Options Compensation as a Commitment Mechanism in Oligopoly Competition

Jun Ishii
Amherst College Department of Economics

David Hao Zhang
Federal Reserve Bank of Boston

Author Note

Acknowledgements: We thank Jessica Reyes, Geoffrey Woglom, and Christopher Kingston at Amherst College and Ali Ozdagli and Jianlin Wang at the Federal Reserve Bank of Boston for most helpful discussions and comments.
Abstract

We analyze how stock options compensation vega can be used as a commitment device in oligopolistic competition. We develop a two period model where shareholders structure managerial compensation to commit their managers to being risk-taking in equilibrium. We show using a difference-in-difference (DiD) approach that, for a sample of manufacturing firms in relatively competitive industries, a 100 point increase in industry concentration HHI is linked to a $10,000-$24,000 increase in stock options compensation vega. We conduct an IV robustness check using competitor mergers as instruments.
Options Compensation as a Commitment Mechanism in Oligopoly Competition

Introduction and Literature Review

It has long been suspected that some firms’ use of stock options compensation makes their managers overly risk taking. [Dong et al. (2010)](#) finds that stock options compensation for CEOs sometimes leave over-leveraged firms even more over-leveraged, suggesting that stock options incentivize too much risk taking in terms of capital structure policies in those firms. [Cooper et al. (2014)](#) also finds that CEOs who receive high incentive payments tend to overinvest and facilitate value-destroying mergers and acquisitions.

A natural question is why would these firms incentivize their CEOs to take excessive risks. Are they simply ignorant of the effects of too much stock options compensation? Are their board members deliberately acting contrary to their shareholders’ interests? Or can the phenomena be explained as an equilibrium outcome of product market competition? In this paper we focus on the last explanation, and model how stock options compensation vega can be used as a commitment device in product market competition, leading to this type of 'excessive' risk-taking by firms as an equilibrium outcome. We then supply empirical evidence that options compensation vega is linked to product market competition, which supports our model.

We find that for shareholders, committing to a risk taking and aggressive management style may be an optimal strategy. Managers who are incentivized to be risk seeking through stock options compensation would tend to direct the firm to produce more than the expected profit maximizing quantity — perhaps by heavily investing in capacity and market expansions. This would force the other firms to scale back their own planned production and expansion to avoid flooding the market. As a
result, firms that commit to an aggressive strategy through managerial compensation may gain market share and profits. In equilibrium, all firms would adopt managerial compensation that incentivizes their managers to be aggressive in order to avoid ending up as a disadvantaged Stackelberg follower.

Our paper is most closely related to the literature linking executive compensation to competition. Vickers (1985), Fershtman (1985), Fershtman and Judd (1987), and Sklivas (1987) modelled how sales or revenue based bonuses can be used as commitment devices in oligopolistic competition. Aggarwal and Samwick (1999) explores the optimal design of relative performance evaluation given oligopoly competition. Raith (2003) develops theory for how incentives for cost-cutting relates to product market competition. More recently, Manasakis et al. (2010), Chirco et al. (2011), and Jansen et al. (2012) modelled the use of relative performance contracts and market share contracts as commitment mechanisms under Cournot competition. Yu (2014) develops a similar two-stage Cournot model to show that CEO overconfidence can also be a commitment mechanism. Our paper contributes to this mostly theoretical literature by looking at stock options compensation vega as an additional commitment device, which is particularly of interest given the widespread use of stock options in executive compensation. We also contribute empirical evidence linking executive stock options vega with product market competition.

In classical models of options compensation, managers and shareholders have conflicting interests regarding risk – shareholders can eliminate idiosyncratic risk through diversifying their portfolio, but managers have significant human capital tied to their firms that are not easily diversifiable making them more conservative. Awarding managers stock options, which go up in value as the volatility of the underlying asset goes up, has the potential to make managers more willing to take risks and make decisions that are more aligned with shareholder interests. Empirical
studies including Rajgopal and Shevlin (2002), Knopf et al. (2002), Coles et al. (2006), Sanders and Hambrick (2007), Low (2009), Billett et al. (2010), Tchistyi et al. (2011) and Gormley et al. (2013) show that stock options compensation is linked to managerial risk-taking. Our paper goes one step further by finding that in oligopoly competition shareholders have an incentive to make managers more risk taking than themselves — making the managers risk seeking, rather than just risk neutral, to gain an advantage in oligopolistic competition.

Compared to the other compensation alternatives for commitment that are discussed in the literature (i.e. revenue based bonuses, relative performance evaluations, market share contracts, and CEO overconfidence), options compensation has several advantages. First, awarding stock options may be more efficient than awarding alternative compensation schemes because it utilizes information contained in stock prices. Second, options compensation may be less costly than its alternatives because it has the tax advantage of allowing firms to circumvent the cap on the deductibility of employee compensation (Hanlon and Shevlin 2002) and the accounting feature of enabling the compensation expenses to be hidden from income statements (Core et al. 2003). Third, options compensation may serve the dual purpose of committing the firm to both aggressive expansion and aggressive investment in innovation.

One empirical implication of our result, which we have already discussed, is that firms may award stock options to managers such that managers are incentivized to take risks in excess of the "risk neutral level" predicted by the traditional incentive alignment model of options compensation. A second, more direct empirical

---

1 For a more detailed survey of the accounting practices that affected options compensation, see Murphy (2012).

implication of our model is that executive compensation vega should be linked to market structure. Specifically, starting from a duopoly, the less concentrated the industry is, the less valuable oligopoly commitment mechanisms are, and the less stock options vega would be used. We conduct empirical analysis that shows for a sample of manufacturing firms in relatively competitive industries on which the Census Bureau provides data, controlling for firm and industry characteristics, CEO compensation vega is indeed positively linked to industry concentration.

