor)		-0.061	0.089	0.085	0.115	0.301**
		(0.17)	(0.10)	(0.10)	(0.23)	(0.15)
ln(R&D Stock)			0.323***	0.331***		0.492***
			(0.08)	(0.08)		(0.08)
Stock Ownership		-0.297	-0.626	-0.527	-2.107	-2.455
		(2.31)	(2.32)	(1.42)	(3.08)	(2.89)
Vested Options		0.004***	0.004***	0.004***	-0.789	-0.458
		(0.00)	(0.00)	(0.00)	(2.56)	(1.56)
M&A				0.075**		
				(0.03)		
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	Yes	Yes	Yes
CEO Controls	No	Yes	Yes	Yes	Yes	Yes
Firm Effects	BGV	BGV	BGV	BGV	BGV	BGV
Observations	2441	2441	2441	2441	1512	1512
Firms	229	227	227	227	226	226
CEOs	303	301	301	301	301	301

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Overconfidence is the maximum value for Holder67 for a given CEO. BGV fixed effects are based on including pre-sample means of the dependent variable. CEO controls are Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings.

Table 3: Overconfidence and Alternative Innovation Measures

Poisson Panel Regressions

Unit of Observation = Firm-Year

Outcome Variable	Unweighted Patents		R&D Expense		Citations per Patent	
	(1)	(2)	(3)	(4)	(5)	(6)
Overconfidence	0.198**	0.177**	0.185*	0.145**	0.180**	0.183**
	(0.10)	(0.07)	(0.10)	(0.06)	(0.08)	(0.07)
ln(R&D Stock)	0.428***	0.227***			0.011	-0.012
	(0.05)	(0.07)			(0.10)	(0.10)
ln(Sales)	0.400***	0.187***	1.040***	0.765***	0.042	0.039
	(0.08)	(0.06)	(0.10)	(0.06)	(0.14)	(0.12)
ln(Capital/Labor)	0.039	0.043	-0.335*	-0.273***	0.036	0.051
	(0.11)	(0.11)	(0.19)	(0.09)	(0.10)	(0.10)
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	n/a	Yes	Yes
CEO Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm Effects	No	BGV	No	Yes	No	BGV
Observations	2229	2229	1216	1199	2229	2229
Firms	209	209	123	119	209	209
CEOs	279	279	167	163	279	279

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. BGV fixed effects are based on including pre-sample means of the dependent variable. CEO controls are Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings (CEO Age and Tenure effects are omitted in the R&D conditional fixed effects model due to co-linearity with the time trend).

Table 4: Overconfidence and Patent Citations

Poisson Panel Regressions

Unit of Observation = Patent-Year

Dependent Variable = Citation Count

	(1)	(2)	(3)	(4)
Overconfidence	0.037**	0.121***	0.127***	0.122***
	(0.01)	(0.04)	(0.03)	(0.02)
ln(Sales)	-0.016	0.030	0.035**	0.019
	(0.01)	(0.02)	(0.02)	(0.01)
ln(Capital/Labor)	0.074***	-0.030	-0.024*	-0.026**
	(0.01)	(0.02)	(0.01)	(0.01)
ln(R&D Stock)	0.045***	0.010	0.007	0.009*
	(0.01)	(0.01)	(0.01)	(0.01)
Patent-age Effects	Yes	Yes	Yes	Yes
Firm Effects	No	Yes		Yes
Citing-year Effects		Yes	Yes	
App-year Effects	Yes	n/a	n/a	n/a
Tech-citeyear Effects†	Yes	No	No	Yes
Tech-firm Effects†	No	No	Yes	No
Observations	1035339	1035344	1035344	1035344

Robust standard errors in parentheses: *10% significance; **5% significance; ***1% significance. Standard errors are clustered at the level of the conditional fixed effect, which is Technology Class in models (1), (3) and (4), and Firm in model (2). Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. All models control for CEO Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings. †Technology-year effects are based on technology subcategories defined in the NBER patent data file, while Technology-Firm effects are based on the primary (3-digit) US patent classification.

Table 5: Competition Interactions

Poisson Panel Regressions

Unit of Observation = Firm-Year

Dependent Variable = Total Cites

	(1)	(2)	(3)	(4)
Overconfidence	0.742***		0.640***	0.328***
	(0.17)		(0.23)	(0.12)
Lerner Index	-0.495	-0.836		
	(4.15)	(3.89)		
Lerner x Overconf	-4.621***			
	(0.97)			
Holder67		0.669***		
		(0.17)		
Lerner x Holder67		-2.635**		
		(1.18)		
LernerSIC x Overconf			-3.584**	
			(1.47)	
Lerner50 x Overconf				-0.503**
				(0.24)
Year Effects	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	Yes
Firm Effects	BGV	BGV	BGV	BGV
Observations	2200	1344	2200	2200
Firms	207	200	207	207
CEOs	277	270	277	277

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Overconfidence is the maximum value for Holder67 for a given CEO. Lerner Index is the median gross profit margin of all Compustat firms in a 2-digit SIC code (see text). BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings.

