Data Breach and Managerial Risk-taking Incentives

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Abstract

This paper investigates how data breach costs influence the design of CEO compensation contracts. Exploiting the staggered adoption of data breach notification (DBN) laws across U.S. states, we find that firms provide managers with greater risk-taking incentives following DBN adoption. The effect is more pronounced for firms with risk-averse CEOs, well-diversified shareholders, and greater outside investment opportunities. Overall, this paper provides new evidence that firms consider data breach costs when designing managerial incentive contracts.

Keywords: Cybersecurity, Cyber Risk, Executive Compensation, Risk Taking

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1 Introduction

In today's digital age, data has become the lifeblood of modern enterprises. It enables firms to understand their customers and make well-informed business decisions, providing a competitive edge. However, as electronic systems are vulnerable to breaches, firms now face the rising threat of cyberattacks and data breaches. According to IBM's data breach report, the average cost of a data breach in the U.S. jumped to $9.46 million in 2024, the biggest increase since the pandemic (IBM, 2024). A natural question arises: how do firms adjust their corporate strategies in response to the increased costs of data breaches? As these costs are likely to affect the risk preferences of managers and shareholders,[1] in this paper, we shed light on this question by investigating whether data security costs can reshape managerial incentive contracts to adjust the level of desired risk-taking.

To do this, we exploit the staggered adoption of the Data Breach Notification (DBN) law across U.S. states. The DBN law prevents firms from withholding negative news once a breach occurs.[2] It mandates that firms experiencing a breach inform every individual whose information has been leaked. Firms that fail to comply with the mandatory disclosure requirements may face penalties. Revealing data breach incidents not only incur significant direct costs (e.g., costs associated with notification, remedial activities, etc.), but also negatively affect a firm's reputation and weaken customer trust, potentially impacting its future growth opportunities (Ponemon, 2017; Kamiya et al., 2021; Akey et al., 2023). Therefore, by ensuring prompt and adequate disclosure of data breach incidents, the DBN law significantly increases the potential costs that firms face associated with data breaches.

How does DBN adoption affect the design of managerial incentive contracts? Firms can address increased data breach costs by reducing risk-taking activities, leading to a lower probability of financial distress. When these costs increase, a value-maximizing board is likely to decrease the magnitude of risk-taking to align with value maximization.

However, a central friction exists in the alignment between the CEO and the board's interests. Due to reputation and career concerns, CEOs tend to adopt risk-averse behavior

[1] For example, a data breach can harm the careers of managers, as firms might primarily blame their top executives (Fuhrmans, 2017; Lending et al., 2018)

[2] Managers often delay or avoid disclosing data breach incidents due to the adverse consequences that follow such disclosures (Amir et al., 2018).

(Jensen and Meckling, 1976; Gormley and Matsa, 2016; Heron and Lie, 2017). That means a risk-averse CEO might not be fully aligned with the board's value maximization objectives. In other words, the CEO's risk aversion can be a significant hurdle, complicating the path toward decreased risk-taking. After the enactment of the DBN law, a risk-averse CEO might face heightened personal costs of distress that cannot be diversified away. Therefore, they would adopt more conservative strategies that fall below the level desired by diversified shareholders. In such cases, we expect the board to renegotiate the convexity of the payoff inherent in the CEO's compensation package to overcome the CEO's risk aversion.

For our tests, we employ a difference-in-differences (DID) design using a large panel of U.S. public firms from 1998 to 2018. We follow previous studies (e.g., Hayes et al., 2012; De Angelis et al., 2017; Chen et al., 2022) and measure the risk-taking incentives provided to managers by the sensitivity of CEO wealth to stock return volatility (*Vega*). Consistent with our hypothesis, we find that CEO Vega increases by 3.4% relative to the sample mean after the adoption of DBN. This result holds after controlling for several firm and CEO characteristics, as well as various fixed effects. Overall, these results suggest that the increase in data breach costs induced by DBN encourages boards to provide more managerial risk-taking incentives.

Testing the parallel trend assumptions, we show that the pre-treatment trends of treated and control firms are indistinguishable. Most of the impact of DBN on CEO Vega occurs in the second year after the event, which provides evidence against reverse causality. Moreover, recent studies have criticized the staggered DID framework due to heterogeneous treatment effects. To address this concern, we implement two newly developed approaches (Callaway and Sant'Anna, 2021; Baker et al., 2022) and find that our results remain robust.

Next, we explore the underlying channel of the DBN's impact on Vega by first investigating the granular components of CEO compensation. We interpret the change in Vega as boards actively adjusting managerial risk-taking incentives. However, Vega can also change if CEOs independently adjust their corporate security portfolios, which is not under the board's control. To investigate this possibility, we examine CEOs' decisions to exercise options and find that the results are primarily driven by new option grants, with no evidence that DBN adoption impacts option exercises by the CEO. Additionally, we examine whether DBN affects other components of CEO compensation. We find that the adoption of DBN increases total compensation and stock options but has no significant effect on other components of the compensation package. These results reinforce our argument that, in response to DBN, firms restructure executive compensation by providing more risk-taking incentives.

To further support our argument, we conduct several cross-sectional analyses. As previously discussed, when faced with increased data breach costs, managers tend to take less risk than the level desired by shareholders. This misalignment between managerial and shareholder interests is expected to be more pronounced in firms with risk-averse CEOs, well-diversified shareholders, and greater outside investment opportunities. As a result, boards have stronger incentives to adjust CEO vega in response to DBN adoption. Consistent with this hypothesis, our results show that these firms experience a greater increase in managerial risk-taking incentives following DBN adoption, providing evidence in support of our argument.

How does the adjustment of the CEO's convexity payoff following DBN adoption affect firms' risk-taking behavior? If CEOs are successfully incentivized to overcome risk aversion and career concerns, we should observe more risk-taking activities by firms. We implement a two-stage least squares (2SLS) regression, where we instrument CEO Vega using the change in data breach costs. Consistent with our prediction, we find that the instrumented Vega is associated with lower cash levels, but higher leverage, R&D investment, asset growth, and cash flow volatility. This suggests that the increase in CEO Vega following DBN adoption has a real effect on firms' corporate policies.

Our paper contributes to two strands of literature. First, we contribute to the executive compensation research on the determinants of CEO risk-taking incentives. Hayes et al. (2012) show that firms reduce the use of stock options after the adoption of FAS 123R. De Angelis et al. (2017) provide evidence that changes in the information environment of financial markets affect incentive contract design. Chen et al. (2022) find that a firm's customer-base structure can influence its CEO pay convexity. Ellul et al. (2024) show that firms tend to provide managers with more risk-taking incentives when they are exposed to lower unemployment risk. By exploiting DBN adoption as a natural experiment, we add a new dimension to this literature by showing that data breach costs can also play a significant role in the design of CEO pay.

Second, we contribute to the growing literature on corporate data breaches. The increasing use of digitalization has exacerbated the issue of data security. To protect consumers from data breaches, regulators have introduced data breach regulations, such as mandatory data breach notification laws. While many studies have examined the consequences of data breaches (e.g., Ponemon, 2017; Huang and Wang, 2021; Kamiya et al., 2021; Akey et al., 2023), there is limited evidence on the impact of data breach regulations on corporate policies (Ashraf and Sunder, 2023). In this paper, we add to this literature by investigating how firms adjust their corporate strategies in response to these regulations. Specifically, we show that firms reshape managerial incentive contracts when facing increased data breach costs induced by DBN.

The remainder of the paper is organized as follows. Section 2 introduces the background of the DBN. Section 3 describes our sample construction and provides summary statistics. Sections 4 presents the empirical results. Section 5 concludes.

2 Data breach notification laws

In the United States, the requirements of disclosing data breach incidents are primarily governed by state law. California pioneered this legislation by enacting the first breach notification law, which became effective in 2003. This legislative move was triggered by a widely publicized delay in reporting a data breach at the Stephen P. Teale Data Center, affecting approximately 265,000 state employees. Subsequently, from 2003 to 2018, the remaining 49 U.S. states and the District of Columbia adopted similar data breach laws in a phased manner.