We adopt a difference-in-difference (DiD) approach to examine how changes in manufacturing firm HHI are linked to changes in CEO vega in the following year. The DiD approach allows us to control for firm and industry specific characteristics that do not change over the short term. We also include industry level fixed effects to control for time varying omitted variables that are specific to each industry, such as changes in the supply chain or changes in regulatory pressures. Our OLS results are robust to adding additional control variables and point to a roughly $10,000 increase in vega for every 100 point increase in HHI (with HHI measured on a 0-10,000 scale).

As a robustness check, we use competitor mergers of non-merging companies as instruments for changes in HHI. In making merger decisions, the merging parties do not tend to factor in the compensation vega of their non-merging competitors, which allows our competitor merger instrument to satisfy the exclusion criteria. Our IV estimates are somewhat higher than, but are in roughly the same magnitude as, our OLS estimates. They are on the order of $24,000 increase in vega for every 100 point increase in HHI.
Model

Model setup

We use a two period model with two sets of players, shareholders and managers, to illustrate the strategic opportunity embedded in options compensation. In this model, shareholders (principals) first choose a type of compensation for the managers (agents), and the managers then act on the shareholders’ behalf given some uncertainty. We use the following notations:

- \((x, y)\), indices for firm \(x\) and \(y\)
- \((q_x, q_y)\), the level of production set by managers in firm \(x\) and \(y\)
- \(p\), the price of the goods
- \(c\), the marginal cost of the goods
- \(\epsilon\), the uncertainty in either price or cost
- \(\sigma_{\epsilon}\), the standard deviation of the uncertainty in price or cost
- \(\pi\), the profit from production
- \(\sigma_{\pi}\), the uncertainty in profit, as a standard deviation
- \(f(\pi)\), a function relating the compensation awarded to managers to the profits of the firm
- \(E()\), \(\text{var}()\), the expected value and the variance
- \(U(f)\), the utility function of the manager
- \(U^*(E(\pi), \sigma_{\pi})\), the expected utility of the manager expressed as a function of the expected value and the variance of the profits

We assume that for both shareholders and managers there exists stochastic uncertainty in either demand or cost \((\epsilon)\), that shareholders are expected profit maximizing but managers are expected utility maximizing, and that the firms engage
in Cournot competition with linear demand and constant marginal cost, such that:

\[ \pi = pq - cq = (p - c)q = (E(p) - E(c) + \epsilon)q = (E(p) - E(c))q + \epsilon q \]

We also assume that price or cost uncertainty, \( \epsilon \), follows a distribution that is characterizable by the first two moments (such as the Gaussian distribution).

Following [Ross (2004)], we assume that executive compensation \( f(\pi) \) is monotonically increasing and differentiable in profits \( \pi \). We also assume that managerial utility varies only with compensation and is increasing in compensation.

The manager of firm \( x \) sets the production \( q_x \) to maximize expected utility of the compensation \( f(\pi_x) \):

\[ \max_{q_x} E(U(f(\pi_x))) \]  

(1)

Given the assumption that \( \epsilon \) follows a distribution that is characterizable by the first two moments, we can express managers’ expected utility in terms of the mean (the first moment) and the variance (the second moment) of the profits [3].

Since shareholders could diversify away idiosyncratic risks, they are assumed to be expected profit maximizing. As a result, shareholders structure management compensation \( f \) to maximize expected profit of the firm:

\[ \max_f E(\pi) = E(p)q - E(c)q \]  

(2)

The firm’s expected utility depends on the quantity decision made by managers which, in turn, depends on the expected utility the managers associate with the

\[ \text{See Pennacchi (2008), Ch. 2, which notes that for normally distributed } \pi, \ E(U(\pi)) = U(E(\pi)) + \frac{1}{2} \text{var}(\pi)U''(E(\pi)) + \frac{1}{4} \text{var}(\pi)^2 U''(E(\pi)) + \ldots \]  

Through similar Taylor expansions, as long as the higher moments of \( \pi \) are characterizable by the first two moments, utility can be expressed in terms of the first two moments. Given this assumption, the managers’ incentive function can be written as:

\[ \max_q E(U(\pi)) = U^*(E(\pi), \sigma_{\pi}) \]
quantity. As such, shareholders choose \( f(\pi) \) factoring the managers subsequent quantity decision. The shareholder problem is solved through backward induction: we first examine the equilibrium quantities and profits resulting from managers choosing quantity facing a given \( f(\pi) \) and then explore how shareholders would set \( f(\pi) \) given these equilibrium quantities and profits.

**Equilibria**

We now develop the key lemmas underlying our proposed insight on the strategic value of options compensation.

**Lemma 1.** The best response function of the managers can be expressed as

\[
\frac{\partial E(\pi)}{\partial q} + b(\pi) = 0,
\]

where \( b(\pi) \) takes the sign of \( \frac{\partial E(U)}{\partial \sigma_{\pi}} \).

**Proof.** First, we show that using a compensation structure \( f(\pi) \), shareholders can shape the manager’s utility function with respect to profit \( U(f(\pi)) \) into any (monotone increasing) shape.