Table 6: Overconfidence and Innovative Direction

Panel Regressions Unit of Observation = Firm-Year				
Outcome Variable	Originality Weighted Patents		Derivative Patent Share	
	Poisson (1)	Poisson (2)	OLS (3)	OLS (4)
Overconfidence	0.173** (0.09)	0.406*** (0.13)	-0.005 (0.01)	-0.028** (0.01)
Lerner SIC x Overconf		-2.056* (1.24)		0.250** (0.10)
Year Effects	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	n/a	n/a
Firm Effects	BGV	BGV	Yes	Yes
Observations	2124	2124	1343	1343
Firms	199	199	155	155
CEOs	268	268	206	206

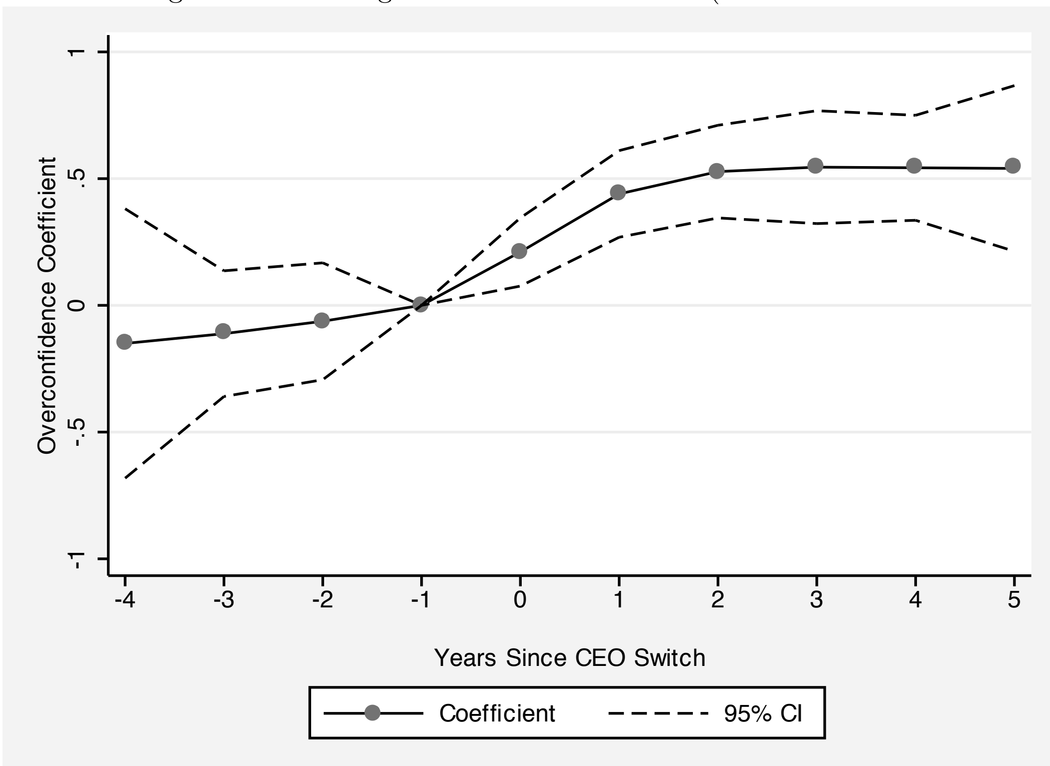
Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. See Hall et al. (2001) for a definition of originality. Derivative patents have more than 50 percent of self-citations. Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Lerner Index is the median gross profit margin of all Compustat firms in a 2-digit SIC code (see text). LernerSIC and Lerner50 are alternative measures of industry gross-profitability that exclude longitudinal variation (see text). BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings.

Table 7: CEO Independence and Cash Flow Interactions

Poisson Panel Regressions Unit of Observation = Firm-Year				
Outcome Variable	Total Cites		R&D Expense	
	(1)	(2)	(3)	(4)
Overconfidence	0.122		-0.292*	
	(0.13)		(0.16)	
CEO-Chairman	-0.194*	-0.152*		
	(0.11)	(0.09)		
Overconf x CEO-Chair	0.365**			
	(0.15)			
Holder67		0.303***		-0.314
		(0.11)		(0.20)
Holder67 x CEO-Chair		0.409***		
		(0.13)		
ln(CashFlow)			-0.033	-0.014
			(0.02)	(0.03)
Overconf x ln(CashFlow)			0.062***	
			(0.02)	
Holder67 x ln(CashFlow)				0.048*
				(0.03)
Year Effects	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	N/A	N/A
CEO Controls	Yes	Yes	No	No
Firm Effects	BGV	BGV	Yes	Yes
Observations	2195	1344	1199	747
Firms	207	200	119	113
CEOs	277	270	163	155

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. CEO Chairman is a dummy equal to one if a CEO also holds the titles of Chairman and President. Cash Flow equals Compustat earnings before extraordinary items (item 18) plus depreciation (item 14). Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option holdings.

Figure 1: Switching to Overconfident CEOs (Annual Treatment Effects)



This figure plots coefficient estimates and robust standard errors from a Poisson regression with firm conditional fixed effects, a full set of calendar year effects, and a full set of year-relative-to-CEO-switch dummies (omitting the year prior to the change in CEO) for firms that hire an overconfident CEO. The dependent variable is Total Cites. The estimation sample contains four years prior to the CEO switch and all years following the switch.

