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Managerial risk-taking incentives and the systemic risk of financial institutions

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Abstract

This paper examines whether the systemic risk of financial institutions is associated with the risk-taking incentives generated by executive compensation. We measure managerial risk-taking incentives with the sensitivities of chief executive officer (CEO) and chief financial officer (CFO) compensation to changes in stock prices (pay-performance sensitivity) and stock return volatility (pay-risk sensitivity). Using data on large U.S. financial institutions over the period 2005–2010, we document a negative association between systemic risk and the sensitivities of CEO and CFO compensation to stock return volatility. However, our results also demonstrate that financial institutions with greater managerial risk-taking incentives were associated with significantly higher levels of systemic risk during the peak of the financial crisis in 2008. We further document that the relation between pay-performance sensitivity and systemic risk is essentially nonexistent. Overall, our empirical findings indicate that the association between managerial risk-taking incentives and banks' systemic risk is ambiguous and is not stable over time.

Keywords Executive compensation · Risk-taking incentives · Systemic risk · Bank risk-taking · Financial crisis

JEL Classification G01 · G20 · G21 · G30 · G32 · G34

1 Introduction

"Compensation practices at some banking organizations have led to misaligned incentives and excessive risk-taking, contributing to bank losses and financial instability."

Chairman Ben S. Bernanke (Board of Governors of the Federal Reserve System 2009a)

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This paper examines whether the systemic risk of financial institutions is associated with the compensation-based risk-taking incentives of the top executives. In the aftermath of the global financial crisis of 2008–2009, policy makers, regulators, and bank supervision authorities have alleged that the risk-taking incentives generated by executive compensation policies at banking organizations were among the key factors contributing to the development of the crisis (see e.g., Kirkpatrick 2009; Basel Committee on Banking Supervision 2010; Board of Governors of the Federal Reserve System 2009b, 2010; Mehran et al. 2011). Furthermore, the financial crisis revealed the distinct adverse consequences of excessive bank risk-taking and systemic risk on global financial stability, economic growth, and societal well-being. Given that the compensation policies of top executives are generally designed to mitigate agency problems and to maximize shareholder value, the incentives generated by executive compensation may encourage excessive risk-taking in the financial industry (e.g., Palia and Porter 2004; Chen et al. 2006; Bebchuk et al. 2010; Bebchuk and Spamann 2010; Bai and Elyasiani 2013; Gande and Kalpathy 2017).

Do compensation-based risk-taking incentives of the top executives increase the riskiness of financial institutions and the level of systemic risk? In this paper, we aim to address this question by empirically examining the linkage between systemic risk and the sensitivities of chief executive officer (CEO) and chief financial officer (CFO) compensation to changes in stock prices and stock return volatility.[1] Using data on large, publicly traded U.S. financial institutions, we find somewhat ambiguous evidence on the association between managerial risk-taking incentives and the systemic risk of financial institutions. Our results indicate that the sensitivities of top executive compensation to volatility are negatively related to systemic risk. However, our empirical findings also demonstrate that financial institutions with greater managerial risk-taking incentives were associated with significantly higher levels of systemic risk in 2008 during the peak of the global financial crisis.

Our analysis is closely related to the prior literature addressing the effects of managerial compensation structures on bank performance and risk-taking.[2] Previous studies have examined how different elements of top executive compensation and the incentives generated by managerial compensation structures are reflected in the riskiness of financial institutions (e.g., Chen et al. 2006; DeYoung et al. 2013; Guo et al. 2015; Minhat and Abdullah 2016; Gande and Kalpathy 2017; Bharati and Jia 2018). Using data on U.S. commercial banks, Chen et al. (2006) document that option-based compensation and the option-based wealth of bank CEOs induce greater risk-taking. DeYoung et al. (2013) document that the compensation structures of CEOs are important determinants of bank business policies and risk-taking. Their findings also suggest that banks with higher CEO compensation sensitivities to volatility are associated with higher levels of systematic and idiosyncratic risk and are more involved with non-traditional banking activities. Guo et al. (2015) examine the relation between CEO compensation structure and bank risk-taking, and find that a higher proportion of incentive compensation increases default risk and stock return volatility.

The studies perhaps most related to our analysis are those of Bai and Elyasiani (2013) and Bharati and Jia (2018) which examine the linkages between CEOs' compensation-based risk-taking incentives and banks' default risk, stock return volatility, systematic risk,

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[1] We focus on CEO and CFO compensation incentives because they are arguably the most powerful executives within a firm and have substantial influence on corporate decisions and outcomes.

[2] Mehran et al. (2011) and de Haan and Vlahu (2016) provide comprehensive reviews of the link between executive compensation of risk-taking in the financial industry.

and idiosyncratic risk. Bai and Elyasiani (2013) find that higher sensitivity of CEO compensation to stock return volatility induces risk-taking and leads to greater bank instability and higher levels of systematic as well as idiosyncratic risk. In contrast to Bai and Elyasiani (2013), Bharati and Jia (2018) document a negative relationship between systematic risk and the risk-sensitivity of CEO compensation, and find no association between idiosyncratic risk and managerial risk-taking incentives. We aim to contribute to the prior literature by examining the effects of managerial risk-taking incentives on the systemic risk of financial institutions.

Systemic risk can broadly be defined as a measure of interdependencies between the risk-taking of individual financial institutions and the overall riskiness of the financial system. Based on the prior literature about the effects of managerial compensation structures on bank risk-taking, we presume in this paper that managerial risk-taking incentives may influence the level of systemic risk. The risk-taking incentives generated by executive compensation are generally designed to maximize shareholder value by decreasing managerial risk aversion so that the managers would undertake risky, value-enhancing investments.

As noted by Fahlenbrach and Stulz (2011), among others, greater alignment of incentives between executives and shareholders in the financial industry may create a conflict between shareholder orientation and financial stability. Given the moral hazard problems in the financial industry caused by the too-big-to-fail phenomenon, implicit and explicit government guarantees, and deposit insurance systems, shareholder-oriented managerial compensation arrangements might encourage bank executives to adopt more risky business strategies and operations which, in turn, may lead to increased systemic risk.[3] Because financial institutions and the executives of these institutions do not have to pay directly for the negative consequences of their excessive risk-taking, compensation-based managerial risk-taking incentives may not only increase the riskiness of an individual institution but also create negative externalities on the financial system by increasing the aggregate level of systemic risk. We therefore hypothesize that managerial risk-taking incentives are positively associated with the level of systemic risk.