Taking the derivative through:

\[
\frac{dU(f(\pi))}{d\pi} = \frac{dU}{df} \frac{df(\pi)}{d\pi}
\]

\[
\equiv g(\pi)
\]

As utility is monotone increasing with respect to compensation, \( \frac{dU}{df} > 0 \), rearranging yields:

\[
\frac{df(\pi)}{d\pi} = \frac{g(\pi)}{\frac{dU}{df}}
\]

With \( g(\pi) \) and \( \frac{dU}{df} \) differentiable, an \( f(\pi) \) exists that satisfies the above condition for any \( g(\pi) \), by the existence property of first order differential equations. In addition, with \( g(\pi) \geq 0 \) and \( \frac{dU}{df} > 0 \), \( \frac{df(\pi)}{d\pi} \geq 0 \) as required.
Given that shareholders can incentivize their managers to have any risk preference with respect to profits through executive compensation, we now look at how shareholders will want to incentivize their managers. We use backward induction starting with the manager’s best response function under quantity competition.

By first order condition for expected utility maximization:

\[
\frac{dE[U(\pi)]}{dq} = \frac{dU^*}{dq} = \frac{\partial U^*}{\partial E(\pi)} \frac{\partial E(\pi)}{\partial q} + \frac{\partial U^*}{\partial \sigma_\pi} \frac{\partial \sigma_\pi}{\partial q} = 0
\]

Dividing both sides by \(\frac{\partial U^*}{\partial E(\pi)}\) yields:

\[
\frac{\partial E(\pi)}{\partial q} + \frac{\partial U^*}{\partial \sigma_\pi} \frac{\partial \sigma_\pi}{\partial q} = 0
\]

This can be expressed as:

\[
\frac{\partial E(\pi)}{\partial q} + b(\pi) = 0
\]

where \(b(\pi) = \sigma_\epsilon \frac{\partial U^*}{\partial \sigma_\pi}\) by \(\sigma_\pi = q\sigma_\epsilon\) and therefore \(\frac{\partial \sigma_\pi}{\partial q} = \sigma_\epsilon\).

This expression illustrates the intuition that \(b(\pi)\) is what drives managers to deviate from simple expected profit maximization. A positive \(b(\pi)\) leads to risk taking and higher production and a negative \(b(\pi)\) to risk aversion and lower production (with risk taking defined in terms of firm profits).

More formally, by the monotonic increasing nature of \(f(\pi)\) and \(U(f)\), \(U(f(\pi))\) is monotonically increasing in \(\pi\) and hence \(\frac{\partial U^*}{\partial E(\pi)} > 0\). As such, \(b(\pi)\) takes the sign of \(\frac{\partial U^*}{\partial \sigma_\pi}, \text{or} \frac{\partial E(U)}{\partial \sigma_\pi}\).

Using this best response function, we are able to find the Nash equilibrium quantities chosen by managers in the second period for a given utility function \(U(\pi)\). We can then determine whether shareholders would incentivize managers to be risk averse or risk taking through backward induction.
For proofs of lemmas 2 to 4, we linearize $b(\pi) = b \ast \pi$ by setting $\frac{\partial \bar{U}^*}{\partial E(\pi)}$ and $\frac{\partial \bar{U}^*}{\partial \sigma \pi}$ at their marginal effects. We then investigate the implications of flexible $b(\pi)$ in Lemma 5. As we will show, the sign of $b(\pi)$, which is the parameter of interest, is the same regardless of linearization.

**Lemma 2.** In the two player equilibrium, shareholders would simultaneously set executive compensation structure such that managers would be incentivized to be risk taking. That is, both managers will have $\frac{\partial E(U)}{\partial \sigma \pi} > 0$.

*Proof.* First, the best response function for the managers of firm $x$ and firm $y$ obtained in Lemma 1 (with the linearization that $b_x(\pi) = b_x$):

$$q_x = \frac{1}{2}(a - q_y - E(c) + b_x)$$
$$q_y = \frac{1}{2}(a - q_x - E(c) + b_y)$$

and the corresponding Nash equilibrium quantities:

$$q_x = \frac{1}{3}(a - E(c) + 2b_x - b_y)$$
$$q_y = \frac{1}{3}(a - E(c) + 2b_y - b_x)$$

As before, $b_x$ and $b_y$ represent the deviation from the case where managers are expected profit maximizing. In a simple Cournot game with expected profit maximizing managers (or $b_x = b_y = 0$ representing no deviation from expected profit maximization), the best response function for firm $x$ is $q_x = \frac{1}{2}(a - q_y - E(c))$ and the Nash equilibrium is $q_x = q_y = \frac{1}{3}(a - E(c))$.

Shareholders would choose an executive compensation structure $f$ so as to maximize expected firm profits under the equilibrium quantities $q_x$ and $q_y$.

$$\max_f E(\pi) = E(p)q - E(c)q$$
For shareholders of firm $x$, substituting in the previously found Cournot Nash quantities into the incentive function yields:

$$\max_{f_x} E(\pi) = \frac{1}{9}(a + 2E(c) - b_x - b_y)(a - E(c) + 2b_x - b_y)$$
$$-\frac{1}{3}E(c)(a - E(c) + 2b_x - b_y)$$

Taking the first order conditions for shareholders of both firms $x$ and $y$ gives:

$$b_x = \frac{1}{4} (a - E(c) - b_y)$$
$$b_y = \frac{1}{4} (a - E(c) - b_x)$$

Solving out the equilibrium yields:

$$b_x = b_y = \frac{a - E(c)}{5} > 0$$

By Lemma 1, $b$ takes the sign of $\frac{\partial E(U)}{\partial \sigma_{\pi}}$. Since the shareholders of both firms would set $b > 0$, $\frac{\partial E(U)}{\partial \sigma_{\pi}} > 0$, and managers are incentivized to be risk taking.

Here, it is worth noting that while the connection between stock options compensation vega and managerial risk taking is empirically well established, whether a particular stock option will make managers even more risk taking is theoretically ambiguous, as discussed in Ross (2004). The practice of loopback options or options repricing, as explored in Ju et al., forthcoming, mitigates this theoretical ambiguity. For our model, it suffices that, in practice, options compensation vega generally leads to greater managerial risk taking.