On-line Appendix to CEO Overconfidence and Innovation

April 12, 2011

Part A: Extensions to the Theoretical Model

Non-Sector Specific Ability

In the baseline model we assumed that CEO talent is sector specific and that after relocating to a new sector the CEO receives a compensation that does not depend on his past performance:

$$\underline{w} = \frac{1}{2}\overline{\theta} - \delta.$$

We now relax this assumption and consider the case in which managerial ability is the same in all sectors. This implies that after low revenue realization the compensation obtained in a different sector will be

$$\underline{w} = w_2(y_1 = 0) - \delta = \frac{1-p}{2-p-\alpha p}\overline{\theta} - \delta$$

and that a CEO will never switch sector as long as $\delta > 0$. If $i = 1$, CEO's expected period 2 compensation is:

$$\begin{aligned} U(i=1) &= \left[\frac{1}{2}(1+o)p + \frac{1}{2}(1-o)\alpha p\right]\frac{\overline{\theta}}{1+\alpha} \\ &+ \left[\frac{1}{2}(1+o)(1-p) + \frac{1}{2}(1-o)(1-\alpha p)\right]\left(\frac{1-p}{2-p-\alpha p}\overline{\theta}\right) \\ &= \frac{1}{2}p\overline{\theta} + \frac{1}{2}(2-p-\alpha p)\frac{1-p}{2-p-\alpha p}\overline{\theta} \\ &+ o\frac{p}{2}(1-\alpha)\left(\overline{\theta}\frac{(1-\alpha)}{(\alpha+1)(2-p-\alpha p)}\right). \end{aligned} \tag{A-1}$$

Because innovation occurs only if $I \leq \widehat{I} = U(i=1) - U(i=0)$ and $U(i=0) = \overline{\theta}/2$ does not depend on overconfidence $\partial U(i=1)/\partial o \geq 0$ implies that $\partial\widehat{I}/\partial o > 0$. Moreover,

$$\frac{\partial^2 \widehat{I}}{\partial o \partial \pi} = p\overline{\theta}\frac{(1-\alpha)}{(\alpha+1)^2(p+p\alpha-2)^2}(3+\alpha-2p(1+\alpha)) \geq 0$$

so both of our testable implications hold in this alternative setting.

Aghion, Van Reenen and Zingales (2009) consider the extreme case in which, after a low revenue realization, the CEO leaves the firm and is never hired by other sectors i.e. $\underline{w} = 0$. In this case the ex ante compensation of a manager that innovates is:

$$U(i=1) = \frac{1}{2}p\overline{\theta} + o\frac{p}{2}(1-\alpha)\frac{\overline{\theta}}{1+\alpha}.$$

Notice that $U(i=1) - U(i=0) \leq 0$ if $o = 0$ (non-overconfident CEOs never innovate when

$\underline{w}$= 0) and that this difference becomes positive for overconfident CEOs as long as p is not too small. Moreover $\partial U(i=1)/\partial o \geq 0$ and $\partial^2 U(i=1)/\partial o \partial \pi \geq 0$ therefore this alternative model is also consistent with our testable predictions.

No Switching Cost

In the baseline model we assumed that when a CEO reallocates to another sector he sustains a switching cost δ. If CEOs can switch costlessy $\underline{w} = \overline{\theta}/2$. The absence of switching costs renders innovation more appealing because there is a higher payoff in the case of low revenue realization. Nevertheless, even in this alternative setting $\partial U(i=1)/\partial o \geq 0$ and $\partial^2 U(i=1)/\partial o \partial \pi \geq 0$. Therefore the assumption that $\delta > 0$ has no impact on our testable predictions.

No Innovation Cost

In the baseline model we assumed that the CEO sustains a private cost I when he innovates. If we remove this cost innovation occurs as long as $U(i=1) \geq U(i=0)$ that is satisfied as long as the switching cost is not too large:

$$\delta \leq \widehat{\delta} = p\theta\left(\alpha - 1\right) \frac{o + \alpha - o\alpha + 1}{2p - 4\alpha + 4p\alpha + 2p\alpha^2 + 2op - 2op\alpha^2 - 4}.$$

Also in this framework innovation takes place for a larger range of parameters when the CEO is overconfident:

$$\frac{\partial \widehat{\delta}}{\partial o} = p\theta \frac{\left(\alpha - 1\right)^2}{\left(\alpha + 1\right)\left(p + p\alpha + op - op\alpha - 2\right)^2}.$$

The cross partial derivative

$$\frac{\partial^2 \widehat{\delta}}{\partial o \partial \alpha} = p\theta \frac{\left(1 - \alpha\right)\left(2\alpha - 5p - 4p\alpha + p\alpha^2 - op + 2op\alpha - op\alpha^2 + 6\right)}{\left(\alpha + 1\right)^2 \left(p + p\alpha + op - op\alpha - 2\right)^3} < 0$$

and therefore overconfidence and competition are complements (i.e. $\partial^2 \widehat{\delta}/\partial o \partial \pi > 0$) as in our baseline model. To see this notice that the second term in the denominator is negative because

$$\begin{aligned} p + p\alpha + op - op\alpha - 2 &= \\ p(1+\alpha) + op(1-\alpha) - 2 &\leq \\ &2p - 2 \leq 0. \end{aligned}$$

The term $2\alpha - 5p - 4p\alpha + p\alpha^2 - op + 2op\alpha - op\alpha^2 + 6$ in the numerator is positive as long as

$$p \leq \widetilde{p}(o) = \frac{2\alpha + 6}{o(1-\alpha)^2 + 4\alpha - \alpha^2 + 5}$$

and because $\widetilde{p}'(o) < 0$ and $\widetilde{p}(1) = 1$ the term is positive for any value of α and o.