In our empirical analysis, we use data on 71 large U.S. financial institutions over the period 2005–2010. Following the prior literature (e.g., Chava and Purnanandam 2010; Fahlenbrach and Stulz 2011; Bai and Elyasiani 2013; DeYoung et al. 2013; Minhat and Abdullah 2016; Gande and Kalpathy 2017), we measure the risk-taking incentives of the CEOs and CFOs with the sensitivities of their personal compensation to changes in the stock price and stock return volatility of their institutions. These two compensation sensitivities are commonly known as delta and vega. Delta is a relatively direct proxy for pay-performance sensitivity and it provides a broad measure for how well top executive incentives are aligned with shareholder interests (e.g., Fahlenbrach and Stulz 2011). As noted for example by Bai and Elyasiani (2013), vega provides an explicit measure of the risk-sensitivity of executive compensation.

We measure the systemic risk of individual financial institutions with the market-based approach proposed by Acharya et al. (2012, 2017), and Brownlees and Engle (2017).[4] Specifically, we use the marginal expected shortfall (*MES*) and systemic risk (*SRISK*) to gauge

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[3] Acharya (2009, 2011) provides a detailed discussion on how moral hazard problems and the too-big-to-fail phenomenon may contribute to systemic risk.

[4] Several alternative approaches for measuring systemic risk have been proposed in the literature in the aftermath of the global financial crisis. Different approaches are discussed and compared, for instance, in Bisias et al. (2012), Hattori et al. (2014), Kleinow et al. (2017), and Grundke (2018).

systemic risk. *MES* measures the decline of a financial institution's equity capital when the market drops more than 2% and *SRISK* is the expected capital shortage of an institution during a financial crisis. Essentially, *MES* and *SRISK* aim to measure how exposed a given financial institution is to aggregate tail shocks in the financial system.

Our empirical findings indicate that the relationship between managerial risk-taking incentives and systemic risk is ambiguous. The results show that the sensitivities of top executive compensation to volatility (i.e., the CEO and CFO vegas) are generally negatively associated with systemic risk, while the relation between pay-performance sensitivity (i.e., the delta) and systemic risk is essentially nonexistent. Our regressions indicate that one standard deviation increases in CEO and CFO vegas are associated with approximately 6% reductions in *SRISK*. These findings are in stark contrast with the hypothesis that greater managerial risk-taking incentives would increase the level of systemic risk. Nevertheless, the documented negative association between vegas and banks' systemic risk is consistent with the alternative view is that compensation-based risk-taking incentives do not necessarily encourage risk-averse executives to increase firm risk-taking and may even induce executives to adopt less risky policies (e.g., Carpenter 2000; Ross 2004).

On the other hand, our empirical findings also demonstrate that the relationship between managerial risk-taking incentives and banks' systemic risk is not stable over time. We find that financial institutions with greater managerial risk-taking incentives were associated with significantly higher levels of systemic risk in 2008 during the peak of the global financial crisis. The positive association between the pre-crisis deltas and vegas of the top executives and systemic risk during the crisis is economically significant; our estimates indicate that a one standard deviation increase in deltas and vegas increases *MES* by about 25–40 basis points during the crisis. The documented positive association between CEO and CFO risk-taking incentives and systemic risk during the severe market turmoil in 2008 may indicate that financial institutions with greater compensation-based managerial risk-taking incentives were taking more risk before the crisis in order to maximize shareholder wealth, and that these risks were then materialized and exposed during the financial crisis. This interpretation of our results is broadly consistent with the previous studies which suggest that banks with more shareholder-focused corporate governance structures were taking more risk before the crisis (e.g., Fortin et al. 2010; Erkens et al. 2012; Peni and Vähämaa 2012).

The remainder of the paper proceeds as follows. Section 2 reviews the related literature on managerial risk-taking incentives, the linkages between executive compensation and bank outcomes during the global financial crisis, and firm-specific attributes of systemic risk. Section 3 describes the data and introduces the variables used in our empirical analysis. Section 4 presents the methods and reports our empirical findings on the association between managerial risk-taking incentives and the systemic risk of financial institutions. Finally, the Sect. 5 summarizes the findings and concludes the paper.

2 Related literature

Our study builds upon several strands of research. In addition to the prior literature addressing the effects of managerial compensation structures on bank performance and risk-taking discussed in the introduction (e.g., Chen et al. 2006; DeYoung et al. 2013; Guo et al. 2015; Minhat and Abdullah 2016; Gande and Kalpathy 2017; Bharati and Jia 2018), our empirical analysis is closely related to three broad streams of research. First, we draw on the prior

literature examining the linkages between executive compensation policies and firm risk-taking. Since the risk-taking incentives generated by executive compensation are designed to decrease managerial risk aversion, it is not surprising that these risk-taking incentives have been abundantly documented to have a positive impact on the riskiness of non-financial firms (see e.g., Rajgopal and Shevlin 2002; Coles et al. 2006; Chava and Purnanandam 2010; Armstrong and Vashishtha 2012; Alam et al. 2015).

Nevertheless, the less recognized alternative view is that compensation-based risk-taking incentives do not necessarily encourage risk-averse executives to increase firm risk-taking and may even induce executives to adopt less risky policies (e.g., Carpenter 2000; Meulbroek 2001; Ross 2004; Hayes et al. 2012). Although most empirical studies have linked higher managerial risk-taking incentives to higher stock return volatility and riskier corporate policies, many recent papers have documented a nonexistent or even a negative relationship between managerial risk-taking incentives and firm risk-taking, and have also documented that risk averse executives may offset compensation-based risk-taking incentives by adopting less risky financial policies (e.g., Serfling 2014; Bharati and Jia 2018; Doukas and Mandal 2018; Feng and Rao 2018; Chakraborty et al. 2018).

Despite the ample empirical literature on managerial risk-taking incentives in non-financial firms, surprisingly little attention has so far been devoted to the compensation-based risk-taking incentives in financial institutions. Banks and other financial institutions are fundamentally different from non-financial firms in terms of their business models, opaqueness, exposure to regulations and supervision, societal importance as well as amplified risk-taking incentives due to the implicit and explicit government guarantees and deposit insurance systems. Moreover, in contrast to non-financial firms, the additional regulatory oversight of financial institutions also encompasses their managerial compensation structures.[5] Thus, more research is warranted on the implications of the managerial risk-taking incentives in financial institutions.