Lemma 2 is based on a two stage perfect information model. However, the principal agent relationship between managers and shareholders are usually characterized as one of imperfect information. The commitment mechanism can work under some degree of imperfect information.
Lemma 3. Suppose that the managers’ assessment of expected marginal cost $E_m(c)$ is private information for the managers. Shareholders only know a probability distribution $P(E_m(c))$. Shareholders would still set executive compensation structure such that both managers will have $\frac{\partial E(U)}{\partial \sigma} > 0$.

Proof. Given that shareholders assume that the managers’ assessment of expected marginal cost is correct, the incentive function for shareholders in Lemma 2 leads to the following first order condition:

$$d\pi/db_x = -\frac{1}{9}(a - E(E_m(c)) + 2b_x - b_y) + \frac{2}{9}(a + 2E(E_m(c)) - b_x - b_y) - \frac{2}{3}E(E_m(c)) = 0$$

This first order condition is exactly equivalent to the one in the proof of Lemma 2, except with $E(c)$ replaced by $E(E_m(c))$. Hence, the Nash equilibrium would simply be:

$$b_x = b_y = \frac{a - E(E_m(c))}{5} > 0$$

Therefore, $a - E(E_m(c)) > 0$ and by Lemma 1, $b$ takes the sign of $\frac{\partial E(U)}{\partial \sigma}$. □

Our model can be extended to $N$ symmetric firms. In the N-firm case, shareholders still use options compensation to commit to higher production, but to a lesser extent as higher production confers smaller benefits as the firm’s market power decreases.

Lemma 4. In the $N$-firm symmetric equilibrium, $\frac{\partial E(U)}{\partial \sigma} \to 0$ as $N \to \infty$.

Furthermore, $p = \frac{1}{N+1}(a + NE(c) - \frac{N-1}{N^2+1}) \to E(c)$ as $N \to \infty$.

Proof. In the N-firm case, starting from the best response in Lemma 1:

$$\frac{\partial E(\pi_i)}{\partial q_i} + b_i(q_i) = 0, \text{ where } b_i(q_i) = \frac{\partial U^*}{\partial \sigma_{\pi_i}} \frac{\partial \sigma_{\pi_i}}{\partial E(\pi_j)}$$
Substituting and taking the derivative yields the following best response function for player \( i \), where \( q_{-i} \) represents the quantity produced by all other players:

\[
a - q_{-i} - 2q_i - E(c) + b_i(q_i) = 0
\]

Summing over all firms \( i \) and letting \( Q \) be the sum of all \( q_i \) yields:

\[
N a - N Q - Q - N E(c) + \sum_i b_i = 0
\]

Rearranging gives us the total output:

\[
Q = \frac{N}{N + 1} (a - E(c)) + \frac{\sum_i b_i}{N + 1}
\]

which enables us to solve for price:

\[
p = a - Q = \frac{1}{N + 1} a + \frac{N}{N + 1} E(c) - \frac{\sum_i b_i}{N + 1}
\]

Now, we turn to the shareholders, who choose \( b_i \) to maximize expected profits. We define \( \sum_{-i} b = \sum_{j,j \neq i} b_j \), or the sum of all of the other firms’ choice of compensation scheme.

\[
E(\pi_i) = E((p - c)q_i) = \frac{1}{N + 1} (a - E(c) - \sum_{-i} b - b_i)
\]

\[
= \left( \frac{a - E(c) - \sum_{-i} b - b_i}{N + 1} + b_i \right)
\]

Taking the derivative with respect to \( b_i \) yields the following first order condition:

\[
(N - 1)(a - E(c)) - (N - 1)(\sum_{-i} b) - 2N b_i = 0
\]

Summing over all firms \( i \) yields the following:

\[
\sum_i b_i = \frac{N(N - 1)}{N^2 + 1} (a - E(c))
\]

Finally, by symmetry \( \sum_i b_i = N b_i \), we find that:

\[
b_i = \frac{N - 1}{N^2 + 1} (a - E(c))
\]
Substituting that back into price yields:

\[ p = \frac{1}{N+1} \left( a + NE(c) - \frac{N-1}{N^2+1} \right) \]

As \( N \to \infty \), \( b_i \to 0 \) and therefore \( \frac{\partial E(U)}{\partial \sigma_\pi} \to 0 \). Furthermore, as \( N \to \infty \), \( p \to E(c) \). \( \square \)

We now turn our attention to what happens if shareholders are free to choose any functional form for the managerial best response curves.

**Lemma 5.** If shareholders can choose flexible functional forms for managerial best response curves, they will make them relatively inelastic to the behavior of other firms. Furthermore, the observation that \( \frac{\partial E(U)}{\partial \sigma_\pi} > 0 \) in equilibrium is preserved.

**Proof.** We know from Lemma 1 that shareholders can transform the utility of managers with respect to profits into any monotone increasing shape. This implies that they can set the managerial best response curves to be any non-increasing function.