Competition Affects Non-Innovating Managers

We now relax the assumption that $U(i = 0)$ is not affected by product market competition and extend the model assuming that competition affects non-innovating managers because it forces them to relocate to a different sector. We follow Aghion, Van Reenen and Zingales (2009) and assume that with probability $f(\pi)$ a non innovating firm incurs a loss and that $f'(\pi) > 0$. We also assume that that the CEO must relocate whenever the loss is incurred. In this case the CEO payoff without innovation is:

$$U(i = 0) = (1 - f(\pi))\,\frac{\overline{\theta}}{2} + f(\pi)\underline{w}.$$

Because an increase in π increases the net gain $U(i = 1) - I - U(i = 0)$, competition renders innovation more appealing. It is important to notice that in this setting, as in our baseline model, $U(i = 0)$ does not depend on o. This implies that the two testable predictions of our baseline model hold in this alternative environment.[1]

Generalization of the Competition Effect

In the baseline model we assumed that the difference in talent between high and low quality CEOs was captured by $\alpha = 1 - \pi$. We now generalize the framework by assuming that if the CEO innovates ($i = 1$), the period 1 revenue realization is equal to:

$$y_1 = \begin{cases} 1 \text{ with probability } p(\pi) \\ 0 \text{ with probability } 1 - p(\pi) \end{cases}$$

if $\theta = \overline{\theta}$ and it is equal to

[1] If the probability of incurring the loss is also affected by overconfidence (i.e. $f(o, \pi)$ with $\partial f/\partial o < 0$) an increase in o increases innovation as long as:

$$\left|\frac{\partial f}{\partial o}\right| < \frac{\frac{p}{2}(1-\alpha)\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right)}{\left(\frac{\overline{\theta}}{2} - \underline{w}\right)}.$$

$$y_1 = \begin{cases} 1 \text{ with probability } q(\pi) \\ 0 \text{ with probability } 1 - q(\pi) \end{cases}$$

if ability is low. We assume $q'(\pi) < p'(\pi) < 0$ and $q(\pi) \leq p(\pi)$: competition reduces the likelihood of high revenue but its effect is stronger for low ability CEOs. In this setting

$$w_2(y_1 = 1) = \frac{p(\pi)}{p(\pi) + q(\pi)}\overline{\theta} \tag{A-2}$$

and there is no change in

$$\underline{w} = \frac{1}{2}\overline{\theta} - \delta. \tag{A-3}$$

Notice that

$$\begin{aligned} U(i = 1) = &\left[\frac{1}{2}(1 + o)p(\pi) + \frac{1}{2}(1 - o)q(\pi)\right] w_2(y_1 = 1) \\ &+ \left[\frac{1}{2}(1 + o)(1 - p(\pi)) + \frac{1}{2}(1 - o)(1 - q(\pi))\right] \underline{w} \end{aligned} \tag{A-4}$$

and that the CEO innovates when $U(i = 1) - I \geq U(i = 0)$. Therefore innovation occurs in equilibrium only if innovation costs are not too large, specifically:

$$I \leq \widehat{I} = U(i = 1) - U(i = 0).$$

Because

$$\frac{\partial \widehat{I}}{\partial o} = \frac{1}{2}\left(p(\pi) - q(\pi)\right)\left(w_2(y_1 = 1) - \underline{w}\right) > 0$$

the first testable prediction holds in this generalized setting. Moreover:

$$\frac{\partial^2 \widehat{I}}{\partial o \partial \pi} = \frac{1}{2}\left(w_2(y_1 = 1) - \underline{w} + (p(\pi) - q(\pi))\frac{p(\pi)}{(p(\pi) + q(\pi))^2}\right)\left[p'(\pi) - q'(\pi)\right] > 0$$

because $p'(\pi) - q'(\pi) > 0$ so the second testable prediction is also valid.

Competition reduces the impact of talent

In the baseline model we assumed that $\alpha = 1 - \pi$. This assumption implies that product market competition affects the probability that low ability CEOs have of generating high revenue from an innovation and that talent is more valuable in a competitive environment rather than in a non-competitive environment. We now follow Aghion, Van Reenen and Zingales (2009) and assume that $p = 1 - \pi$ and that α does not depend on π. Notice that in this variant of the model talent is more valuable when competition is less intense.

In this alternative setting the direct effect of overconfidence on innovation is analogous to the one in our baseline model:

$$\frac{\partial \widehat{I}}{\partial o} = \frac{p}{2}(1-\alpha)\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right) > 0.$$

Nevertheless, because talent is less valuable when competition is intense, the cross partial derivative has the opposite sign than the one in our model:

$$\frac{\partial^2 \widehat{I}}{\partial o \partial \pi} = -\frac{1}{2}(1-\alpha)\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right) < 0.$$

Therefore the impact of overconfidence on innovation is lower when π is large and the second testable prediction of our baseline model no longer holds.

It is important to notice that, despite the negative cross partial derivative, this alternative framework can still provide support to the idea that only overconfident CEOs innovate when competition is intense. To see this let us fix the level of innovation cost I. Notice that $U(i = 1) - I > U(i = 0)$ as long as

$$p > \widehat{p}(o) = \frac{(2I - 2\underline{w} + \overline{\theta})}{(1+\alpha+o(1-\alpha))} \frac{(1+\alpha)}{\left(\overline{\theta} - \underline{w}(1+\alpha)\right)}$$

and that $\widehat{p}$ is decreasing in o. This implies that non overconfident CEOs will innovate only if the level of product market competition is below $1 - \widehat{p}(0) \equiv \pi^0$. Therefore when $\pi \leq \pi^0$ both overconfident and non-overconfident CEOs innovate whereas if $\pi > \pi^0$ only overconfident CEOs innovate.