The DBN laws mandate firms to disclose data breach incidents and notify individuals of security breaches involving personally identifiable information. A data breach is generally defined as the unauthorized acquisition of data that compromises the security, confidentiality, or integrity of personal information (e.g., social security numbers, driver's licenses, state ID cards). To ensure the reporting of data breach in a timely manner, the laws typically mandate that firms disclose breaches within a specified timeframe ranging from 30 to 90 days. This allows affected parties ample time to minimize losses and take other preventive measures. Non-compliance with notification requirements can lead to civil penalties; for instance, Texas imposes penalties of up to $250,000 per incident, plus a daily penalty of $100 for each individual owed notification, accruing daily until compliance.

State-level DBN laws may vary in some specific provisions, including state enforcement, caps on civil penalties, and explicit notification time limits, among others (Sullivan and Maniff, 2016). Despite these relatively minor variations, the laws are largely homogeneous and harmonious across states, sharing the primary intention of safeguarding customers and employees through prompt and adequate notification of personal information theft (Shaw, 2009). It is worth noting that the laws do not mandate market-wide public disclosure of data breaches; instead, they require private disclosure to the affected parties. However, Ashraf and Sunder (2023) note that the laws are *de facto* requirement to make market-wide public disclosure of a data breach, as private notifications to potentially millions of affected individuals are unlikely to remain confidential. Thus, it is reasonable to assume that these laws also increase awareness of data breaches among firm stakeholders beyond just the affected parties.

While transparent and timely disclosure of data breach incidents incentivizes firms to enhance their data security practices, such disclosure also incurs substantial direct and indirect costs for firms. Prior research has shown that firms are subject to substantial litigation and redress costs following cybersecurity incidents (Romanosky et al., 2014; Ponemon, 2017). For example, the data breach incident at Equifax in 2017, which compromised account information for 147 million people, resulted in a total settlement of $425 million. [3] Apart from costs that directly stem from data breach incidents, revealing these incidents can also induce widespread stakeholder anxiety, potentially leading to deteriorated customer relationships, increased financing costs, and damage to the firm's reputation (Akey et al., 2023; Huang and Wang, 2021; Kamiya et al., 2021; Crosignani et al., 2023).

[3] See details in https://www.ftc.gov/enforcement/refunds/equifax-data-breach-settlement

3 Data and Summary Statistics

3.1 Sample construction

Our sample begins with all CEOs in the Execucomp database over the period from 1998 to 2018. The sample starts in 1998 so there are five years before the first adoption of DBN in 2003. We end the sample in 2018 to avoid noises from the COVID-19 pandemic.[4] All CEO compensation variables are measured using Execucomp data. We merge these data with stock return data from the Center for Research in Security Prices (CRSP), accounting data from Compustat, analyst coverage data from I/B/E/S and institutional ownership data from Thomson Reuters 13F filings. Information on companies' historical headquarter location is obtained from the Augmented 10-X Header Database provided by Bill McDodald.[5] Following the literature (Coles et al., 2006), we exclude financial firms (SIC codes 6000-6999) and utility firms (SIC codes 4900-4999). After requiring the availability of lagged values of the control variables, we are left with a final sample of 17,067 firm-year observations of 1,818 unique U.S. public firms over the sample periods of 1998-2018.

3.2 Measure of managerial risk-taking incentives

To measure CEO risk-taking incentive, we follow prior literature (i.e., Guay, 1999; Coles et al., 2006) and compute the compensation vega of the CEO's equity portfolio in the firm as the primary measure in our analysis. Specifically, portfolio vega equals the dollar change in the value of a CEO's option portfolio per 0.01 increase in the annualized standard deviation of a firm's stock returns (Core and Guay, 2002). By capturing the convexity of compensation payoff, portfolio vega serves as a straightforward metric for assessing the CEO's motivation to adopt risky firm policies (Smith and Stulz, 1985) [6]. To alleviate concerns that arise from the skewness of portfolio vega, we use the log transformation throughout our analysis (e.g., Low, 2009; Armstrong and Vashishtha, 2012; Chen et al., 2022).

To further investigate the source of the change in vega, we construct *Flow vega*, a measure

[4]In untabulated results, we confirm that the baseline findings still hold when the sample is extended through 2023.

[5]See https://sraf.nd.edu/data/augmented-10-x-header-data/

[6]Empirically, (Coles et al., 2006; Chava and Purnanandam, 2010; Armstrong and Vashishtha, 2012; Hayes et al., 2012) all examine the association between vega and risk taking and find a positive relation

that is based solely on newly granted options in the current year (Armstrong et al., 2013). By focusing exclusively on new grant, *Flow vega* more accurately captures potential adjustments in risk-taking incentives made by the board of directors in response to regulatory changes or shocks to firms' risk environment, thereby mitigating confounding effects from unexercised past grants (Gormley et al., 2013; De Angelis et al., 2017). We discuss this analysis in more detail in section 4.4.1.

3.3 Measure of DBN indicator

We obtain the effective year of DBN law in each state from the Privacy & Security group of Perkins Coie.[7] We then construct a dummy variable, *DBN*, which equals to one for a state in years after the enactment of the DBN law, and zero otherwise. Table 1 provides a list of states, along with the timing of DBN adoption. By the end of 2018, all 50 states and the District of Columbia had enacted the law, with California adopting it first in 2003, and Alabama and South Dakota being the last in 2018.

[Insert Table 1 here.]

To justify the use of DBN law as a viable quasi-natural experiment, we address reverse causality concerns by regressing the DBN adoption status of each state against the state average CEO compensation Vega. The results are reported in Table B.1. Specifically, we average *Vega* across all firms in each state and test whether the lagged state average *Vega* influence the likelihood of a state adopting the law in the current year. We first include the state average *Vega* as the sole explanatory variable in Column (1). The coefficient for state average *Vega* is found to be statistically insignificant, suggesting that the pre-existing CEO risk-taking incentives cannot predict the timing of the law. In column (2), we further add a series of state variables capturing the macroeconomic and political environments, including GDP growth, unemployment rate, population, and state governor party. As shown, the coefficient on state-average *Vega* remains insignificant, which further indicates that reverse causality concerns are unlikely to be severe.

[7] For detailed description of the law in each state and the District of Columbia, see https://perkinscoie.com/insights/publication/security-breach-notification-chart.

3.4 Summary Statistics

Table 2 reports the descriptive statistics of the sample. The variable of interest, *DBN*, has a mean of 0.67, suggesting that 67% of firm-year observations are affected by DBN laws during the sample period. The mean value of *Vega* (*Flow Vega*) is 3.7 (1.52), indicating that CEO wealth increase $142,789 ($22,063), on average, for a 1% increase in the annualized standard deviation of a firm's stock price. An average CEO's compensation package (in log transformation) has an annual total pay of 8.228, a base salary of 6.562, a bonus of 2.281, a restricted stock holdings of 4.510, an option grant of 4.523, and a *Delta* (*Flow delta*) of 5.492 (3.996).

[Insert Table 2 here.]

Regarding firm-level characteristics, an average firm in our sample has a firm size of 7.544, a market-to-book ratio of 2.109, a leverage ratio of 19.6%, a return on assets of 4.8%, a R&D ratio of 3.7%, a sales growth rate of 10.6%, an annual stock return of 48.6% and an annual stock volatility of 10.8%. The average sample firm is followed by around 11 analysts and has 78.1% of its shares being held by institutional investors. An average CEO in our sample is 56 years old and has a tenure of 8 years. The summary statistics for our incentive and financial variables are generally comparable with prior literature (Hayes et al., 2012; Gormley et al., 2013; Chen et al., 2022; Ellul et al., 2024).