Recall that the managerial equilibrium for firms \( x \) and \( y \) from Lemma 2 is:

\[ q_x = \frac{1}{3} \left( a - E(c) + 2b_x(\pi_x) - b_y(\pi_y) \right) \]
\[ q_y = \frac{1}{3} \left( a - E(c) + 2b_y(\pi_y) - b_x(\pi_x) \right) \]

To better illustrate this as a function of shareholder choice variables and shareholder choice functional forms, we first re-write the managerial equilibrium with greater generality, and then loop back to the specific case. As such, re-write, for some shareholder choice variables \( \gamma_x, \gamma_y \) and some shareholder choice functions \( h_x, h_y \):

\[ q_x = h_x(\gamma_x, \gamma_y) \]
\[ q_y = h_y(\gamma_y, \gamma_x) \]

Define \( \frac{\partial h_x}{\partial \gamma_x} > 0 \) and \( \frac{\partial h_y}{\partial \gamma_y} > 0 \). This captures the notion that shareholders can both commit to some level of production and how responsive that level is to other firms’ behavior.
Taking the first order conditions with respect to $\gamma_x$ and $\gamma_y$, we have:

$$\frac{\partial \pi_x}{\partial \gamma_x} = (-\frac{\partial h_x}{\partial \gamma_x} + (-\frac{\partial h_y}{\partial \gamma_x}))q_x + (p - c)\frac{\partial h_x}{\partial \gamma_x} = 0$$

$$\frac{\partial \pi_y}{\partial \gamma_y} = (-\frac{\partial h_y}{\partial \gamma_y} + (-\frac{\partial h_x}{\partial \gamma_y}))q_y + (p - c)\frac{\partial h_y}{\partial \gamma_y} = 0$$

This says that when setting $\gamma_x$ shareholders of firm $x$ must consider both the effect of $\gamma_x$ on own production ($\frac{\partial h_x}{\partial \gamma_x}$) and the other firms’ production ($\frac{\partial h_y}{\partial \gamma_x}$).

By positive monotonicity of managerial utility function with respect to profits, the managerial best response curves must be non-positively sloped, so $\frac{\partial q_x}{\partial \gamma_x} = \frac{\partial h_x}{\partial \gamma_x} \leq 0$ and $\frac{\partial q_y}{\partial \gamma_y} = \frac{\partial h_y}{\partial \gamma_y} \leq 0$. In other words, positive monotonicity requires aggressive commitment by rival firms to be accommodated through reduced own firm production.

To see that shareholders of both firms would both like to set $\frac{\delta h_x}{\delta \gamma_x}$ as close to zero as possible, observe that a more negative value for $\frac{\delta h_x}{\delta \gamma_x}$ leads to greater equilibrium $q_y$ and therefore lower prices and profits for firm $x$. Intuitively, this is true because the more a firm accommodates to its rivals, the worse off it becomes as rival firms take advantage of the accommodation. The optimal strategy is to commit to as little accommodation as possible.

Thus, managerial behavior will be relatively inelastic to rival behavior in the equilibrium. Perfect inelasticity is impossible to achieve in this case, however. This is because compensation for firm $x$ is based on own profits $\pi_x$, which is an imperfect measure of other firm production $q_y$. To see this, going back to the managerial best response function derived in Lemma 2 we have:

$$q_x = \frac{1}{2}(a - q_y - E(c) + b_x(\pi_x))$$

$$q_y = \frac{1}{2}(a - q_x - E(c) + b_y(\pi_y))$$
Focusing on firm $x$, the derivative with respect to other firms’ production is:

\[
\frac{dq_x}{dq_y} = \frac{1}{2}(-1 + \frac{db_x(\pi_x)}{d\pi_x} \frac{d\pi_x}{dq_y})
\]

\[
= \frac{1}{2}(-1 - \frac{db_x(\pi_x)}{d\pi_x} q_x)
\]

While shareholders would like to set $\frac{db_x(\pi_x)}{d\pi_x} = -1/q_x$ and achieve perfect inelasticity, it is impossible for them to do so because $b_x$ is a function of $\pi_x$ which has no one-to-one mapping to $q_x$ in the strategy space.

To prove the last part of the lemma, observe that for any functional form where managerial best response is downward sloping (which is required because $\pi_x$ is an imperfect measure of $q_x$ and the compensation monotonicity condition ensure that the best response curve can never have a positive slope), commitment has value and the argument in Lemma 2 shows that $\frac{\partial E(U)}{\partial \sigma} > 0$. 

\[\square\]

**Empirical Analysis**

**Data and OLS Results**

Our theory links executive compensation vega with oligopoly strategy. Shareholders may use options compensation to commit to higher production, which leads to higher expected profits. The value of this commitment is related to the market power of the firms, and (starting from a duopoly) becomes less relevant as the number of players in the market increases (Lemma 4). Therefore, our model predicts that the use of options compensation vega is positively related to industry concentration for our sample of manufacturing firms in relatively competitive industries. \[\text{\textsuperscript{4}}\]

\[\text{\textsuperscript{4}}\text{In the limiting case where the number of firms in an industry fall from a duopoly to a monopoly (and ignoring threats of entry), Lemma \[\text{\textsuperscript{4}}\] would not apply. This is related to the inverted U-shape effect that Yu (2014) emphasized. For privacy reasons, the Census Bureau declines to provide data}\]
To test this prediction, we run a difference-in-difference (DiD) regression using US Census Bureau data on industry concentration and CompuStat ExecuComp data on CEO compensation. We compute CEO compensation vega, or the change in CEO wealth for a 1% increase in stock price volatility, following Coles et al. (2013). For firms with a manufacturing NAICS classification, the Census Bureau provides data on the Herfindahl-Hirschman Index (HHI) by value of shipments as a measure of industry concentration in 2002 and 2007. With these data we regress the change in CEO compensation vega against changes in HHI between 2002 and 2007. We winsorize vega, cash compensation, and market-to-book ratios at the first and 99th percentiles to mitigate the effects of the outliers, as is commonly done in the managerial compensation literature. The summary statistics of our sample are presented in Table 1. The pairwise correlations for the variables used in our regressions are presented in Table 2.