Cash Flow Sensitivity

We compare the investment decision of overconfident CEO (with $o > 0$) with the decision of a non-overconfident CEO (with $o = 0$). Let us indicate with $\widehat{I}^{\phi}$ the maximum innovation cost for a CEO that is not overconfident and with $\widehat{I}^{o}$ the threshold for an overconfident CEO. Specifically a rational CEO innovates as long as the innovation cost is below $\widehat{I}^{\phi}$ and an overconfident CEO innovates as long as the innovation cost is below $\widehat{I}^{o}$ where the two thresholds are defined as:

$$
\begin{aligned}
\widehat{I}^{\phi} &= \frac{1}{2}p\overline{\theta} + \frac{1}{2}(2 - p - \alpha p)\underline{w} - \frac{1}{2}\overline{\theta} \\
\widehat{I}^{o} &= \frac{1}{2}p\overline{\theta} + \frac{1}{2}(2 - p - \alpha p)\underline{w} - \frac{1}{2}\overline{\theta} + o\frac{p}{2}(1-\alpha)\left(\frac{\overline{\theta}}{1+\alpha} - \underline{w}\right).
\end{aligned}
$$

Implication 1 indicates that $\widehat{I}^{\phi} < \widehat{I}^{o}$ for every $o > 0$. Our baseline model, following Aghion et al. (2009) assumed that the innovation cost is a private cost sustained by the CEO only. We now introduce an innovation cost sustained by the firm F and we assume that there is a one to one mapping between private cost I and firm cost F and that the two costs are positively correlated (i.e. F is an increasing function of I). This assumption captures the idea that projects requiring a large amount of firm resources are also those requiring a greater use of CEO time and personal resources. In this extended setting we can identify two cutoffs $\widehat{F}^{\phi}$ and $\widehat{F}^{o}$ (with $\widehat{F}^{\phi} < \widehat{F}^{o}$) indicating the maximum firm investment levels of unbiased and overconfident CEOs.

Following Malmendier and Tate (2005) we assume that to finance F the CEO can use either internal funds or external finance (debt). We assume that the firm has an exogenous capacity for riskless debt D and a cash flow of C (for simplicity we ignore the use of equity). We consider three cases. First if $C + D \geq \widehat{F}^{o}$ resources are very abundant and a marginal increase in C has no effect on the investment decisions of both overconfident and non-overconfident CEOs. Second, if $C + D < \widehat{F}^{\phi}$ resources are scarce both for rational and overconfident CEOs so a marginal increase in C affects the investment decisions of both types of CEOs. Finally, consider the case in which $\widehat{F}^{\phi} \leq C + D < \widehat{F}^{o}$. In this case the rational CEOs invest as long as $F \leq \widehat{F}^{\phi}$ whereas overconfident CEOs invest in projects for which $F \leq C + D$. Therefore, in this range of values a marginal increase in C has no effect on rational CEOs but it increases the range of projects for overconfident CEOs.

This simple extension generates a third testable implication:

Implication 3: *The innovation investment of overconfident CEOs is more sensitive to cash flow than the investment of non-overconfident CEOs.*

Part B: Additional Empirical Results

Conditional Fixed Effects

To isolate the within-firm co-variation of overconfidence and innovation, in Table B1 we rely on the fixed-effects Poisson estimator (Hausman et al., 1984) which is analogous to the familiar within group OLS estimator and assumes that all covariates are strictly exogenous.

Columns (1) and (3) in Table B1 use the overconfidence dummy and therefore exploit only variation between overconfident and non-overconfident CEOs within firms. In columns (2) and (4) we use the Holder67 dummy and estimate its coefficient using not only within firm variation but also variation between years when a CEO is classified as overconfident or not. Despite eliminating all between-firm variation, we still find support for the two testable implications of our model: overconfidence is positively correlated with innovation and the correlation is stronger when product market competition is intense. While many of our other results are robust to this alternative estimator, some lose statistical significance. This is not surprising given the limited CEO turnover within firms.[2]

Endogeneity

The CEO switching analysis is based on 28 cases where a CEO who was either not-overconfident or unclassified was replaced by an overconfident CEO. In each case, we retained data for the four years preceding the switch and all subsequent years of data for the overconfident CEO. To obtain a control sample, we performed a similar exercise to identify 24 cases where a not-overconfident or unclassified CEO was replaced by a not-overconfident CEO. We estimate fixed-effects Poisson models to isolate within-firm variation, and we drop the firm-level controls which are unlikely to be strictly exogenous.

Table B2 shows that within the switching sample, as with the full sample above, we find a statistically significant increase in innovative activity following the arrival of an overconfident CEO. More interestingly, we find no significant difference in the time-trend of pre-switch innovative activity between firms that hire rational versus overconfident CEOs. This suggests that the selection process is not driven by *ex ante* differences in firm performance. As an additional robustness check, we created an indicator for firms that ever hire an Overconfident CEO, and use the Coarsened Exact Matching procedure of Iacus, King and Porro (2010) to balance on firm-level observables in the first year of the sample. While this procedure drops some the

[2] The models in Table B1 do not include firm level controls for sales, capital-labor ratios or R&D Stock, since we do not expect those variables to be strictly exogenous. While the main effect of Overconfidence on innovation is robust to adding these controls, the competition effects are more fragile, perhaps because of a strong within-firm correlation between growth and industry profitability.

largest firms, our baseline results are qualitatively unchanged within this firm-matched sample.