Our study is closely related to the literature that examines linkages between executive compensation structures and bank outcomes during the global financial crisis of 2008–2009. The prior studies by Bebchuk et al. (2010), Fortin et al. (2010), Fahlenbrach and Stulz (2011), Bhagat and Bolton (2014), Minhat and Abdullah (2016), and Gande and Kalpathy (2017) provide somewhat mixed evidence about the effects of managerial compensation incentives on bank performance and riskiness amidst the crisis. Bebchuk et al. (2010) investigate the compensation structures of the top executives in Bear Stearns and Lehman Brothers, and conclude that the compensation arrangements in those banks may have provided excessive risk-taking incentives for the top executives. Fortin, Goldberg and Roth (2010) examine the determinants of bank risk-taking at the onset of the global financial crisis. Their empirical findings indicate that banks with higher CEO option-based compensation and bonuses were associated with greater risk-taking.

Fahlenbrach and Stulz (2011) investigate the influence of CEO compensation on the stock returns and profitability of U.S. banks during the financial crisis. In contrast to the view that managerial compensation incentives encouraged excessive risk-taking, Fahlenbrach and Stulz (2011) document that option-based compensation incentives and cash bonuses were unrelated to bank performance during the crisis. Using data on 14 of the largest U.S. financial institutions, Bhagat and Bolton (2014) find evidence that the incentives generated by executive compensation led to greater bank risk-taking and contributed

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[5] The 2010 Dodd–Frank Wall Street Reform and Consumer Protection Act, for instance, stipulates enhanced oversight of executive compensation structures in financial institutions.

to the outbreak of the financial crisis. Minhat and Abdullah (2016) document that managerial risk-taking incentives induced by stock options are positively associated with banks' stock return volatility and insolvency risk. However, their findings also demonstrate that the relation between risk-taking incentives and bank risk is not stable over time. Finally, Gande and Kalpathy (2017) document that CEO equity incentives before the global financial crisis are positively associated with the amount of Federal Reserve emergency loans banks obtained during the crisis.

Finally, our study complements the growing body of literature that examines how certain firm-specific attributes are related to the systemic risk of financial institutions. Studies by Brunnermeier et al. (2012), Pais and Stork (2013), Mayordomo et al. (2014), Calluzzo and Dong (2015), and Acharya and Thakor (2016), among others, have documented that the size of the institution, the amount of equity capital, and the extent of lending activities are important factors for explaining the cross-sectional variation in systemic risk. These studies indicate larger institutions with lower capital ratios and greater involvement in non-traditional banking activities are associated with higher levels of systemic risk. Closely related to our analysis, Iqbal et al. (2015) and Battaglia and Gallo (2017) examine the relationship between shareholder-focused corporate governance structures and systemic risk. Their empirical findings suggest that financial institutions with more shareholder-oriented corporate governance mechanisms and boards of directors are associated with greater systemic risk. In this paper, we aim to extend the prior literature by examining the linkage between systemic risk and the compensation-based risk-taking incentives of the top executives.

3 Data and variables

We use data on 71 large, publicly traded U.S. financial institutions spanning the period 2005–2010. The data on CEO and CFO compensation, systemic risk, and financial statement and balance sheet variables of the financial institutions are obtained from S&P Capital IQ's ExecuComp, the V-Lab of the Stern School of Business of New York University, and the Bureau van Dijk Bankscope, respectively. Our initial sample consists of the 98 financial institutions examined in Fahlenbrach and Stulz (2011) and we eliminate from this initial sample the institutions with missing or insufficient executive compensation and systemic risk data on Execucomp and/or V-Lab. This leaves us with a sample of 71 individual financial institutions and an unbalanced panel of 332 firm-year observations.[6] The sample includes commercial banks, investment banks, non-bank lending institutions, and financial services firms. The list of financial institutions included in the sample is presented in "Appendix 1".

3.1 Systemic risk

Our dependent variable is the systemic risk of individual financial institutions. Systemic risk can be broadly defined as a measure of the relation of a particular financial institution's

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risk-taking to the overall risk-taking in the financial industry. The systemic risk of an individual financial institution can be regarded as the contribution of the institution to the downside risk of the entire financial system (Anginer et al. 2014). The global financial crisis prompted considerable interest in the measurement of systemic risk and several alternative risk metrics have been proposed in the literature in recent years (for surveys, see e.g. Bisias et al. 2012 and Hattori et al. 2014). These alternative approaches to measuring systemic risk can be classified into accounting-based and market-based risk measures. The accounting-based systemic risk measures are estimated from balance sheet variables and are by construction backward-looking, while the market-based measures utilize financial market data and can thereby provide a timelier estimate of systemic risk.

In our empirical analysis, we apply the market-based approach developed by Acharya et al. (2012, 2017), and Brownlees and Engle (2017) to gauge systemic risk. Specifically, we utilize the marginal expected shortfall (*MES*) and systemic risk (*SRISK*) obtained from the NYU Stern's V-Lab to measure the systemic risk of individual financial institutions. These two systemic risk metrics are estimated from stock market data and attempt to capture the capital shortfall of an institution during periods of market stress based on its stock return volatility and correlation with the market. Essentially, *MES* and *SRISK* measure how exposed a given financial institution is to aggregate tail shocks in the stock markets. We use the year-end (December) estimates of *MES* and *SRISK* as the dependent variable in our analysis.

SRISK can be defined as the amount of "capital that a firm is expected to need if we have another financial crisis" (Acharya et al. 2012). Formally, *SRISK* for a financial institution i at time t can be expressed as:

$$SRISK_{i,t} = E_{i,t}\left(Capital\ Shortfall_i | Crisis\right) \tag{1}$$

Capital Shortfall in Eq. (1) is determined under the assumption that the book value of debt of a financial institution would remain relatively unchanged if a crisis occurred within the next 6 months whereas the value of equity would decline. The computation of *SRISK* is based on *MES* which measures the expected loss of equity capital during periods of market stress. *MES* can be broadly interpreted as the marginal contribution of an individual financial institution to the overall systemic risk, with higher *MES* reflecting a greater contribution of the institution to the aggregate level of systemic risk. If a financial institution has high levels of *MES*, most of the institution's equity capital will be depleted during a financial crisis, and hence, the institution will be in danger of failure. This also implies that undercapitalization of financial institutions contributes positively to the overall systemic risk in the financial system (Brownlees and Engle 2017).