4 Empirical Findings

4.1 Impact of the DBN on CEO's Compensation Vega

To investigate whether boards adjust the managerial incentives in response to DBN adoption, we employ a generalized difference-in-differences approach. The baseline regression is shown as follows:

$$Vega_{i,t} = \alpha + \beta DBN_{i,t} + \gamma Controls_{t-1} + Fixed\ Effects + \epsilon_{i,t} \tag{1}$$

where *Vega* represents the level of risk-taking incentive embedded in a CEO's annual compensation packages at firm i in year t (i.e., CEO compensation vega). The variable of interest is *DBN*, which is a dummy that equals one for any fiscal year ending after a data breach notification law is enacted in the state where firm i is headquartered, and zero otherwise. All specifications include firm and year fixed effects. Since DBN is adopted at the state level, we cluster standard errors by state.

To mitigate omitted variable concern, we follow prior literature by including a set of control variables that may affect CEO Vega (Coles et al., 2006; Hayes et al., 2012; Chen et al., 2022). We first control for firm characteristics, including firm size (measured by the logarithm transformation of the book value of total assets), leverage, market-to-book ratio, ROA, sales growth, stock returns, and stock return volatility. The CEO characteristics that we control for include CEO age and tenure. Following Hartzell and Starks (2003) and Chen et al. (2015), we also control for external influences on compensation design, such as the number of analysts and institutional ownership. All control variables are lagged by one year. We winsorize all continuous variables at the 1st and 99th percentiles to minimize the effect of outliers. Detailed variable definitions are provided in Appendix A.

Table 3 presents the regression results. The coefficients on *DBN* are positive and significant across all specifications, suggesting a positive effect of DBN adoption on managerial risk-taking incentives. Column (1) includes only *DBN*, firm, and year fixed effects as the independent variables. The coefficient estimate of *DBN* is 0.124 and significant at the 5% level. In terms of economic significance, this represents a relative increase of 3.4% compared to the sample average of CEO Vega (=0.124/3.7).

In columns (2)-(3), we additionally control for various firm and CEO characteristics and find similar results. To address the possibility that our results are driven by unobservable state-level factors, we include state fixed effects in column (4), and the results remain unchanged. Finally, in column (5), we include the industry-year fixed effects to control for time-varying differences across different industries. The coefficient estimate of *DBN* continues to be positive and significant. Overall, the results in Table 3 are in line with our prediction that boards adjust managerial risk-taking incentives in response to increased data breach costs induced by DBN adoption.

[Insert Table 3 here.]

4.2 Dynamic effects and alternative estimators

The validity of a difference-in-differences approach depends on the parallel trends assumption: the CEO Vega of treated firms would have evolved in the same way as that of control firms in the absence of DBN adoption. To check for preexisting trends, we follow Bertrand and Mullainathan (2003) and replace the DBN dummy in Equation 1 with nine year dummies, DBN_t, where t ranges from -4 to 4. DBN_t is an indicator set to one if the firm is headquartered in a state that adopted DBN t years ago. $DBN_{\geq 4}$ is an indicator set to one if the firm is headquartered in a state that adopt DBN 4 or more years ago, and zero otherwise. Table 4 presents the results. We do not observe any statistically significant results in the year before the DBN adoption, suggesting that the parallel trend assumption holds.

The standard two-way fixed effects (TWFE) DiD regression could be biased due to the presence of heterogeneous treatment effects when using "already-treated" units as effective controls (Baker et al., 2022). To mitigate this concern and provide further evidence of the dynamic effects, we use two recently developed methods, Callaway and Sant'Anna (2021) estimator and the stacked regression approach proposed by Baker et al. (2022), to reexamine the difference-in-differences estimates. In both cases, we use "not yet-treated" units as effective controls because all states had adopted the DBN before 2018. To remain consistent with the event-study analysis in Table 4, we include the relative-time periods in the $t-4$ to $t+4$ window. The implementation details and event study plots for these two methods are shown in Figure 1. Consistent with our baseline TWFE results, we continue to observe a significant increase in CEO Vega after the adoption of DBN.

[Insert Table 4 here.]

4.3 Exploiting industry cyber risk exposure

To address the concern of omitted correlated variables, in this section we explore whether the effect of DBN adoption on CEO Vega varies across industries with different levels of cyber risk exposure. Kamiya et al. (2021) argue that firms in certain industries (i.e., service, finance, and retail) handle large amounts of customer information, making them more likely to experience data breaches and face a higher risk of cyberattacks. If this is the case, firms operating in these industries would react more strongly to DBN adoption and incur higher data breach costs. Therefore, we should observe stronger treatment effects for these firms.

We follow Kamiya et al. (2021) and define the *High Cyber Risk* indicator as one if the firm belongs to service, manufacturing, and wholesale and retail trade industries.[8] We reestimate Equation 1 by including the interaction term of *DBN* $\times$ *High Cyber Risk*. As shown in column (1) of Table 5, the coefficient of the interaction term is positive and significant at the 1% level, suggesting that the treatment effect is significantly more pronounced for firms in industries with higher cyber risk exposure.

For robustness, we employ two alternative measures to proxy for industry cybersecurity risk exposure. Firms in high-tech industries or industries with significant intangible assets are more involved with advanced technology and handle large amounts of important and technical data, making them more likely targets for hackers and more prone to data breach incidents. We identify an industry as a high R&D (or high intangibility) industry if the industry-level R&D (or intangibility) is above the sample median, and zero otherwise. We perform cross-sectional analysis using these two alternative measures. As shown in columns (2) and (3), we continue to observe positive and significant coefficients for the interaction term.

[Insert Table 5 here.]

4.4 Compensation metrics

4.4.1 Effect of DBN on new option grant and option exercise

In the previous section, we argue that the increase in CEO Vega following DBN adoption is due to boards actively adjusting the compensation package to influence the CEO's risk-taking behavior. However, an alternative explanation for the changes in CEO Vega could be

[8]We identify firms following four-digit SIC codes: 7000-8999 (Service), 2000-3999 (Manufacturing), or 5000-5999 (Wholesale and Retail Trade).

that CEOs themselves modify their holdings of securities, for example, by exercising vested options. To better understand the mechanism through which DBN adoption affects CEO compensation packages, we further examine the effect of DBN on new option grants and options exercised in a given year and report the results in Table 6.

Specifically, we replace the dependent variable in Equation (1) with *Flow Vega*, which is proxied by the Vega of options granted in the current year. This measure excludes past accumulated stock options and is under more direct control of the board (Hayes et al., 2012). The results are presented in column (1). We find that the coefficient for DBN is still positive and significant. Empirically, the adoption of the *DBN* leads to a 9.5% increase in CEO Vega relative to the sample average (0.144/1.520=0.095).

[Insert Table 6 here.]

We then examine whether CEOs adjust their options portfolios by exercising options in response to DBN adoption. Using the same specifications, we examine the effect of DBN adoption on the *Value of Options Exercised* and the *Number of Options Exercised*. As shown in columns (2) and (3), we find that the DBN adoption has not effect on CEO option exercise. Overall, the results support our argument that the observed increase in CEO Vega following DBN adoption is driven by boards' active adjustments, rather than by CEO's decisions to exercise options.

4.4.2 Effect of DBN on CEO compensation structure

Having established that managerial risk incentives increase after DBN adoption, we next explore whether boards adjust other elements of CEO compensation packages in response to the increased costs of data breaches. Investigating this question can help rule out alternative explanations and provide a clearer understanding of the underlying mechanism.

In Table 7, we reestimate Equation (1) and replace CEO Vega with total compensation, salary, bonus, stock grants, and option grants. As shown in column (1), the coefficient estimate of DBN is positive and significant, suggesting a positive effect of DBN on total compensation. This may be because CEO require higher pay to compensate for the increased personal costs associated with data breaches induced by DBN. In columns (2)-(4), we find that DBN only has a significant effect on option grants, while there is no effect on salary, bonus, and stock grants.

[Insert Table 7 here.]

In Panel B of Table 7, we further examine whether boards also adjust other types of incentives provided, such as performance incentives (i.e., delta). Prior literature suggests that increases in compensation Vega may be driven by the provision of performance incentives, rather than the board's intention to increase risk-taking incentives (e.g., Islam et al., 2022). We therefore use the *Delta* and *Flow Delta* as the dependent variables. The coefficient on *DBN* is positive but insignificant, indicating that boards do not adjust other types of incentives after DBN adoption.