Overconfidence and Citation Levels

Hall et al. (2005) divide firms into categories depending on their stock of citations. Specifically, they show that firms receiving an average of 7-10 cites per patent experience an increase in market value that is 10% greater than those with less than 7 cites per patent. For firms with 11-20 cites per patent the difference is 35%, and for firms with more than 20 cites per patents the difference is 54%.

From their results, it is not clear whether there is any difference between a broad based increase in the forward-citation rate (so a firms share of patents with, say, more than 7 cites increases) and having one or two more home runs that receive hundreds of citations. To explore this issue we run a number of linear probability models at the patent level, using a series of dummies for total (truncation adjusted) citations count above a series of thresholds. For thresholds, we chose 5, 10, 20, 40 and 60 cites, which correspond (roughly) to the 25th, 50th, 75th, 90th and 95th percentile in the unconditional distribution of total citations. All of the models contain firm by technology-class and grant-year fixed effects, so the relevant comparison is to a patent in the same technology class filed by a non-Overconfident CEO at the same firm. Results are presented in Table B3.

We find no effects below the 75th percentile. However, there is a statistically significant 3 percentage point increase in the probability of receiving 20 or more cites (i.e. being in the upper quartile). Thus, the marginal effect is a 0.03 / 0.25 = 12 percent increase in the conditional probability of being in the top quartile of the citation distribution. We find similar effects at the 90th and 95th percentile (though the marginal effects are much larger, at 30 and 45 percent respectively, given the small baseline probability of receiving that many cites). This is consistent with a relatively broad right shift in the citation distribution for patents filed under Overconfident CEOs.

Alternative Controls and Specifications

In Table B4 we present a series of extensions that demonstrate the robustness of our main results to including extra covariates and changing the model specification. Column (1) shows that our estimates are not affected when we control for investment opportunities (Tobin's Q) and for firm ability to raise capital (cash flow). We computed Tobin's Q following Kaplan and Zingales (1997) and define cash-flow as Compustat earnings before extraordinary items (item 18) plus depreciation (item 14).[3] In column (2) we control for CEO educational background.

[3] Kaplan and Zingales use the following Compustat items: Q=[item6+(item24*item25)-item60-item74]/item6.

Although we lose roughly 32 percent of the observations because of missing data on educational background, there is essentially no change in the overconfidence coefficient. In column (3) we allow for dynamics using a multiplicative feedback model that controls for the logarithm of lagged cite-weighted patent counts. Not surprisingly we found strong persistence in patenting; the coefficient on lagged patents is highly significant, while the coefficient on overconfidence is positive and significant at the 0.1 level.[4] In column (4) we control for industry specific time-trends by interacting the industry fixed effects with the calendar year. The magnitude of the overconfidence coefficient is similar to the one in our baseline regression and we cannot reject the null hypothesis that the industry trends are jointly insignificant. Finally, in column (5) we show that results are similar when using a negative binomial regression model.

Press Based Overconfidence Measures

The overconfidence measures employed above use CEOs' private investment decisions to capture their "revealed beliefs." To strengthen the overconfidence interpretation of their results, Malmendier and Tate (2008) also collect data on outsiders' perception of CEOs. Specifically, they use business press coverage data to identify CEOs depicted as "optimistic" or "confident."

In this sub-section, we conduct a similar exercise using articles in the Wall Street Journal, the New York Times, Business Week, the Financial Times and the Economist during the sample period. For each CEO, Malmendier and Tate (2008) identify the number of articles describing the CEO as "Confident" or "Cautions."[5] Let us indicate with a_{it} the number of articles that refer to CEO i as "Confident" in year t. Similarly, let us indicate with b_{it} the number of articles that refer to CEO i as "Cautious" in year t. Following Malmendier and Tate (2008), we define the following press-based overconfidence measure:

$$Totalconfident_{it} = \begin{cases} 1 \text{ if } \sum_{s=1}^{t-1} a_{is} > \sum_{s=1}^{t-1} b_{is} \\ 0 \text{ otherwise.} \end{cases}$$

The correlation between Totalconfident and Holder67 is 0.09 and the correlation with Overconfidence is 0.08 and they are both statistically significant at the 0.01 level. In Table B5 we use this measure and control for the total number of press mentions received by the CEO (TOTALmentions). We also control for CEO educational background and title accumulation.

[4] The overconfidence coefficient drops once we introduce the lagged value of citations indicating that CEO overconfidence has mostly a long run effect on innovation (see Blundell et al. (1999)). Moreover, the estimated long-run impact (after accounting for autoregressive feedback through lagged cites) is equal to $\frac{\alpha}{1-\lambda} = \frac{0.06}{1-0.81} = 0.32$, which is quite close to our baseline result.

[5] An article identifies the CEO as "Confident" if it contains one of the following words: confident, confidence, optimistic, optimism. An article identifies the CEO as "Cautious" if it contains one of the following words: reliable, cautious, conservative, practical, frugal or steady.

The correlations support the predictions of our model. Overconfidence is positively correlated with citation-weighted patent counts and the correlation is stronger in more competitive industries. In columns (3) and (4) we explore the correlation between the press-based measure and un-weighted patent counts. While the correlation is not significant in the pooled regression we find that patenting is substantially higher for overconfident CEOs when competition is intense.

Execucomp Data

Our main analysis uses a dataset originally constructed by Yermack (1995), Hall and Liebman (1998) and Malmandier and Tate (2005; 2008). The main virtue of these data is the presence of Holder67, the measure of overconfidence developed by Malmendier and Tate (2008). Their primary limitation is the small sample, which contains only 290 innovating firms. In this final sub-section, we explore the relation between overconfidence and innovation using the larger S&P ExecuComp Compustat database, which reports information on executive compensation for S&P 1,500 companies from 1992 to 2009. To avoid truncation problems with the patent data, we focus on the period 1992-2001.