Acharya et al. (2012) define *MES* as the expected daily percentage decrease in the value of equity of an individual financial institution when the aggregate stock market declines by more than 2%. By extrapolating *MES* to a longer and more severe period of market stress, Acharya et al. (2012) obtain the long run marginal expected shortfall (*LRMES*) which can be approximated as:

$$LRMES_{i,t} = 1 - \exp\left(-18 \times MES_{i,t}\right) \tag{2}$$

Based on *LRMES*, Acharya et al. (2012) estimate *SRISK* of financial institution i at time t as follows:

$$SRISK_{i,t} = E_{i,t}\left[k\left(Debt_{i,t} + Equity_{i,t}\right) - Equity_{i,t} | Crisis\right] \tag{3}$$

$$SRISK_{i,t} = k\left(Debt_{i,t}\right) - (1-k)\left(1 - LRMES_{i,t}\right)Equity_{i,t} \tag{4}$$

where *k* denotes the prudential capital ratio which is taken to be 8%, *LRMES* is the long run marginal expected shortfall, *Equity* is the market value of equity, and *Debt* is the market value of debt. Hence, *SRISK* is the amount of equity capital needed by a financial institution in a severe crisis in which the current equity value falls according to the *LRMES* and the level of debt stays constant.

MES and *SRISK* are estimated from historical stock price data. First, *MES*, or the expected daily decrease in equity value of a financial institution when the aggregate stock markets declines by more than 2% is calculated based on the institution's stock return volatility, correlation with the aggregate market, and extreme stock price movements. Then, these *MES* estimates are extrapolated to a financial crisis. Based on these extrapolated decreases in equity value, and under the assumption that a financial institution needs at least 8% of equity capital relative to the value of assets, *SRISK* is computed as the expected amount of equity capital that the institution would need to raise during a severe financial crisis. A more detailed description of the estimation of *MES* and *SRISK* can be found in Acharya et al. (2012, 2017), and Brownlees and Engle (2017).

3.2 CEO and CFO risk-taking incentives

The main independent variables in our empirical analysis are measures of risk-taking incentives generated by executive compensation. Following the prior literature on compensation-based incentives (see e.g., Chava and Purnanandam 2010; Fahlenbrach and Stulz 2011; Kini and Williams 2012; Shaw 2012; DeYoung et al. 2013; Minhat and Abdullah 2016; Gande and Kalpathy 2017; Hu and Jiang 2018; Yung and Chen 2018), we measure the risk-taking incentives of the CEOs and CFOs with the sensitivities of their personal compensation to changes in the stock price and stock return volatility of their institutions. More specifically, we utilize the delta and vega of the stock option holdings of individual executives as proxies for the compensation-based risk-taking incentives of the top executives.

CEO delta and *CFO delta* measure the dollar gain or loss in personal executive wealth for a 1% change in the stock price of the financial institution. Consequently, delta is a relatively direct proxy for pay-performance sensitivity and it provides a broad measure of how well managerial incentives are aligned with shareholder interests (e.g., Fahlenbrach and Stulz 2011). The delta also provides an indirect measure of managerial risk-taking incentives because in order to increase shareholder wealth and their own compensation, the top executives are incentivized to take risks that ultimately increase the overall risk exposure of the firm (Chava and Purnanandam 2010; Kini and Williams 2012). *CEO vega* and *CFO vega* measure the dollar gain or loss in personal executive wealth for a 1% point change in the stock return volatility of the financial institution. As discussed by Bai and Elyasiani (2013), vega is an explicit measure of risk-sensitivity of executive compensation, and thereby it provides a direct proxy for the compensation-based risk-taking incentives of the top executives.

We follow the approach of Core and Guay (2002) and Fahlenbrach and Stulz (2011) to calculate the deltas and vegas for the top executives in each financial institution. Specifically, we collect data on the components of CEO and CFO compensation from

ExecuComp.[7] The deltas and vegas are calculated based on the Black–Scholes option valuation model using detailed information on fiscal year-end outstanding option grants awarded to the CEOs and CFOs.[8] For each option grant, we obtain the strike prices and expiration dates from ExecuComp. We use the fiscal year-end stock price and stock return volatility over the previous 3 years as the Black–Scholes inputs for stock price and volatility, and the 10-year Treasury rate is used as a proxy for the risk-free interest rate. With these inputs, the deltas and vegas can be computed as the first partial derivatives of the Black–Scholes model with respect to stock price and volatility, respectively. By aggregating the deltas and vegas on each option grant for each executive, we are able to measure the changes in personal executive wealth associated with changes in stock price and stock return volatility.

3.3 Control variables

We employ a number of control variables in our empirical analysis to account for the potentially confounding effects of institution-specific factors on the level of systemic risk. Previous studies have documented that the riskiness of financial institutions is related to variables such as size, capital ratio, profitability, growth, and asset and income structure (see e.g., Pathan 2009; Fortin et al. 2010; Brunnermeier et al. 2012; Bai and Elyasiani 2013; Iqbal et al. 2015; Akhigbe et al. 2016; Berger et al. 2016; Ahmed et al. 2019).

Firm size is often considered the most important control variable when comparing financial institutions because different sized organizations may have very different characteristics, business strategies, governance mechanisms, and product compositions (Peni et al. 2013; Palvia et al. 2015). Moreover, larger institutions are likely to have greater systemic importance. Following the prior banking literature (e.g., Laeven and Levine 2009; DeYoung et al. 2013; Ellul and Yerramilli 2013; Akhigbe et al. 2016), we measure the size of the financial institutions (*Size*) by the natural logarithm of total assets. With respect to systemic risk, Brunnermeier et al. (2012), Pais and Stork (2013), and Iqbal et al. (2015) document that larger financial institutions are associated with higher levels of systemic risk, while Mayordomo et al. (2014) do not find any significant relation between systemic risk and bank size.

The second important variable that needs to be controlled for when comparing financial institutions is the amount of equity capital. The capital ratio is the main variable of interest for banking supervisors and regulators. The amount of equity capital is the predominant factor in reducing insolvency risk and capital ratio can be considered as a proxy for the soundness and financial health of the institution. We measure *Capital ratio* as the ratio of equity capital to total assets. Brownlees and Engle (2017) posit that the degree of undercapitalization of financial institutions reflects the level of systemic risk in the entire financial system. Moreover, Acharya and Thakor (2016), Brunnermeier et al. (2012), and

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[7] To ensure that we have the correct CEOs and especially CFOs, we manually match the names of the CEOs and CFOs from the proxy statements of the financial institutions.

[8] In 2004, the Financial Accounting Standards Board (FASB) issued FAS 123R and the Securities and Exchange Commission (SEC) adopted new disclosure requirements for executive compensation that require firms to report detailed information on the compensation of at least five highest-paid executives. Given these disclosure requirements, firms have to report outstanding equity awards at fiscal year-end by providing detailed information about outstanding option grants, including the exercise prices and expiration dates of the options.

Mayordomo et al. (2014) have documented that capital ratio is an important factor for explaining the systemic risk of individual financial institutions.