Overall, these results reinforce our main findings and provide further evidence in support of our argument that, in response to increased data breach costs, boards restructure the CEO compensation package by providing more risk-taking incentives.

4.5 Cross-sectional heterogeneity

To better understand why boards adjust the convexity payoff of CEO compensation packages in response to increased data breach costs, we perform several cross-sectional analyses to examine the heterogeneous treatment effects.

4.5.1 CEO risk aversion

We first examine whether the impact of DBN on managerial risk-taking incentives depends on CEO risk aversion. If firms aim to use the convexity payoff of compensation packages to mitigate managerial risk aversion, we should observe a larger increase in CEO managerial incentives when CEOs are more risk averse.

We use three proxies to measure CEO risk aversion. First, we define the *Old CEO* indicator as one if the CEO is over 65 years old, as 65 is widely recognized as the common age for retirement. Existing literature suggests that, compared with young managers, old managers are less willing to engage in risky activities (Serfling, 2014; Li et al., 2017). Second, we construct a measure based on the external managerial labor market. Coles et al. (2018)

argue that when faced with strong industry tournament incentives, CEOs are more willing to take risks to maximize their chances of claiming the tournament prize. Following Coles et al. (2018), we measure industry tournament incentives as the pay gap between a firm's CEO and the second-highest-paid CEO in the same Fama-French 30 industry. To capture a CEO's risk aversion, we define the *Low industry tournament* incentive indicator as one if the pay gap is below the sample median, and zero otherwise. Third, Bakke et al. (2022) argue that since CEOs with longer tenure are likely to have more wealth tied to the firm, they tend to be more under-diversified, leading them to undertake less risky activities. We use CEO tenure as another proxy for risk aversion. We define the *High CEO tenure* indicator as one if the CEO's tenure is longer than the sample median, and zero otherwise.

[Insert Table 8 here.]

We conduct our cross-sectional analysis using these three proxies and report the results in Table 8. Consistent with our expectations, the coefficients of the interaction terms are significant and positive across all specifications, suggesting that the increase of CEO Vega following DBN adoption is more pronounced when CEOs are more risk averse.

4.5.2 Shareholder diversification

In response to heightened data breach costs, firms are likely to adjust CEO risk-taking incentives to address the misalignment between managerial and shareholder interests. As this misalignment is likely to widen when shareholders are more diversified, we expect stronger results for firms with more diversified shareholders. In particular, we focus on the firm's largest shareholder, who typically holds effective and active control over the firm.

[Insert Table 9 here.]

Following Boone et al. (2024), we construct four proxies to measure shareholder portfolio diversification. The first proxy is the idiosyncratic volatility of an investor's portfolio (*Idio_vol*), calculated as the standard deviation of residuals from regressing the quarterly returns of the institution's portfolio on the contemporaneous three Fama-French factors over the past four years. The second proxy is inverse return synchronicity (*Inv_sync*), defined as the natural logarithm of the ratio of $(1-R^2)$ to R^2, where R^2 is obtained from a regression of historical returns using the Fama-French three-factor model. We also construct another two proxies on the number of firms in which the institution holds shares (*Hold_count*) and the concentration of holdings (*HHI_conc*), measured as the Herfindahl-Hirschman Index (HHI) of fractional holdings. Investors are classified as well diversified if they have below-median values for *Idio_vol*, *Inv_sync*, and *HHI_conc*, as well as above-median values for *Hold_count*.

Table 9 presents the regression results. The coefficients of the interaction term are positive and significant across all specifications, except for *HHI_conc*, where the sign remains positive but not statistically significant at conventional levels. These results indicate that the effect of DBN adoption on managerial incentives is significantly more pronounced for firms with well-diversified shareholders.

4.5.3 Firms' outside investment opportunities

Due to risk aversion, CEOs might forgo value-creating risky projects in response to increased data breach costs. If a firm has more valuable investment opportunities, the costs of such managerial risk aversion are likely to be higher, giving the firm greater incentives to adjust the CEO's compensation structure and provide more risk-taking incentives. We therefore expect the treatment effects to be stronger for firms with more investment opportunities.

[Insert Table 10 here.]

To examine this, we follow Chen et al. (2022) and use Tobin's Q as our first proxy. We define the *High Tobin's Q* indicator as one if the firm's Tobin's Q is above the sample median, and zero otherwise. Moreover, following Guay (1999), we construct a composite measure to capture variation in firms' investment opportunities. Specifically, this composite measure is a common factor derived from three widely used measures: (i) the book-to-market ratio; (ii) R&D expenditures scaled by total assets; and (iii) a measure of investment expenditures, defined as the sum of capital expenditures and acquisitions over the most recent three years, scaled by total assets. We define *High factor score* as one if a firm's common factor score derived from these three measures is above the median, and zero otherwise. We present the results in Table 10. As expected, the coefficients on the interactions are positive and significant. This result indicates that the treatment effect is significantly more pronounced for firms with more investment opportunities.

4.6 DBN, CEO Vega, and risk-taking behavior

The evidence reported so far suggests that boards increase CEO risk-taking incentives in response to the adoption of DBN. In the following, we ask: how does this relationship, in turn, affect corporate risk taking?

To examine this question, we start by exploring the impact of DBN adoption on overall corporate risk-taking. In equilibrium, the effect of DBN on corporate risk-taking is ambiguous, as CEOs tend to take less risk but are simultaneously incentivized to take on more risk. We follow Coles et al. (2006) and construct several proxies for the riskiness of a firm's investment and financial policies, including cash holdings, leverage, R&D, asset growth, and cash flow volatility. Using quarterly financial data, a firm's cash flow volatility is measured as the standard deviation of cash flow over the years $t-1$ to t.[9] Specifically, we replace the dependent variable in Equation 1 with corporate risk-taking measures and present the results in Panel A of Table 11. We find that none of the corporate risk-taking proxies show a significant change following DBN adoption. These results suggest that, on average, boards' efforts to provide CEOs with greater risk-taking incentives effectively counterbalance their risk aversion after the adoption of the DBN.

To further pin down convex compensation as the mechanism encouraging CEO risk-taking behavior, we conduct a 2SLS analysis where we use *Vega hat* (the predicted values of *Vega* based on Equation 1) as the independent variable and corporate risk-taking behaviors measured at $t+1$ as the dependent variable. Panel B of Table 11 presents the results. As shown in column (1), there is a positive and significant effect of *Vega hat* on a firm's cash holdings. This result suggests that firms increasing CEO Vega after DBN adoption tend to hold lower levels of cash. Column (2) shows that DBN-induced Vega leads firms to take on higher leverage, although this effect is not statistically significant. In columns (3) - (5), we find that the coefficient estimate of *Vega hat* is positive and significant, indicating that the increase

[9] Cash flow is the sum of income before extraordinary items and depreciation and amortization divided by total assets.

in Vega leads to higher R&D investment, asset growth, and cash flow volatility. Overall, these results suggest that the boards' strategy of increasing managerial risk-taking incentives following DBN induces CEOs to implement riskier financial and investment policies.

[Insert Table 11 here.]

4.7 Additional tests

4.7.1 Alternative explanation: financial constraints channel

Our central hypothesis posits that the observed increases in Vega result from firms' attempts to align risk-averse managers' interests with those of shareholders following DBN adoption. In this section, we explore an alternative explanation for the observed effects, where post-DBN financial condition deterioration prompts firms to replace executive cash compensation with incentive pay.

Prior literature shows that firms incur significant costs after revealing data breaches, and affected firms may struggle to obtain external funds or face higher costs of debt financing (Kamiya et al., 2021; Huang and Wang, 2021). After DBN adoption, firms need additional free cash specifically to hedge against the increasing risks and future costs of data breaches, potentially leading to deteriorated financial conditions. Additionally, greater data security awareness among stakeholders following DBN increases the need for investments in data security, further raising the demand for funding. As a result, firms tend to substitute executive cash compensation (i.e., salary and bonus) with equity compensation (i.e., restricted stocks or stock options), which can also result in higher CEO Vega. We call this view the *financial constraints channel*.