Our main regression model is:

\[ \Delta \text{Vega}_t = \beta_0 + \beta_1 \Delta \text{HHI}_{t-1} + \beta_2 \Delta \text{FirmSales}_{t-1} + \text{industry fixed effects} + \varepsilon_t \]

The prediction that higher industry concentration is associated with higher levels of options compensation can be examined through the estimated coefficient before \( \Delta \text{HHI}_{t-1} \) on \( \Delta \text{Vega}_t \). Table 3 summarizes the regression results. Regression (1) is the main regression as specified, which shows a positive correlation between \( \Delta \text{Vega}_t \) and \( \Delta \text{HHI}_{t-1} \) (.103, p=0.012).

In terms of magnitudes, the regression coefficient of .103 shows that, for every 100 point increase in HHI (HHI being on a scale from 0 to 10,000), CEO compensation vega increases by $10,300. Thus, the relationship we found is both economically and statistically significant.

In industries where market concentration gets close to monopoly/duopoly levels, and the highest HHI observed in our sample is 2,982. So we do not expect such a scenario to be relevant for our sample.
Because we use a difference-in-difference (DiD) approach, we are able to control for (i) omitted variables within individual firms that do not change over the short term, such as branding and corporate culture and (ii) omitted variables within industries that do not change over the short term. We also add 4-digit industry fixed effects, which controls for time varying omitted variables that are common to firms within each industry, such as changes in the nature of the supply chain or changes in regulatory pressures. We also have firm sales as a control variable to address possible correlation between vega and firm sales which could drive a positive correlation between vega and HHI.

We report clustered robust standard errors to account for within-industry correlations that are not captured by first differencing, fixed effects, and control variables. Firms may tend to follow their peers in the same industry when setting compensation, so compensation within industries may be correlated. Reporting cluster robust standard errors allows the statistical significance of our estimates to incorporate the possibility of unknown within-industry correlations of managerial compensation structures.

Our main OLS results are presented in Regression (1) of Table 3. We add CEO tenure and CEO cash compensation as additional control variables in our regression. Although these variables are commonly used to explain CEO vega and are correlated with firm size, they are not obviously related to HHI. The correlations table (Table 2) confirms this, showing that CEO tenure and cash compensation are significantly correlated with vega and firm size, but not with HHI. Indeed, we find that including these additional variables in our regressions, as presented in Regression (2) of Table 3, do not lead to qualitatively different coefficients than our main regression results in Regression (1).

We also investigate whether firm scale (as measured by total assets) and firm
outlook (as measured by market to book ratio) are driving the relationship between $\Delta HHI_{t-1}$ and $\Delta Vega_t$. This could happen if, for example, HHI is correlated with firm scale which leads to an increase in vega, or if HHI is correlated with firm outlook which leads to an increase in vega. As we show in Regression (3) of Table 3 while including these variables increases the explanatory power of the regressions, it does not lead to qualitatively different coefficients than our main regression results. This result is suggestive that these variables are not driving the observed correlations between $\Delta HHI_{t-1}$ and $\Delta Vega_t$.

A similar investigation also found concerns that changes in stock prices from prior year to current year may lead to a mechanistic increase in vega unintended by shareholders to be unwarranted. Regression (4) of Table 3 shows that the inclusion of stock price changes do not qualitatively alter our main results.

Competitor mergers as instruments

To address potential simultaneity between $\Delta Vega_t$ and $\Delta LogSales_{t-1}$, we conduct robustness checks with competitor mergers as instruments.

In our OLS regressions, we control for firm sales as a potential confounding factor driving the positive relationship between changes in CEO compensation vega and changes in HHI. However, the effect of vega on firm sales is difficult to empirically identify because of simultaneity of compensation incentives and firm sales, which implies that the coefficient is likely estimated with upward bias. Since firm sales are positively correlated with industry HHI, an upwardly biased coefficient in front of $\Delta LogSales_{t-1}$ implies a downwardly biased (i.e. more conservative) coefficient in front of $\Delta HHI_{t-1}$ in the main OLS specification. The time lag is likely unable to fully

---

5A positive correlation between CEO compensation vega and firm sales is well established, but not the direction of causality. See eg. Coles et al. (2006), Gormley et al. (2013), and Angelis et al. (2014).
resolve this simultaneity issue, which makes an IV approach attractive.

Competitor mergers are valid instruments because they are plausibly exogenous to own firm compensation incentives. In other words, merging parties do not tend to factor in the compensation vega of their non-merging competitors when deciding to merge. This allows our instrument to satisfy the exclusion criteria. We do not consider firms that underwent mergers themselves from in our analysis, and focus only on the changes in the compensation incentives of competitors following mergers.

Nonetheless, there are some issues with using competitor mergers as instruments. First, competitor mergers are related to a specific source of variation in industry concentration (i.e. that of companies merging), and cannot capture variation in industry concentration that result from the dominance of one company’s product over others through aggressive marketing or predatory pricing. Since we do not model marketing or predatory pricing, this may be an advantage of the IV approach as it allows us to better link our empirical analysis with theory. It does, however, limit the comparability between our OLS and IV results.

Second, competitor mergers are not exogenous to changes in cost in the industry. An industry-wide increase in marginal cost may reduce profitability of existing companies and encourage mergers. Our 4-Digit industry fixed effects would control for some of these cost changes. Nevertheless, if cost changes are more specific than the 4-Digit industry level (and are correlated with mergers), that may bias our coefficient estimates. The likely direction of bias is downwards/more conservative because an increase in marginal cost reduces the amount of potential profits in the market which leads to less use of performance pay through the market size channel (Raith 2003). Alternatively, our IV analysis can be viewed as additional correlative

\[ b_x = b_y = \frac{a - E(c)}{5}. \]

This result is also present in our model. The last equation in Lemma 2, \( b_x = b_y = \frac{a - E(c)}{5} \), implies that an increase in expected marginal costs decreases executive compensation vega.
evidence that increases in market concentration due to competitor mergers are associated with increases in options compensation vega.