Furthermore, following the prior bank risk-taking literature, we control for the financial performance, growth, and asset and income structure of the financial institutions. We measure profitability of the institutions with *Return on assets* which is computed as the ratio of net income to total assets. Profitability can be seen as a crude proxy of management quality and more profitable institutions may be in better positions to build capital buffers and to reduce systemic risk. Previous studies have documented a negative association between profitability and systemic risk (Iqbal et al. 2015; Berger et al. 2016). We use the annual percentage change in the amount of outstanding loans as a proxy for the growth of the institutions (*Growth*). The growth rate is an important determinant of the riskiness of financial institutions (Foos et al. 2010). We utilize the ratio of net loans to total assets (*Loans to assets*) and total deposits divided by total assets (*Deposits to assets*) to control for the asset and liability structures of the financial institutions. These variables reflect the lending and funding risks of the institutions. Finally, we use the ratio of non-interest income to total income (*Non-interest income*) to control for the level of income diversification and the differences in business models across institutions. The balance sheet and income statement data for our control variables are collected from the Bureau van Dijk Bankscope.

4 Empirical analysis

4.1 Descriptive statistics and correlations

Table 1 reports the descriptive statistics for the variables used in our empirical analysis. The table illustrates that the financial institutions in our sample are very heterogeneous in terms of the compensation-based risk-taking incentives of their top executives. *CEO delta* takes values from a minimum of about USD 700 to a maximum of USD 53.1 million, while CFO delta takes varies between USD 50 and USD 38.2 million. The mean *CEO delta* of USD 1.6 million is about four times larger than the mean *CFO delta* of USD 400,000, and also the mean *CEO vega* of USD 320,000 is approximately four-fold compared to the mean *CFO vega* of USD 81,000. The mean and median values of the CEO deltas and vegas over the sample period are plotted in Fig. 1. Regarding the systemic risk measures, Table 1 shows that our sample contains financial institutions associated with very different levels of systemic risk. *MES* varies from a minimum of 0.8% to a maximum of 8.7% with a mean of 2.5%, while *SRISK* ranges from −67.7 billion to 136.5 billion with a mean value of 4.1 billion USD.

The descriptive statistics for the control variables in Table 1 demonstrate that our sample comprises very divergent types of financial institutions. Although all firms in our sample are large, publicly traded financial institutions, the amount of total assets (*Size*) varies substantially from about USD 540 million to USD 3.2 trillion. The inclusion of commercial banks as well as other types of financial institutions (investment banks, non-bank lending institutions, and financial services firms) in our sample is manifested in the considerable variation of the asset and income structure variables (*Loans to assets*, *Deposits to assets*, and *Non-interest income*). Overall, it can be concluded from the descriptive statistics that our empirical analysis is based on a heterogeneous sample of financial institutions.

Pairwise correlations between the two systemic risk measures, managerial risk-taking incentives, and the control variables are presented in Table 2. The negative correlations

Table 1 Descriptive statistics

Variable	Mean	Median	St.dev.	Min	Max	P25	P75	No. of obs
Dependent variables								
Marginal expected shortfall (%)	2.51	2.34	1.10	0.84	8.65	1.66	3.11	332
Systemic risk ($ billions)	4.10	−0.44	20.90	−67.66	136.47	−1.83	2.33	332
Managerial risk-taking incentives								
CEO delta ($ thousands)	1642.42	526.56	4735.40	0.69	53,121.09	181.33	1621.78	336
CEO vega ($ thousands)	320.14	154.90	476.14	1.59E−25	3032.25	34.79	424.24	347
CFO delta ($ thousands)	403.64	61.60	3051.02	0.05	38,202.76	22.48	166.82	285
CFO vega ($ thousands)	80.92	31.65	135.91	7.73E−14	859.53	9.07	94.35	285
Control variables								
Size	257.41	57.21	481.59	0.54	3221.97	15.94	193.32	367
Capital ratio	12.68	9.88	13.73	−3.60	90.51	7.91	12.02	367
Return on assets	1.12	0.97	3.08	−18.42	22.57	0.46	1.39	367
Loans to assets	50.70	60.26	24.63	0.00	90.74	34.83	69.50	338
Loan growth	14.64	6.99	58.46	−72.26	704.49	−1.47	17.10	310
Deposits to assets	61.77	69.43	24.27	0.05	89.95	50.07	80.20	362
Non-interest income	49.94	43.58	31.55	−76.02	175.13	30.02	74.15	367

The table reports the descriptive statistics for the sample. The sample consists of 71 publicly traded U.S. financial institutions. Systemic risk is measured with the following two variables: (1) *Marginal expected shortfall* (*MES*) is the expected daily percentage decrease in equity value of a financial institution when the aggregate stock market falls more than 2% and (2) *Systemic risk* (*SRISK*) is the expected capital short-fall (in $ billions) of a financial institution in a crisis scenario. Managerial Incentives (in $ thousands) are defined as: *Delta* is the sensitivity of manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes and *Vega* is the sensitivity of manager's portfolio to changes in equity volatility. The control variables are defined as follows: *Size* is measured as the total assets (in $ billions), *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t−1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income

between the systemic risk measures and the deltas and vegas of the top executives suggest that financial institutions with greater managerial risk-taking incentives are generally associated with lower levels of systemic risk. The correlations in Table 2 also demonstrate that *MES* and *SRISK* are strongly positively correlated with each other (0.48), and furthermore, that the risk-taking incentives of the CEOs and CFOs are strongly positively correlated.[9] Given the relatively high correlations between *CEO delta* and *CFO delta* (0.45) and especially *CEO vega* and *CFO vega* (0.83), we estimate separate regression models for CEO and CFO risk-taking incentives.