We first explore this possibility by investigating changes in the cash components of CEO compensation packages around DBN adoption. Specifically, if the financial constraints channel drives the results, executive cash compensation should decrease following DBN adoption. However, Panel A of Table 7 shows no significant change in cash compensation, including both salary in column (2) and bonus in column (3), which provides limited evidence in support of the financial constraints channel.

Second, we investigate how variations in firm financial conditions affect our baseline results. The financial constraints channel suggests that the increase in Vega following DBN adoption should be more pronounced among financially constrained firms, as these firms face greater liquidity pressure and have a stronger incentive to reduce cash components in executive compensation design. To test this conjecture, we use two widely used measures of firm financial constraints: the Kaplan-Zingales (KZ) index and the Whited-Wu (WW) index (Kaplan and Zingales, 1997; Whited and Wu, 2006). We then define the *High KZ index (High WW index)* indicator as one if the firm's KZ index (WW index) is above the sample median, and zero otherwise. The cross-sectional analysis using these two measures is reported in Table B.2. For both measures, the coefficients of the interaction terms are insignificant, indicating that our main findings are unlikely to be driven by the financial constraints channel.

4.7.2 Other robustness tests

In this section, we conduct several additional robustness tests to confirm our results are robust against various alternative explanations and definitions. Our first set of tests examines if our findings persist with alternative measures of CEO risk-taking incentives. First, following Liu et al. (2021), we use option intensity, defined as the Black-Scholes value of a CEO's stock options relative to their annual total compensation. Second, to account for the confounding effects of delta and total compensation on managerial risk-taking incentives, we scale *Vega* by *Delta* and *Total pay.* Lastly, considering that the board's adjustments to risk-taking incentives post-DBN adoption may extend beyond CEO to include all top executives, we adopt the average *Vega* of the top five executives. Table B.3 presents the results. Across all four columns, the coefficient estimate of *DBN* continues to be positive and statistically significant.

Our second set of tests is associated with various sampling strategies. Table B.4 presents the results. First, to address the concern that the increase in compensation Vega is due to changes in firm CEO, we verify that our results continue to hold after excluding firm-years with CEO turnover in column (1). Second, to control for the influence of specific market timing, we verify our results still hold after removing observations of the period of the global financial crisis from 2008-2010 in column (2). Relatedly, to ensure our findings are not solely influenced by the 2005 cohort, where nearly half of the U.S. states adopted the law, we further verify our results by excluding firms headquartered in those states that adopted the law in 2005 in column (3). Third, we address potential measurement errors by employing two sampling strategies that exclude geographically dispersed firms. [10] Specifically, we exclude firms from geographically dispersed industries (retail, transportation, and wholesale) in column (4) and exclude firms in the top quartile based on the number of Compustat geographic segments in column (5). We find the results remain consistent after removing geographically dispersed firms. Finally, to account for the influence of changing firm headquarters on CEO pay, we show our results are robust to excluding firms that change their headquarters in our sample period in column (6).

Our third set of robustness tests investigates whether our results are robust to the inclusion of additional control variables. We present the results in Table B.5. First, we incorporate several state-level control variables into our baseline model, including GDP growth, unemployment rate, total population, and the political party of the state governor. Results presented in column (1) suggest our results are robust to potential state-level confounding factors. In column (2), we add control variables related to the CEO compensation package to our baseline model, including total pay and delta, and continue to find consistent results.

Lastly, we conduct a placebo test to affirm that our findings are not purely driven by chance. In particular, we perform 5000 simulations to generate randomized treated states and enactment years of *DBN* within our sample period from 1998 to 2018. Using these pseudo-treatment and control groups, we reestiamte Equation 1 5000 times and plot the distribution of the pseudo *DBN* coefficients in Figure 2. The mean of pseudo coefficients on *DBN* from these simulation is close to zero (-0.0004), with a standard deviation of 0.0717. Importantly, the actual coefficient on *DBN* (0.132) significantly differs from the mean of these simulated pseudo coefficients, lying nearly two standard deviations on the extreme right tail of the distribution. This result indicates that the observed increase in CEO compensation Vega is unlikely to be driven by chance.

[10] For example, measurement errors in the DBN indicator based on a firm's headquarters state may arise if the firm is conducting business in states other than its home state, since the firm is only partly exposed to the law.

5 Conclusion

In this study, we examine the interaction between CEO incentive compensation and data breach costs. We predict that in response to higher data breach costs, corporate boards actively incentivize managers to overcome their risk aversion, aligning the interests of executives with those of shareholders. To empirically test this question, we exploit the staggered adoption of DBN as a source of variation in the data breach costs.

Using a difference-in-differences approach, we find consistent evidence that there is a significance increase in CEO Vega following increases in data breach costs. Furthermore, we show that the increase in CEO Vega after DBN adoption is due to active adjustments by corporate boards rather than CEO option-exercising behavior. The positive effect of DBN on managerial-risk-taking incentive becomes more pronounced for firms with risk-averse CEOs, well-diversified shareholders, and greater outside investment opportunities. Finally, we find that the DBN-induced increase in managerial incentives encourages mangers to undertake more risk-taking corporate decisions.

Overall, our findings imply that boards would consider data breach costs when designing optimal incentive contracts for managers. We provide new insights into how firms respond to data breach regulations, with a focus on CEO compensation structures.

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Figure 1: Dynamic effects and alternative estimators

Notes: This figure plots the event-study estimates using alternative estimators. We first implement the Callaway and Sant'Anna (2021) estimator using later-adopting states as effective controls. Our second estimator is to use the stacked regression approach following Baker et al. (2022). We stack cohort-specific datasets that include observations from states that adopted DBN in a certain year (treated) and all states that do not adopt DBN within the 9-year window (effective controls). We include cohort-firm and cohort-year fixed effects, and standard errors are clustered by cohort-state. For robustness, we also perform the stacked regression approach using the matched sample.

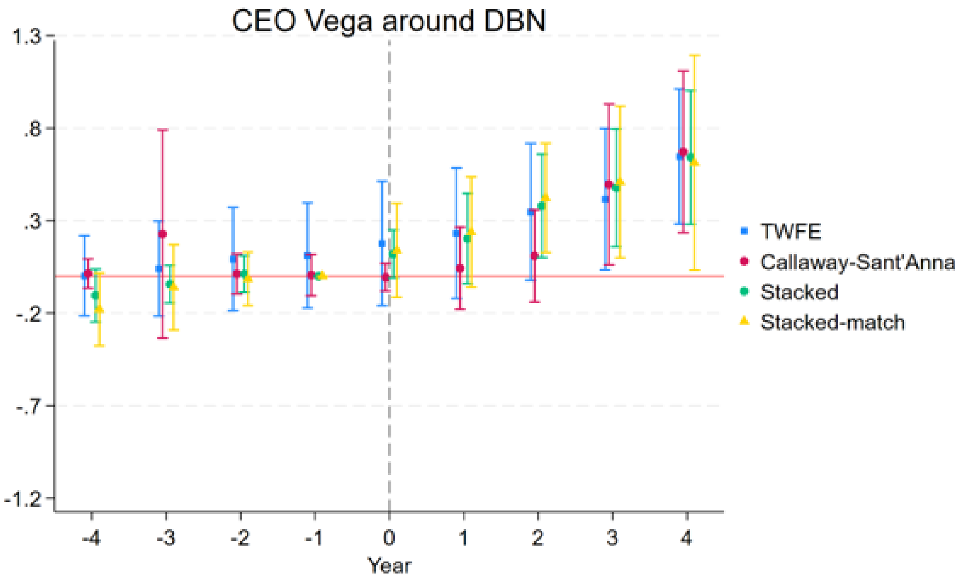

Figure 2: Placebo test

Notes: This figure plots the distribution of placebo coefficient estimates. In particular, we perform 5000 simulations to generate randomized treated states and enactment years of *DBN* within our sample period from 1998 to 2018. We then estimate the effect of pseudo-events on pseudo treated states with the full set of control variables in our baseline model and store the coefficients and standard error estimates for each placebo tests. The vertical line shows the actual coefficient from our baseline regression.