We manually matched Bloomberg companies to Compustat companies. We incorporated all same industry mergers of more than $2 billion in transaction size within the period of 2003-2006 (chosen because our HHI data range from 2002 to 2007). This includes a total of 65 mergers in 29 different manufacturing NAICS industries. To be precise about our methodology, we define the variable \( \text{competitor\_merger} \) as:

\[
\text{competitor\_merger} = \frac{(Merged\_Companies'\_Sales)}{(Industry\_Sales)}
\]

Where \( Industry\_Sales \) are defined by summing up the CompuStat sales of all firms in the NAICS industry, plus the sales of the merged companies if they are not already in the CompuStat sample.

We present the first stage results in Table 4. As expected, competitor mergers are strongly and positively correlated with changes in HHI. The first stage F statistic for our main specification is 40.1. The critical value for a 10% rejection rate with a 5% Wald test is 16.4. These results suggest that the instrument is strong.

We present our second stage results in Table 5. The main IV specification, Regression (1), gives a coefficient of 0.24 with a robust standard error of 0.11. We investigate controlling for \( \Delta LogSales \) and \( \Delta StockPrice \) in Regressions (2), (3), and (4). Adding those variables to the regression do not affect our main estimates. Attesting to the success of our IV approach in resolving the problem of simultaneity of \( \Delta Vega \) and \( \Delta LogSales \), the instrumented \( \Delta HHI \) is no longer positively correlated with \( \Delta LogSales \), and adding \( \Delta LogSales \) to in Regression (2) no longer decreases the coefficient in front of \( \Delta HHI \).
Discussion and Conclusion

To summarize, we propose a mechanism to explain the use of compensation structures that make managers more risk taking. Our model is consistent with two empirical observations. First, our model predicts that shareholders should award options compensation such that the managers are risk-taking rather than risk-neutral. Such a prediction fits observations by Dong et al. (2010) and Cooper et al. (2014), which find that some firms’ stock options compensation may be incentivizing their managers to take an excessive amount of risk. Second, our model predicts that, for a relatively competitive industry, the amount of options awarded to managers should positively depend on industry concentration. We tested this prediction and found that, indeed, for a sample of manufacturing firms in relatively competitive industries a change in the Herfindahl Index (HHI) of manufacturing companies is positively linked to a change in executive compensation vega. Our empirical results are robust in an alternative IV specification using competitor mergers as instruments.

Our analysis has some policy implications. In our model, managers choose more production than they would if they were risk neutral and expected profit maximizing, which implies lower prices for consumers.\(^7\) As such, risk rewarding compensation may improve social welfare. However, there may exist external costs to risk taking in some industries, which could overweigh any such benefits. For example, failures for firms in the finance industry could lead to network effects that extend far beyond the failing firms’ shareholders.\(^8\) As a result, depending on the sizes of the external costs, the greater production due to risk rewarding compensation may not benefit consumers.

\(^7\)More specifically, observe that with risk neutral managers, the Cournot game yields an equilibrium of \(q_x = q_y = \frac{a - E(c)}{3}\). With shareholders setting managerial compensation to incentivize risk taking, the equilibrium quantities are higher: \(q_x = q_y = \frac{a - E(c)}{3} + \frac{a - E(c)}{15} = \frac{2(a - E(c))}{5} > \frac{a - E(c)}{3}\).

\(^8\)See eg. Eisenberg and Noe (2001) and Gai and Kapadia (2010).
enough to compensate for the external costs of risk taking and firm failing. If that is the case, limiting stock options compensation by law would benefit both consumers and shareholders: consumers, because of a reduction of externality costs, and shareholders, because of less competition and higher oligopoly profits.

More empirical research is needed to realize the potential in the field. The results from our paper strongly suggest that stock options compensation vega is empirically linked to market concentration. Our paper thus provides a starting point for more structural modelling and estimation of the relationship between executive compensation vega and product market competition.
References


Managerial and Decision Economics 31: 531-543.


Murphy KJ. 2012. Executive compensation: Where we are, and how we got there. *Working paper*.


**Table 1**  
*Summary Statistics*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>25th Pctile</th>
<th>Median</th>
<th>75th Pctile</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta$Vega ('000s)</td>
<td>-6.4</td>
<td>195.6</td>
<td>-43.8</td>
<td>0</td>
<td>46.8</td>
</tr>
<tr>
<td>$\Delta$HHI</td>
<td>51.9</td>
<td>273.0</td>
<td>-86.6</td>
<td>-6.8</td>
<td>122.1</td>
</tr>
<tr>
<td>$\Delta$LogSales</td>
<td>0.47</td>
<td>0.50</td>
<td>0.22</td>
<td>0.44</td>
<td>0.72</td>
</tr>
<tr>
<td>$\Delta$Tenure (years)</td>
<td>0.41</td>
<td>6.78</td>
<td>-2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>$\Delta$Cash Comp ('000s)</td>
<td>-251.0</td>
<td>968.2</td>
<td>-546.4</td>
<td>-113.6</td>
<td>142.4</td>
</tr>
<tr>
<td>$\Delta$LogAssets</td>
<td>0.38</td>
<td>0.58</td>
<td>0.22</td>
<td>0.36</td>
<td>.72</td>
</tr>
<tr>
<td>$\Delta$Market to Book</td>
<td>0.66</td>
<td>3.56</td>
<td>-0.42</td>
<td>0.27</td>
<td>1.14</td>
</tr>
<tr>
<td>$\Delta$StockPrice</td>
<td>-5.79</td>
<td>16.1</td>
<td>-12.0</td>
<td>-3.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Variable</td>
<td>∆Vega</td>
<td>∆HHI (-1)</td>
<td>∆LogSales (-1)</td>
<td>∆Tenure</td>
<td>∆Cash</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------</td>
<td>-------------</td>
<td>-----------------</td>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>(\text{StockPrice}) ((-1)</td>
<td>0.076</td>
<td>-0.014</td>
<td>-0.002</td>
<td>0.065</td>
<td>0.092</td>
</tr>
<tr>
<td>(\text{HHI}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{LogSales}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{Tenure}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{Cash}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{LogAssets}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{MarkettoBook}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
<tr>
<td>(\text{Vega}) ((-1)</td>
<td>0.04</td>
<td>0.137</td>
<td>0.106</td>
<td>0.120</td>
<td>0.149</td>
</tr>
</tbody>
</table>