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[9] We conduct additional tests to ensure that our findings are not affected by the strong correlations between the deltas and vegas.
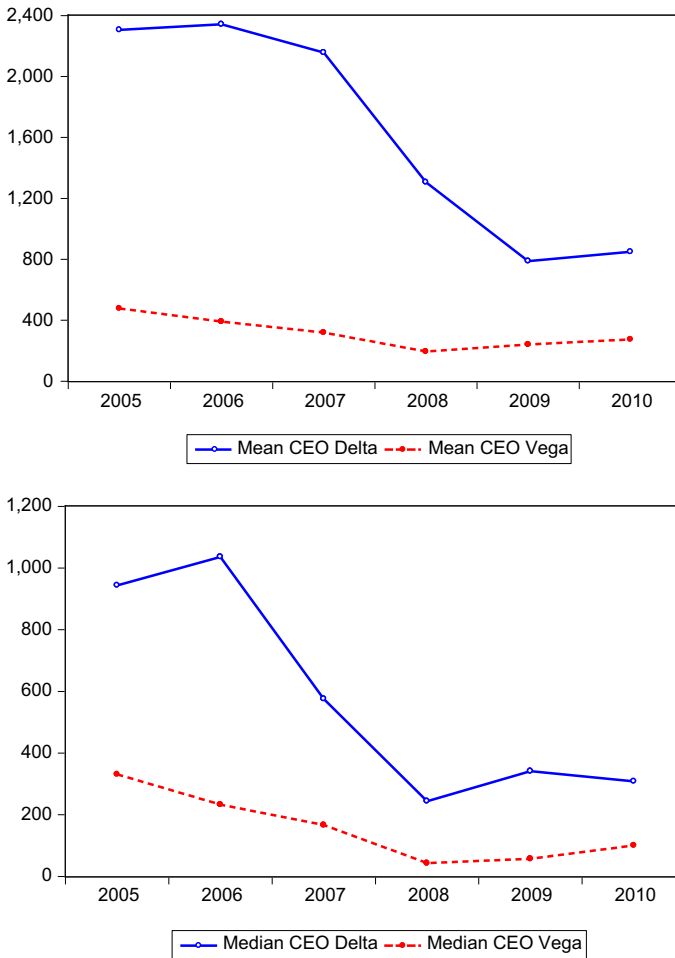
Fig. 1 CEO deltas and vegas. The figures plot the mean and median values of CEO Delta and CEO Vega

With respect to the control variables, it can be noted from Table 2 that the risk-taking incentives of the CEOs and CFOs as well as the two systemic risk measures are positively correlated with the *Size*. Hence, these correlations indicate that larger financial institutions are associated with higher levels of systemic risk and that the top executives of larger institutions have stronger personal incentives to increase firm-level risk-taking. Our systemic risk measures *MES* and *SRISK* also appear to be strongly negatively correlated with *Return on assets* and *Loans to assets*. Finally, it is worth noting from Table 2 that several of our control variables are relatively highly correlated with each other.[10] The strongest correlations observed among the control variables are those between *Capital ratio* and *Return on assets* (0.55) and *Loans to assets and Non-interest income* (− 0.65).

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[10] Given these correlations, we perform several robustness checks to ascertain that our results are not affected by multicollinearity.

Table 2 Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) CEO delta												
(2) CEO vega	0.619											
(3) CFO delta	0.454	0.567										
(4) CFO vega	0.473	0.830	0.737									
(5) Marginal expected shortfall	−0.051	−0.051	−0.036	0.015								
(6) Systemic risk	−0.167	−0.182	−0.174	−0.193	0.477							
(7) Total assets	0.300	0.533	0.345	0.527	0.285	0.307						
(8) Capital ratio	−0.030	−0.197	−0.079	−0.187	0.037	−0.160	−0.385					
(9) Return on assets	0.429	0.173	0.172	0.097	−0.147	−0.289	−0.119	0.551				
(10) Loans to assets	−0.286	−0.131	−0.340	−0.152	−0.401	−0.237	−0.250	−0.056	−0.234			
(11) Loan growth	0.089	0.006	0.108	0.006	0.062	−0.034	−0.140	0.221	0.174	−0.136		
(12) Deposits to assets	−0.156	−0.065	−0.128	−0.008	−0.146	−0.080	−0.106	−0.261	−0.364	0.422	−0.216	
(13) Non-interest income	0.299	0.220	0.283	0.230	0.266	−0.050	0.205	0.095	0.302	−0.648	0.157	−0.370

The table reports pairwise correlations for the variables used in the empirical analysis. *Marginal expected shortfall* is the expected daily percentage decrease in equity value of a financial institution when the aggregate stock market falls more than 2%, *Systemic risk* is the expected capital shortfall of a financial institution in a crisis scenario, *Delta* is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes, *Vega* is the sensitivity of manager's portfolio to changes in equity volatility, *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year *t* −1 to year *t*, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income

Table 3 Univariate tests

	High systemic risk	Low systemic risk	Difference in means	t-stat
Risk-taking incentives				
CEO delta	6.086	6.122	− 0.036	− 0.19
CEO vega	5.502	5.623	− 0.121	− 1.22
CFO delta	5.326	5.269	0.057	0.65
CFO vega	5.038	5.051	− 0.013	− 0.22
Control variables				
Size	18.155	17.499	0.657	3.17***
Capital ratio	16.078	10.129	5.950	3.71***
Return on assets	1.230	0.998	0.231	0.65
Loans to assets	40.314	59.512	− 19.198	− 6.98***
Loan growth	15.773	9.640	6.132	0.95
Depostis to assets	93.477	97.697	− 4.220	− 4.63***
Non-interest income	61.886	37.960	23.926	7.43***

The table reports the results of two-tailed t-tests under the null hypothesis that there is no difference in the means between financial institutions having higher level of systemic risk and financial institutions having lower level of systemic risk. We divide our sample into two subsamples. The first subsample contains the financial institutions with higher level of systemic risk (financial institutions having systemic risk values in 3rd quartile) and the second subsample contains institutions with lower level of systemic risk (financial institutions having systemic risk values in 1st quartile). *Marginal Expected Shortfall* is the expected daily decrease in equity value of a financial institution when the aggregate stock market falls more than 2%, *Systemic Risk* is the expected capital shortfall (measured in billion dollars) of a financial institution in a crisis scenario, *Delta* is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes and *Vega* is the sensitivity of manager's portfolio to changes in equity volatility, *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans-to-assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t-1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income

***, **, and *Significance at the 0.01, 0.05, and 0.10 levels, respectively

4.2 Univariate tests

We first examine the relationship between managerial risk-incentives and systemic risk in a univariate setting. For this purpose, we divide the financial institutions into two subsamples based on the level of systemic risk. The first subsample consists of firm-year observations with *MES* in the top quartile (high systemic risk) and the second subsample comprises firm-year observations with *MES* in the bottom quartile (low systemic risk). Table 3 reports the results of two-tailed t-tests with the null hypothesis that there are no differences in the means of the top executive deltas and vegas and the control variables between the high and low systemic risk subsamples.[11] Interestingly, the t-tests indicate that there are no statistically significant differences in the CEO and CFO risk-taking incentives between the financial institutions associated with high and low systemic risk. Thus, in contrast to our

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[11] We also perform the Wilcoxon/Mann–Whitney median tests to examine differences between the high and low systemic risk subsamples. The results are consistent with the t-tests reported in Table 3.

expectations, the univariate tests do not provide support for the view that greater managerial risk-taking incentives would contribute positively to the level of systemic risk.