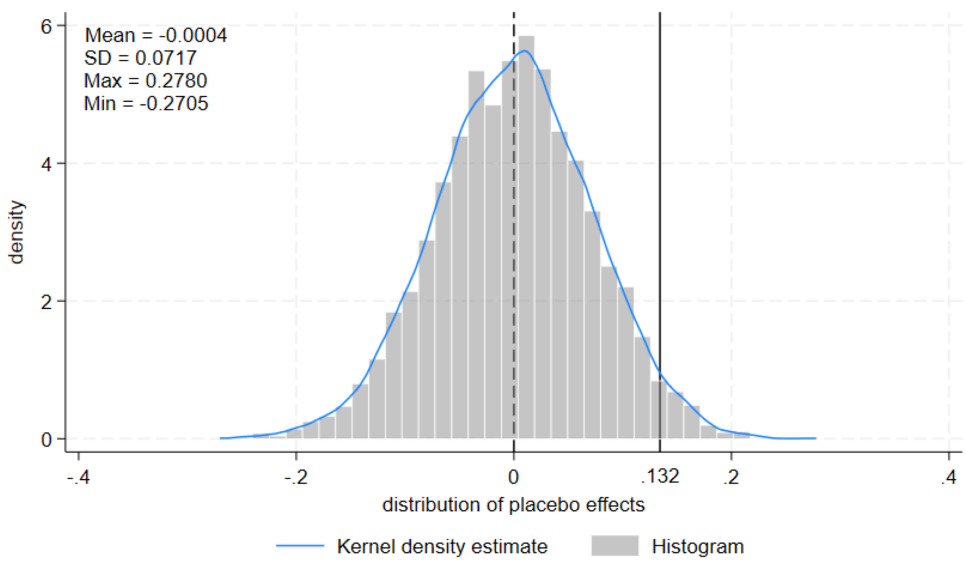

Table 1. DBN laws adoption by states

This table presents the effective year of the DBN laws in each state.

Year	State
2003	CA
2005	AR, CT, DE, FL, GA, IL, IN, LA, ME, MN, MT, NC, ND, NJ, NV, NY, OH, PA, PR, RI, TN, TX, VI, WA
2006	AZ, CO, HI, ID, KS, MI, NE, NH, UT, VT, WI
2007	DC, MA, MD, OR, WY
2008	AK, IA, OK, SC, VA, WV
2009	GU, MO
2010	MS
2014	KY
2017	NM
2018	AL, SD

Table 2. Summary Statistics

This table reports the summary statistics of the main variables in our sample. Our sample comprises all firms from 1998 to 2018 covered by Execucomp. All continuous variables are winsorized at 1% and 99% levels. Detailed variable definitions are provided in Appendix A

Variable name	N	Mean	Median	Variance	P25	P75
DBN	17067	0.673	1.000	0.697	0.000	1.000
CEO compensation						
Vega	17067	3.700	4.068	0.532	2.662	5.141
Flow Vega	17056	1.520	0.592	1.143	0.000	2.985
Delta	16877	5.492	5.467	0.264	4.531	6.469
Flow Delta	17056	3.996	4.157	0.496	2.910	5.259
Total pay	17067	8.228	8.289	0.118	7.559	8.930
Salary	17067	6.562	6.621	0.075	6.277	6.899
Bonus	17066	2.281	0.000	1.344	0.000	5.756
Restricted stock	17067	4.510	6.399	0.835	0.000	7.834
Option	17065	4.523	6.322	0.797	0.000	7.550
Number of options exercised	17058	2.014	0.000	58.655	0.000	0.864
Value of options exercised	17058	3.187	0.000	1.221	0.000	7.297
Firm characteristics						
Firm size	17067	7.544	7.441	0.206	6.437	8.513
Market-to-book	17065	2.109	1.672	0.693	1.249	2.428
Leverage	17036	0.196	0.175	0.985	0.024	0.297
ROA	17067	0.048	0.056	2.277	0.022	0.093
R&D	17067	0.037	0.008	1.749	0.000	0.050
Sales Growth	17065	0.106	0.069	14.670	-0.006	0.157
Return	17067	0.486	0.160	50.870	-0.064	0.421
Volatility	17065	0.108	0.094	0.612	0.068	0.130
Analyst Coverage	16995	10.960	9.083	0.698	5.000	15.580
Institutional Ownership	17067	0.781	0.817	0.223	0.684	0.915
CEO characteristics						
CEO Tenure	17050	7.581	5.000	0.974	2.000	10.000
CEO Age	16784	56.050	56.000	0.126	51.000	61.000

Table 3. Effect of the DBN on CEO risk-taking incentives

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. Control variables include *Size, MTB, Leverage, ROA, Sales growth, Stock return, Stock volatility, CEO tenure, CEO age, Analyst coverage, and Institutional ownership.* Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega				
	(1)	(2)	(3)	(4)	(5)
DBN	0.124**	0.130***	0.132***	0.131***	0.120**
	(2.48)	(2.71)	(2.97)	(3.22)	(2.22)
Size		0.356***	0.274***	0.262***	0.290***
		(4.24)	(3.12)	(2.95)	(4.29)
MTB		0.075***	0.052*	0.053*	0.058*
		(2.91)	(1.69)	(1.68)	(1.77)
Leverage		-0.230	-0.116	-0.112	-0.180
		(-1.05)	(-0.56)	(-0.57)	(-0.93)
ROA			0.487***	0.543***	0.490***
			(3.05)	(3.43)	(2.92)
Sales growth			-0.022	-0.039	-0.036
			(-0.37)	(-0.62)	(-0.69)
Stock return			0.010	0.008	0.007
			(0.39)	(0.33)	(0.26)
Stock volatility			-0.280	-0.247	-0.127
			(-0.67)	(-0.59)	(-0.41)
CEO tenure			0.006	0.006	0.005
			(0.78)	(0.78)	(0.72)
CEO age			-0.012**	-0.012**	-0.009*
			(-2.18)	(-2.10)	(-1.82)
Analyst coverage			0.021***	0.019***	0.020***
			(3.32)	(2.89)	(3.73)
Institutional ownership			0.209	0.166	0.180
			(0.76)	(0.59)	(0.67)
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	No
State FE	No	No	No	Yes	No
Year × Ind. FE	No	No	No	No	Yes
Observations	16,891	16,891	16,891	16,891	16,872
adjusted R-squared	0.625	0.629	0.631	0.634	0.639

Table 4. Dynamic effects

This table reports the tests that examine the dynamic effects of Data Breach Notification (DBN) on CEO risk-taking incentives. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 0.01 increase in the annualized standard deviation of a firm's stock returns. DBN_t is an indicator set to one if the firm is headquartered in a state that adopted DBN t years ago, where t ranges from -4 to 4. $DBN_{\geq 4}$ is an indicator set to one if the firm is headquartered in a state that adopt DBN 4 or more years ago, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega	
	(1)	(2)
DBN_{-4}	-0.001	0.001
	(-0.01)	(0.01)
DBN_{-3}	0.047	0.038
	(0.39)	(0.30)
DBN_{-2}	0.095	0.089
	(0.69)	(0.65)
DBN_{-1}	0.113	0.110
	(0.81)	(0.78)
DBN_0	0.167	0.173
	(0.97)	(1.05)
DBN_1	0.221	0.226
	(1.20)	(1.31)
DBN_2	0.340*	0.340*
	(1.76)	(1.89)
DBN_3	0.406*	0.408**
	(1.99)	(2.19)
$DBN_{\geq 4}$	0.621***	0.639***
	(3.11)	(3.59)
Controls	No	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	16,891	16,891
adjusted R-squared	0.626	0.632