Table 2
Table 3

*OLS regression results*

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta Vega_t$</td>
<td>$\Delta Vega_t$</td>
<td>$\Delta Vega_t$</td>
<td>$\Delta Vega_t$</td>
</tr>
<tr>
<td>$\Delta HHI_{t-1}$</td>
<td>.103**</td>
<td>.112**</td>
<td>.109***</td>
<td>.109***</td>
</tr>
<tr>
<td></td>
<td>(.040)</td>
<td>(.044)</td>
<td>(.040)</td>
<td>(.041)</td>
</tr>
<tr>
<td>$\Delta LogSales_{t-1}$</td>
<td>99.8***</td>
<td>77.2***</td>
<td>38.7**</td>
<td>40.1**</td>
</tr>
<tr>
<td></td>
<td>(20.7)</td>
<td>(19.2)</td>
<td>(19.0)</td>
<td>(18.0)</td>
</tr>
<tr>
<td>$\Delta Tenure_t$</td>
<td>3.01</td>
<td>2.56</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.65)</td>
<td>(2.82)</td>
<td>(2.82)</td>
<td></td>
</tr>
<tr>
<td>$\Delta CashCompensation_t$</td>
<td>.071**</td>
<td>.070**</td>
<td>.068**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.030)</td>
<td>(.028)</td>
<td>(.028)</td>
<td></td>
</tr>
<tr>
<td>$\Delta LogAssets_{t-1}$</td>
<td>47.9**</td>
<td>51.13**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(20.9)</td>
<td>(22.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta MarkettoBook_{t-1}$</td>
<td>6.09***</td>
<td>6.51***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.05)</td>
<td>(2.08)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta StockPrice_{(t)-(t-1)}$</td>
<td>.779</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.829)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4-Digit Industry Fixed Effects | Yes | Yes | Yes | Yes |
| N                           | 393  | 372  | 371  | 371  |
| $R^2$                       | .145 | .227 | .240 | .242 |

Significance levels:  * : 10%  ** : 5%  *** : 1%
Table 4

2SLS regressions using competitor mergers as instruments; First Stage

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta HHI_t$</td>
<td>$\Delta HHI_t$</td>
<td>$\Delta HHI_t$</td>
<td>$\Delta HHI_t$</td>
</tr>
<tr>
<td>competitor_merger</td>
<td>440.5***</td>
<td>443.5***</td>
<td>437.6***</td>
<td>441.7***</td>
</tr>
<tr>
<td></td>
<td>(101.6)</td>
<td>(103.8)</td>
<td>(103.4)</td>
<td>(105.6)</td>
</tr>
<tr>
<td>$\Delta LogSales_t$</td>
<td></td>
<td>30.2</td>
<td></td>
<td>29.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(32.7)</td>
<td></td>
<td>(32.9)</td>
</tr>
<tr>
<td>$\Delta StockPrice(t)-(t-1)$</td>
<td></td>
<td>- .36</td>
<td></td>
<td>- .19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(.61)</td>
<td></td>
<td>(.60)</td>
</tr>
<tr>
<td>4-Digit Industry Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>N</td>
<td>417</td>
<td>412</td>
<td>412</td>
<td>412</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.542</td>
<td>.544</td>
<td>.542</td>
<td>.544</td>
</tr>
</tbody>
</table>

Significance levels:  * : 10%  ** : 5%  *** : 1%
Table 5

2SLS regressions using competitor mergers as instruments; Second Stage

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V_{ega_t}$</td>
<td>$\Delta V_{ega_t}$</td>
<td>$\Delta V_{ega_t}$</td>
<td>$\Delta V_{ega_t}$</td>
<td>$\Delta V_{ega_t}$</td>
</tr>
<tr>
<td>$\Delta HHI_{t-1}$</td>
<td>.24**</td>
<td>.26**</td>
<td>.26**</td>
<td>.30**</td>
</tr>
<tr>
<td></td>
<td>(.11)</td>
<td>(.13)</td>
<td>(.12)</td>
<td>(.13)</td>
</tr>
<tr>
<td>$\Delta LogSales_{t-1}$</td>
<td>92.0***</td>
<td>99.6***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(19.5)</td>
<td>(21.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta StockPrice_{(t)-(t-1)}$</td>
<td>.95</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.97)</td>
<td>(.95)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4-Digit Industry Fixed Effects | Yes | Yes | Yes | Yes |
N                               | 417  | 412  | 412  | 412  |
$R^2$                           | .100 | .133 | .098 | .131 |

Significance levels: * : 10%   ** : 5%   *** : 1%