Regarding the control variables, it can be noted from Table 3 that the high systemic risk institutions are very different from the low systemic risk institutions. Specifically, the univariate tests show that financial institutions associated with higher systemic risk are significantly larger and have higher capital ratios. Moreover, the statistically significant differences between the two subsamples in terms of *Loans to assets*, *Deposits to assets*, and *Non-interest income* suggest that the high systemic risk institutions are more involved in non-traditional banking activities.

4.3 Regression results

We examine the association between managerial risk-taking incentives and systemic by estimating alternative versions of the following panel regressions specification:

$$
\begin{aligned}
Risk_{i,t} = {} & \alpha + \beta_1 Delta_{i,t-1} + \beta_2 Vega_{i,t-1} + \beta_3 Size_{i,t-1} + \beta_4 Capital\ ratio_{i,t-1} \\
& + \beta_5 Return\ on\ assets_{i,t-1} + \beta_6 Loans\ to\ assets_{i,t-1} + \beta_7 Loan\ growth_{i,t-1} \\
& + \beta_8 Deposits\ to\ assets_{i,t-1} + \beta_9 Non-interest\ income_{i,t-1} \\
& + \sum_{k=1}^{n-1} \alpha_k Bank-type_i^k + \sum_{y=2006}^{2010} \omega_y Year_i^y + \varepsilon_{i,t}
\end{aligned}
\tag{5}
$$

where the dependent variable $Risk_{i,t}$ is one of the two alternative systemic risk measures for financial institution i at time t. The first risk measure is the marginal expected shortfall, *MES*, calculated as the expected daily decrease in equity value of a financial institution when the aggregate stock market falls more than 2%. The second risk measure is systemic risk, *SRISK*, defined as the expected capital shortfall of a financial institution in a crisis scenario. *Delta* and *Vega* measure the compensation-based risk-taking incentives of the CEOs and CFOs. *Delta* is the sensitivity of executive compensation to changes in stock price, while *Vega* is the sensitivity of executive compensation to changes in stock return volatility. In the regressions, we use natural logarithms of *MES*, *SRISK*, *Delta*, and *Vega*. Given the high correlations between CEO and CFO risk-taking incentives, we do not include the deltas and vegas of the CEOs and CFOs simultaneously in the regressions. In addition to the baseline specification, we also estimate modified versions of Eq. (5) in which we interact the deltas and vegas with a dummy variable for year 2008. With these additional specifications, we aim to assess the potential effects of the financial crisis on the relation between managerial risk-taking incentives and systemic risk.

The control variables in Eq. (5) are defined as follows: *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t-1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income. Following the prior literature, all the independent variables are lagged by 1 year. Our regressions include year fixed-effects (*Year*) to control for time-specific unobservable factors which may influence systemic risk and we also include bank-type fixed-effects (*Bank-type*) for different types of financial institutions based on SIC codes to control for potentially omitted variables and unobserved heterogeneity. Throughout the regressions, we use robust standard errors which are adjusted for heteroskedasticity

Table 4 Managerial risk-taking incentives and marginal expected shortfall (*MES*)

Variable	CEO incentives			CFO incentives		
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Risk-taking incentives						
Delta	−0.013	−0.028		−0.072*	−0.090***	
	(−0.59)	(−1.45)		(−1.81)	(−3.23)	
Delta×Year[2008]		0.049***			0.179***	
		(2.53)			(3.06)	
Vega	−0.012		−0.056**	−0.002		−0.108***
	(−0.40)		(−2.28)	(−0.28)		(−3.23)
Vega×Year[2008]			0.111***			0.193***
			(3.24)			(3.27)
Control variables						
Size	0.063***	0.061***	0.064***	0.077***	0.072***	0.074***
	(3.92)	(3.73)	(3.99)	(4.54)	(4.41)	(4.39)
Capital ratio	0.005	0.004	0.003	0.003	0.003	0.002
	(0.62)	(0.57)	(0.45)	(0.40)	(0.38)	(0.29)
Return on assets	−0.076***	−0.078***	−0.080***	−0.080***	−0.077***	−0.079***
	(−3.28)	(−3.45)	(−3.54)	(−3.46)	(−3.53)	(−3.27)
Loans to assets	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(−0.80)	(−0.68)	(−0.78)	(−0.93)	(−0.72)	(−0.77)
Loan growth	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000
	(−1.26)	(−1.12)	(−0.35)	(−0.49)	(−0.98)	(−0.14)
Deposits to assets	1.862	1.792	1.884	1.630	1.583	1.584
	(1.25)	(1.18)	(1.27)	(1.46)	(1.1)	(1.08)
Non-interest income	0.004***	0.004***	0.004***	0.003*	0.003*	0.003*
	(2.75)	(2.84)	(2.77)	(1.91)	(1.93)	(1.92)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Bank-type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	69.27%	69.94%	71.55%	63.81%	64.97%	64.25%

Table 4 (continued)

Variable	CEO incentives			CFO incentives		
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
F-stat.	29.88***	30.81***	34.17***	20.99***	22.02***	21.37***

The table reports the estimates of six alternative versions of the following panel regression specification: $MES_{i,t} = \alpha_0 + \beta_1 Incentives_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Capital\,ratio_{i,t-1} + \beta_4 Return\,on\,assets_{i,t-1} + \beta_5 Loans\,to\,assets_{i,t-1} + \beta_6 Loan\,growth_{i,t-1} + \beta_7 Deposits\,to\,assets_{i,t-1} + \beta_8 Non-interest\,income_{i,t-1} + \sum_{k=1}^{n-1} \alpha_k Bank-type_i^k + \sum_{y=2006}^{2010} \omega_y Year_i^y + \varepsilon_{i,t}$

where the dependent variable $MES_{i,t}$ is the marginal expected shortfall for firm i at time t calculated as the expected daily percentage decrease in equity value of a financial institution when the aggregate stock market falls more than 2%. $Incentives_{j,t}$ is either $Delta$ which is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes or $Vega$ which is the sensitivity of manager's portfolio to changes in equity volatility. The control variables are defined as follows: $Size$ is measured as the logarithm of total assets, $Return\,on\,assets$ is the ratio of net income to total assets, $Capital\,ratio$ is the ratio of equity to total assets, $Deposits\,to\,assets$ is the ratio of deposits to total assets, and $Non-interest\,income$ is the ratio of net loans to totals assets, $Loan\,growth$ is the percentage change in loans from year $t-1$ to year t, $Deposits\,to\,assets$ is the ratio of deposits to total assets, and $Non-interest\,income$ is the ratio of non-interest income to total income. $Bank-type_i^k$ is a dummy variable for type of financial institution i and $Year_i^y$ is a dummy variable for fiscal years. The t statistics (reported in parentheses) are based on robust standard errors, which are adjusted for heteroskedasticity and within-firm clustering

***, **, and *Significance at the 0.01, 0.05, and 0.10 levels, respectively

and clustered by firm to account for the potential correlation across observations of the same financial institution over time.