Table 5. Cross sectional analyses - Industry heterogeneity

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives conditional on the industry cyber risk exposure. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. *High cyber risk* is an indicator equal to one if a firm belongs to the service, manufacturing, wholesale and retail trade industries, and zero otherwise. *High R&D* is an indicator equal to one if the industry level R&D expense is above the sample median, and zero otherwise. *High intangible* is an indicator equal to one if the industry level intangible assets is above the sample meidan, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega		
	High Cyber Risk (1)	High R&D (2)	High intangibility (3)
DBN	-0.219*	0.058	0.058
	(-1.74)	(1.03)	(0.94)
DBN * Cyber risk exposure	0.404***	0.160*	0.190*
	(3.01)	(1.96)	(1.90)
Cyber risk exposure		-0.111	-0.001
		(-1.20)	(-0.01)
Control	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	16,891	16,891	16,891
adjusted R-squared	0.632	0.631	0.632

Table 6. Effect of DBN on new option grant and option exercise

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO's portfolio holdings. In column (1), the dependent variable is the natural logarithm of one plus *Current Vega*, where *Current Vega* is defined as the dollar change in the value of the CEO's current option grants for a 1% increase in the annualized standard deviation of a firm's stock returns. In column (2), the dependent variable is *Number of options granted* defined as the number of options granted to the CEO in the current year. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Flow Vega	Number of options exercised	Value of options exercised
	(1)	(2)	(3)
DBN	0.144**	-0.188	-0.204
	(2.19)	(-1.51)	(-1.00)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	16,870	16,870	16,870
adjusted R-squared	0.429	0.176	0.254

Table 7. Effect of DBN on compensation structure

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on other CEO compensation components. In columns (1) - (5) of Panel A, the dependent variables are the natural logarithm transformations of one plus *Total compensation*, *salary*, *bonus*, *stock grants*, and *option grants*. In columns (1) and (2) of Panel B, the dependent variables are the natural logarithm transformations of one plus *Delta* and *Flow Delta*. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

Panel A. Compensation component

	Total pay	*Salary*	*Bonus*	*Restricted stock*	*Option*
	(1)	(2)	(3)	(4)	(5)
DBN	0.059***	0.014	0.087	-0.324	0.480***
	(2.91)	(1.09)	(1.05)	(-1.12)	(3.40)
Baseline Control	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	16,891	16,891	16,890	16,891	16,889
adjusted R-squared	0.729	0.791	0.571	0.571	0.465

Panel B. Delta

	Delta	*Flow Delta*
	(1)	(2)
DBN	0.052	0.084
	(0.95)	(0.92)
Baseline Control	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	16,707	16,880
adjusted R-squared	0.696	0.597

Table 8. Cross sectional analyses - CEO risk aversion

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives conditional on the CEO risk aversion. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. *Old CEO* is an indicator equal to one if the CEO is over 65 years old, and zero otherwise. *Low industry tournament* is an indicator equal to 1 if the pay gap between a firm's CEO and the second-highest-paid CEO in same industry is below the sample median, and zero otherwise. *High CEO tenure* is an indicator equal to 1 if the CEO's tenure is longer than the sample median, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega		
CEO risk aversion=	Old CEO	Low industry tournament incentive	Long tenure
	(1)	(2)	(3)
DBN	0.110**	0.062	0.088
	(2.39)	(1.08)	(1.50)
DBN * CEO risk aversion	0.224**	0.099*	0.195**
	(2.08)	(1.68)	(2.02)
CEO risk aversion	-0.266**	0.024	-0.095
	(-2.48)	(0.38)	(-0.96)
Control	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	16,891	14,630	15,592
adjusted R-squared	0.632	0.633	0.643

Table 9. Cross sectional analyses - shareholder diversification

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives conditional on large shareholder diversification. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. *Low Idio_vol* is an indicator equal to one if a firm's largest shareholder has a portfolio with idiosyncratic volatility (*Idio_vol*) below the sample median, and zero otherwise. *Low Inv_sync* is an indicator equal to one if a firm's largest shareholder has a portfolio with inverse return synchronicity (*Inv_sync*) below the sample median, and zero otherwise. *High hold_count* is an indicator equal to one if a firm's largest shareholder has a portfolio with a number of holdings (*Hold_count*) above the sample median, and zero otherwise. *Low HHI_conc* is an indicator equal to one if a firm's largest shareholder has a portfolio with concentration of holdings (*HHI_conc*) below the sample median, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega			
Shareholder diversification =	Low Idio_vol (1)	Low Inv_sync (2)	High Hold_count (3)	Low HHI_conc (4)
DBN	0.086*	0.108**	-0.059	0.061
	(1.76)	(2.46)	(-0.48)	(0.56)
DBN * Shareholder diversification	0.149*	0.341**	0.205*	0.078
	(1.83)	(2.64)	(1.79)	(0.85)
Shareholder diversification	-0.019	-0.030	-0.089	-0.019
	(-0.28)	(-0.28)	(-0.90)	(-0.23)
Control	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,870	16,870	16,870	16,870
adjusted R-squared	0.631	0.631	0.631	0.631

Table 10. Cross sectional analyses - outside investment opportunities

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives conditional on the firm's outside investment opportunities. The dependent variable is the natural logarithm of one plus *Vega*, where *Vega* is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. *High Tobin's Q* is an indicator equal to one if the firm's Tobin's Q is above the sample median, and zero otherwise. *High factor score* is an indicator equal to one if the firm's common factor score derived from three proxies of firm investment opportunity is above the sample median, and zero otherwise. These proxies are (i) the book-to-market ratio; (ii) R&D expenditures scaled by total assets; and (iii) a measure of investment expenditures, defined as the sum of capital expenditures and acquisitions over the most recent three years, scaled by total assets. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega	
Outside investment opportunity=	High Tobin's Q (1)	High factor score (2)
DBN	0.012	-0.045
	(0.18)	(-0.61)
DBN * Outside investment opportunity	0.234**	0.371***
	(2.52)	(3.05)
Outside investment opportunity	-0.104*	-0.246***
	(-1.93)	(-2.92)
Control	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	16,891	16,891
adjusted R-squared	0.632	0.633

Table 11. DBN, CEO Vega and risk-taking behavior

This table presents tests examining changes in overall corporate risk-taking following Data Breach Notification (DBN) adoption and the role of convex compensation in encouraging CEO risk-taking behavior. Panel A shows the results from difference-in-differences (DiD) regressions of various corporate risk-taking measures on DBN adoption. The indicator variable, *DBN*, takes the value of one if the DBN is adopted in a state, and zero otherwise. In columns (1) - (5), the dependent variables are cash holdings, leverage, R&D investment, asset growth, and cash flow volatility for the current year, respectively. Panel B presents the results from 2SLS regressions of several corporate risk-taking measures on the *Vega hat*. The independent variable, *Vega hat*, obtained from the first-stage regression, represents the predicted values of *Vega* based on Equation 1. In columns (1) - (5), the dependent variables are cash holdings, leverage, R&D investment, asset growth, and cash flow volatility for year $t+1$, respectively. All specifications include controls as in Table 3. Variable definitions are provided in the appendix. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

Panel A. Effect of DBN on risk-taking behavior

	Cash	*Leverage*	*R&D*	*Asset Growth*	*CF vol*
	(1)	(2)	(3)	(4)	(5)
DBN	0.005	0.000	-0.003	-0.016	-0.001
	(0.87)	(0.05)	(-1.54)	(-1.47)	(-0.89)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	16,815	16,783	16,815	16,815	16,584
adjusted R-squared	0.792	0.834	0.854	0.192	0.271

Panel B. Instrumented CEO Vega and risk-taking behavior

	$Cash_{t+1}$	$Leverage_{t+1}$	$R\&D_{t+1}$	$Asset\ growth_{t+1}$	$CF\ vol_{(t,t+1)}$
	(1)	(2)	(3)	(4)	(5)
Vega_hat	-0.018*	0.006	0.005**	0.067***	0.011***
	(-1.71)	(0.39)	(2.28)	(4.74)	(6.65)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	15,595	15,559	15,595	15,595	16,193
adjusted R-squared	0.796	0.833	0.907	0.230	0.437