The ExecuComp dataset provides information both on the salary and on the aggregate value of the stock options awarded to the CEOs. Because grant and expiration date of the individual option packages are not reported, we cannot construct the Holder 67 measure. Nevertheless, we constructed an alternative measure, Holder67-EC, based on aggregate stock option holdings but similar in spirit to Holder67.[6] Intuitively, we identified the CEOs that did not exercise a substantial amount of their stock options despite a considerable increase in the underlying stock value.

Specifically, we focus on CEOs that during their tenure experienced an increase of at least 67 percent in the stock price over a 5 year period. For all these CEOs, we constructed the ratio between the value of unexercised exercisable options and the CEO's salary and bonus. Finally, we classified a CEO as a Holder67-EC if after a 67 percent stock price increase, the ratio of vested option to income was above the 95th percentile of the entire options-income distribution.[7] As for the Holder67 measure, once a CEO is classified as Holder67-EC he keeps that label for the remaining sample years. We also created a variable Overconfidence-EC equal to the maximum of Holder67-EC.

[6]Dezso and Ross (2010) use a similar measure to examine the correlation between CEO options-holding and the cost of borrowing.

[7]We experimented with alternative cutoff rules (75th , 85th and 90th percentiles of the option-income ratio distribution) and found that the correlation between innovation and overconfidence is robust to variation in the value of the threshold. The interaction effect with product market competition is more sensitive to the cutoff rule, and results are consistent with Implication 2 only for cutoff rules above the 90th percentile.

In the new sample, there are 1899 CEOs for which Overconfidence-EC is defined. About ten percent of these CEOs are classified as overconfident. The final sample contains 1491 innovating firms and 7123 observations. The mean firm-year observation consists of 20 patents that receive 344 citations. The average firm in the new sample has 5,365 employees whereas the average firm in the dataset described in Section 3 has 14,565 employees.

Appendix Table B6 investigates the relation between overconfidence and innovation in this alternative sample. The coefficients on Overconfidence-EC and Holder67-EC are positive and significant thus supporting the first testable implication of our theoretical model. We also find support for the second prediction; specifically, the coefficient on the interaction between the Lerner index and overconfidence is negative and significant.

References

Aghion, P., J. Van Reenen, and L. Zingales (2009). Innovation and Institutional Ownership. *NBER Working Paper 14769*.

Blundell, R., R. Griffith, and J. van Reenen (1999). Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms. *Review of Economic Studies 66*(3), 529–54.

Dezso, C. and D. G. Ross (2010). Are Banks Happy when Managers Go Long? Vested Options and the Cost of Private Debt. *SSRN Working Paper*.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2001). The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools. Working Paper 8498, National Bureau of Economic Research.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2005). Market Value and Patent Citations. *RAND Journal of Economics 36*, 16–38.

Hall, B. J. and J. B. Liebman (1998). Are CEOs Really Paid Like Bureaucrats? *The Quarterly Journal of Economics 113*(3), 653–691.

Hausman, J., B. Hall, and Z. Griliches (1984). Econometric Models for Count Data with an Application to the Patents-R&D Relationship. *Econometrica 52*(4), 909–938.

Iacus, S., G. King, and G. Porro (2010). Causal Inference without Balance Checking: Coarsened Exact Matching. *working paper*.

Kaplan, S. and L. Zingales (1997). Do investment-cash flow sensitivities provide useful measures of financing constraints? *Quarterly Journal of Economics 112*, 169–215.

Malmendier, U. and G. Tate (2005). CEO Overconfidence and Corporate Investment. *Journal of Finance 60*(6), 2661–2700.

Malmendier, U. and G. Tate (2008). Who makes acquisitions? CEO overconfidence and the market's reaction. *Journal of Financial Economics 89*(1), 20–43.

Mehta, A., M. Rysman, and T. Simcoe (2010). Identifying the Age Profile of Patent Citations: New Estimates of Knowledge Diffusion. *Journal of Applied Econometrics*.

Yermack, D. (1995). Do corporations award CEO stock options effectively? *Journal of Financial Economics 39*(2-3), 237–269.

Table B1: Overconfidence and Innovation (Conditional FEs)

Poisson Panel Regressions

Unit of Observation = Firm-Year

Dependent Variable = Total Citations

	(1)	(2)	(3)	(4)
Overconfidence	0.319**		0.780***	
	(0.14)		(0.28)	
Holder67		0.256**		0.910**
		(0.12)		(0.39)
Lerner Index			1.435	-1.141
			(3.01)	(2.49)
Lerner x Overconf			-4.053**	
			(1.85)	
Lerner x Holder67				-6.018**
				(2.76)
Year Effects	Yes	Yes	Yes	Yes
CEO Controls	Yes	Yes	Yes	Yes
Firm Effects	Yes	Yes	Yes	Yes
Observations	1678	1041	1678	1041
Firms	155	145	155	145
CEOs	212	201	212	201

Robust standard errors clustered at firm level in parentheses: *10% significance; **5% significance; ***1% significance. Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Lerner Index is the median gross profit margin of all Compustat firms in a 2-digit SIC code (see text). CEO controls are Age, Age^2, Tenure and $Tenure^2$.