Appendix A Variable Definitions

Variable	Definitions
DBN	Indicator variable, assigned a value of one if the fiscal year-end of the firm occurs after the state where the firm is headquartered has mandated DBN laws, and zero otherwise
Vega	The natural logarithm of one plus portfolio vega, calculated as the dollar change in the value of the CEO's portfolio of current option grants and accumulated option holdings for a 1% increase in the annualized standard deviation of a firm's stock returns
Flow Vega	The natural logarithm of one plus flow vega, calculated as the dollar change in the value of the CEO's current option grants for a 1% increase in the annualized standard deviation of a firm's stock returns
Delta	The natural logarithm of one plus portfolio delta, calculated as the dollar change in CEO's equity portfolio for a 1% increase in the firm's stock price
Flow Delta	The natural logarithm of one plus portfolio delta, calculated as the dollar change in CEO's current year equity grants for a 1% increase in the firm's stock price
Total Pay	The natural logarithm of one plus the CEO's total compensation
Salary	The natural logarithm of one plus the dollar value of salary
Bonus	The natural logarithm of one plus the dollar value of bonus

Restricted stock	The natural logarithm of one plus the dollar value of stock grants
Option	The natural logarithm of one plus the dollar value of option grants
Number of options exercised	The number of stock options exercised by the CEO in the current fiscal year scaled by shares outstanding
Value of options exercised	The dollar value of options exercised by the CEO in the current fiscal year
Firm size	The natural logarithm of one plus the book value of assets
Market-to-book	Market value of firm's assets scaled by total assets
Leverage	Total liabilities scaled by total assets
ROA	Net income scaled by total assets
Sales Growth	The annual growth rate of firm sales
Return	The annual stock return of the firm
Volatility	The standard deviation of stock returns over the past 12 months
Analyst Coverage	Average of quarterly analysts following in the current fiscal year
Institutional Ownership	Institutional ownership at the end of current fiscal year
CEO Tenure	The logarithm of one plus the number of years the CEO has been in office
CEO Age	The CEO's age
R&D	Research and development expense scaled by total assets
Cash	Cash and short-term investments scaled by total assets
Asset growth	The annual growth rate of firm total assets
CF Vol	The standard deviation of firm quarterly cash flow

Appendix B Ancillary Results

Table B.1. DBN Adoption: Validity Test

This table shows the validity of the Data Breach Notification (DBN) adoption as a shock not driven by firms' preexisting CEO risk-taking incentives. The analysis in this table is performed at the state-year level. The dependent variable is an indicator variable that takes the value of one for a state-year that adopted DBN, and zero otherwise. *State Avg Vega* is the equal-weighted averages of lagged *Vega* at the state-year level. *State GDP Growth* is defined as the real GDP growth rate of the state. *State Unemployment* is defined as the unemployment rate of the state.*Log (State population)* is the natural logarithm of state population. *Democratic Governor* is defined as a dummy variable equal to one if a state has a democrat governor and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	DBN	
	(1)	(2)
State Avg *Vega*	0.013	0.015
	(0.68)	(0.81)
State GDP growth		-0.007
		(-1.49)
State unemployment		-0.026**
		(-2.13)
Log (State Population)		0.030
		(1.11)
Democratic Governor		0.047
		(1.55)
State FE	Yes	Yes
Year FE	Yes	Yes
Observations	938	938
adjusted R-squared	0.812	0.814

Table B.2. Alternative explanation: financial constraints hypothesis

This table reports the tests that examine the impacts of Data Breach Notification (DBN) on CEO risk-taking incentives conditional on the firm's financial conditions. The dependent variable, *Vega*, is defined as the natural logarithm of one plus CEO portfolio vega, where portfolio vega is defined as the dollar change in the value of the CEO's option portfolio for a 1% increase in the annualized standard deviation of a firm's stock returns. The indicator variable *DBN* takes the value of one if the *DBN* is adopted in a state, and zero otherwise. *High KZ index* is an indicator equal to one if the firm's KZ index is above the sample median, and zero otherwise. *High WW index* is an indicator equal to one if the firm's WW index is above the sample median, and zero otherwise. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega	
Financial Constraint=	High KZ index (1)	High WW index (2)
DBN	0.223***	0.173***
	(3.03)	(3.47)
DBN * Financial Constraint	-0.176	-0.093
	(-1.29)	(-1.26)
Financial Constraint	0.080	0.203*
	(0.95)	(1.91)
Control	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	16,891	16,891
adjusted R-squared	0.632	0.632

Table B.3. Alternative measures of managerial risk-taking incentives

This table reports the tests that examine the impact of Data Breach Notification (DBN) law on four alternative measures of CEO risk-taking incentive compensation. *Option Intensity* is defined as the value of option grant scaled by total compensation. *Vega/Delta* is Vega scaled by Delta. *Vega/Total Pay* is Vega scaled by total compensation. *Top5 Vega* is the average compensation Vega of the five highest-paid executives of a firm. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Option Intensity	*Vega/Delta*	*Vega/Total pay*	*Top5 Vega*
	(1)	(2)	(3)	(4)
DBN	0.045**	0.016*	0.012**	0.119**
	(2.52)	(1.88)	(2.29)	(2.49)
Controls	Yes	Yes	Yes	Yes
Firm FE?	Yes	Yes	Yes	Yes
Year FE?	Yes	Yes	Yes	Yes
Observations	16,881	16,707	16,881	16,891
adjusted R-squared	0.466	0.564	0.598	0.692

Table B.4. Alternative sampling methods

This table reports the tests using various sampling strategies. In column (1), we exclude firm-years with CEO turnover. In column (2), we exclude the financial crisis period (2018-2010). In column (3), we exclude observations of firms headquartered in states that adopt the law in 2005. In column (4), we exclude firms in geographically dispersed industries (retail, transportation, and wholesale). In column (5), we exclude firms in the top quartile based on the number of Compustat geographic segments. In column (6), we exclude firms that change their headquarters in our sample period. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

Sample	Exclude CEO Turnover years	Exclude financial crisis period	Exclude 2005 cohort
Dependent Variable		*Vega*	
	(1)	(2)	(3)
DBN	0.136***	0.184***	0.157***
	(3.23)	(4.23)	(2.75)
Controls	Yes	Yes	Yes
Firm FE?	Yes	Yes	Yes
Year FE?	Yes	Yes	Yes
Observations	15,214	14,090	14,008
adjusted R-squared	0.646	0.629	0.633

Sample	Exclude dispersed industries	Exclude geographically dispersed firms	Exclude relocation firms
Dependent Variable		*Vega*	
	(4)	(5)	(6)
DBN	0.126***	0.094*	0.126***
	(2.83)	(1.93)	(3.30)
Controls	Yes	Yes	Yes
Firm FE?	Yes	Yes	Yes
Year FE?	Yes	Yes	Yes
Observations	13,773	12,485	15,426
adjusted R-squared	0.625	0.650	0.643

Table B.5. Additional control variables

This table reports the tests that incorporate additional sets of controls. In column (1), we add four state-level control variables. *State GDP Growth* is defined as the real GDP growth rate of the state. *State Unemployment* is defined as the unemployment rate of the state. *Log (State population)* is the natural logarithm of state population. *Democratic Governor* is defined as a dummy variable equal to one if a state has a democrat governor and zero otherwise. In column (2), we add control variables related to the CEO compensation package, including *Total pay* and *Delta*. All specifications include controls as in Table 3. Variable definitions are provided in Appendix A. Standard errors are robust and clustered at the state level. We report t-statistics in parentheses. *, ** and *** stand for statistical significance at the 10%, 5%, and 1%, respectively.

	Vega	
	(1)	(2)
DBN	0.148***	0.127***
	(3.05)	(2.97)
State GDP growth	-0.003	
	(-0.44)	
State unemployment	0.031	
	(0.89)	
Log (State population)	-0.097	
	(-1.14)	
Democratic Governor	-0.021	
	(-0.29)	
Total pay		0.000***
		(5.33)
Delta		-0.000
		(-1.08)
Controls	Yes	Yes
Firm FE?	Yes	Yes
Year FE?	Yes	Yes
Observations	16,891	16,429
adjusted R-squared	0.631	0.633