Table B2: Overconfidence and Innovation (CEO Switches)

Poisson Panel Regressions

Unit of Observation = Firm-Year

Outcome Variable	Cite-Weighted Patents	Unweighted Patents	Cites per Patent	Research & Development
	(1)	(2)	(3)	(4)
Overconfidence	0.426***	0.312***	0.504*	0.186*
	(0.08)	(0.10)	(0.27)	(0.10)
Pre-trend*Overconf	0.003	-0.035	-0.106	-0.033
	(0.03)	(0.03)	(0.09)	(0.03)
Pre-trend	0.026	0.012	0.036	-0.055
	(0.06)	(0.04)	(0.07)	(0.05)
Firm Effects	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes
Observations	612	612	612	375
Firms	59	59	59	41
CEOs	120	120	120	75
Treated Switches	28	28	28	21
Control Switches	24	24	24	10

Robust standard errors clustered at firm level in parentheses: *10% significance; **5% significance; ***1% significance. Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. Pre-trend is a time-trend for the four year period prior to a change in CEO for all firms. Pre-trend * Overconf equals Pre-trend multiplied an indicator that equals one if the firm hires an Overconfident CEO.

Table B3: Overconfidence and Citation Levels

Linear Probability Model

Unit of Observation = Patent

Outcome Variable	Cites>5	Cites>10	Cites>20	Cites>40	Cites>60
	(1)	(2)	(3)	(4)	(5)
Overconfidence	-0.014	0.014	0.029***	0.032***	0.023***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
ln(Sales)	-0.006	-0.017*	-0.008	-0.005	-0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
ln(Capital/Labor)	0.004	0.003	-0.008	-0.010*	-0.004
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
Year Effects	Yes	Yes	Yes	Yes	Yes
CEO Controls	Yes	Yes	Yes	Yes	Yes
Tech-Firm Effects	Yes	Yes	Yes	Yes	Yes
Observations	76103	76103	76103	76103	76103
Mean Dependent Variable	0.703	0.486	0.257	0.100	0.049

Robust standard errors clustered at patent level in parentheses: *10% significance; **5% significance; ***1% significance. BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure and Tenure^2.

Table B4: Overconfidence and Innovation (Robustness Checks)

Panel Regressions

Unit of Observation = Firm-Year

Dependent Variable = Total Cites

Specification	Poisson	Poisson	Poisson	Poisson	NegBin
	(1)	(2)	(3)	(4)	(5)
Overconfidence	0.224**	0.244**	0.060*	0.241**	0.509***
	(0.11)	(0.11)	(0.03)	(0.11)	(0.17)
Tobin's Q	0.390				
	(0.24)				
log(Cash Flow)	0.105***				
	(0.04)				
Finance Education		-0.084			
		(0.19)			
Technical Education		0.134*			
		(0.07)			
Chair & President		0.039			
		(0.07)			
$\ln(\text{Cites}_{t-1})$			0.812***		
			(0.03)		
Year Effects	Yes	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	Yes	Yes
SIC 2-digit Trends	No	No	No	Yes	No
Firm Effects	BGV	BGV	BGV	BGV	BGV
Observations	2147	1491	2037	2411	2411
Firms	207	153	206	227	227
CEOs	277	177	275	301	301

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. Overconfidence is the maximum value for Holder67 for a given CEO where Holder67 is a dummy equal to 1 for all CEO years after the CEO fails to exercise an option 67% in the money with 5 years remaining duration. BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure, Tenure^2, Stock Ownership and Vested Option Holdings.

Table B5: Press-Based Overconfidence Measures

Poisson Panel Regressions Unit of Observation = Firm-Year				
Outcome Variable	Total Cites		Unweighted Patents	
	(1)	(2)	(3)	(4)
PressConfidence	0.147*	0.283***	-0.029	0.230***
	(0.08)	(0.10)	(0.13)	(0.08)
PressMentions	-0.000	-0.000	-0.000	-0.000
	(0.00)	(0.00)	(0.00)	(0.00)
Lerner50 x PressConf		-0.269*		-0.418***
		(0.14)		(0.15)
Year Effects	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	Yes
CEO Controls	Yes	Yes	Yes	Yes
Firm Effects	BGV	BGV	BGV	BGV
Observations	1798	1798	1798	1798
Firms	208	208	208	208
CEOs	285	285	285	285

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure, $Tenure^2$, Stock Ownership and Vested Option Holdings.

Table B6: Overconfidence and Innovation (ExecuComp Sample)

Poisson Panel Regressions

Unit of Observation = Firm-Year

Dependent Variable = Total Citations

	(1)	(2)	(3)	(4)
Holder67-EC	0.257***		0.409***	
	(0.10)		(0.09)	
Overconfident-EC		0.379**		0.507***
		(0.17)		(0.13)
Lerner50 x Holder67-EC			-1.223***	
			(0.09)	
Lerner50 x Overconf-EC				-0.665**
				(0.32)
Year Effects	Yes	Yes	Yes	Yes
SIC 2-digit Effects	Yes	Yes	Yes	Yes
Firm Effects	BGV	BGV	BGV	BGV
Observations	4799	7123	4799	7123
Firms	1245	1491	1245	1491
CEOs	1360	1674	1360	1674

Robust standard errors clustered at SIC level in parentheses: *10% significance; **5% significance; ***1% significance. BGV fixed effects are based on including pre-sample means of the dependent variable. All models control for ln(R&D Stock), ln(Sales), ln(Capital/Labor) and CEO Age, Age^2, Tenure and $Tenure^2$.