The regression results with marginal expected shortfall, *MES*, as the dependent variable are reported in Table 4. CEO risk-taking incentives are used as the independent variables of interest in Models 1–3 and CFO incentives in Models 4–6. For both CEO and CFO risk-taking incentives, we first estimate the regressions by including *Delta* and *Vega* in the same regression with all of the control variables (Models 1 and 4). We then estimate four alternative interaction specifications in which the CEO and CFO deltas are interacted with a dummy variable for the crisis year 2008 (Models 2 and 5) and in which the CEO and CFO vegas are interacted with the same dummy (Models 3 and 6). As can be seen from Table 4, the adjusted R^2s of our alternative regression specifications vary between 64 and 72% and the *F*-statistics are all statistically significant at the 1% level, indicating a good fit of the models.[12]

The main variables of interest in our regressions are *Delta* and *Vega* and the two interaction variables *Delta*×*Year*^{2008} and *Vega*×*Year*^{2008}. As can be noted from Table 4, the coefficient estimates for *CEO delta* and *CEO vega* in Model 1 are statistically insignificant, suggesting that *MES* is not affected by CEO risk-taking incentives. However, after the inclusion of the crisis interactions in Models 2 and 3, the coefficient estimate for *CEO vega* is negative and statistically significant and the coefficients for the both interaction variables *CEO delta*×*Year*^{2008} and *CEO vega*×*Year*^{2008} are positive and highly significant. Accordingly, our estimates indicate that financial institutions led by CEOs with greater compensation-based risk-taking incentives were associated with significantly higher *MES* in the midst of the global financial crisis in 2008.

In Models 4–6 with CFO risk-taking incentives as the variables of interest, the coefficients for *CFO delta* are negative and statistically significant, suggesting that *MES* is lower for institutions with greater CFO pay-performance sensitivity. This finding is inconsistent with the view that compensation-based managerial incentives encourage greater risk-taking. Nevertheless, similar to the CEO incentive regressions, the coefficient estimates for both interaction variables *CFO delta*×*Year*^{2008} and *CFO vega*×*Year*^{2008} are positive and statistically significant at the 1% level in Models 5 and 6. Since delta and vega are proxies of managerial risk-taking incentives, the interaction regressions in Table 4 suggest that financial institutions with greater compensation-based risk-taking incentives of the top executives at the onset of the financial crisis were associated with higher levels of systemic risk during the severe financial market turmoil in 2008.

In addition to being statistically significant, the coefficients for the interaction variables in Table 4 can also be considered economically significant. The coefficient estimate for *CEO delta*×*Year*^{2008} in Model 2 suggests that a one standard deviation increase in the pre-crisis *CEO delta* would be associated with a 30 basis point increase in *MES* in the year 2008. Similarly, the magnitudes of the statistically significant coefficients for *CEO vega* and *CEO vega*×*Year*^{2008} in Model 3 jointly imply that a one standard deviation increase in pre-crisis vega of the CEO increases *MES* by approximately 40 basis points during the financial crisis. Consistent with Models 2 and 3, the estimates for the CFO risk-taking incentives in Models 5 and 6 indicate that one standard deviation increases in *CFO delta* and *CFO vega* are associated with about 25 basis point increase in *MES* amidst the crisis. Given that the average book value of equity for the financial institutions in our sample is

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[12] The adjusted R^2 is 26% when only the control variables are used as the independent variables. After the inclusion of bank-type and year fixed-effects, the adjusted R^2 is about 58%.

Table 5 Managerial risk-taking incentives and systemic risk (*SRISK*)

Variable	CEO incentives			CFO incentives		
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Risk-taking incentives						
Delta	0.002	−0.028***		0.011	−0.067**	
	(0.16)	(−2.98)		(0.53)	(−2.25)	
Delta×Year^{2008}		0.035***			0.128***	
		(2.55)			(2.49)	
Vega	−0.072***		−0.098***	−0.124***		−0.144***
	(−2.54)		(−3.33)	(−2.66)		(−4.06)
Vega×Year^{2008}			0.107***			0.171**
			(2.51)			(2.45)
Control variables						
Size	0.060***	0.045***	0.061***	0.080***	0.067***	0.077***
	(4.67)	(3.46)	(5.02)	(4.87)	(4.16)	(4.84)
Capital ratio	−0.001	−0.002	−0.002	0.003	0.003	0.002
	(−0.15)	(−0.51)	(−0.59)	(0.52)	(0.53)	(0.46)
Return on assets	−0.020*	−0.024*	−0.020*	−0.014	−0.017	−0.012
	(−1.80)	(−1.75)	(−1.63)	(−1.17)	(−1.19)	(−0.99)
Loans to assets	−0.001*	−0.002*	−0.002*	−0.002*	−0.002*	−0.002*
	(−1.66)	(−1.63)	(−1.68)	(−1.90)	(−1.82)	(−1.91)
Loan growth	0.000	0.000	0.000*	0.000	0.000	0.000*
	(−0.87)	(0.93)	(1.80)	(1.20)	(0.72)	(1.81)
Deposits to assets	0.253	0.152	0.405	1.059	0.974	1.106
	(0.54)	(0.38)	(0.81)	(1.40)	(1.24)	(1.42)
Non-interest income	−0.001**	−0.002***	−0.001**	−0.002***	−0.002***	−0.002***
	(−2.28)	(−2.61)	(−2.19)	(−2.60)	(−2.65)	(−2.58)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Bank-type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	33.54%	30.54%	41.02%	53.49%	52.24%	56.82%
F-stat.	7.47***	6.63***	10.17***	14.03***	13.4***	15.91***

The table reports the estimates of six alternative versions of the following panel regression specification:

$$SRISK_{i,t} = \alpha_0 + \beta_1 Incentives_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Capital\ ratio_{i,t-1} + \beta_4 Return\ on\ assets_{i,t-1}$$

$$+ \beta_5 Loans\ to\ assets_{i,t-1} + \beta_6 Loan\ growth_{i,t-1} + \beta_7 Deposits\ to\ assets_{i,t-1} + \beta_8 Non-interest\ income_{i,t-1} + \sum_{k=1}^{n-1} \alpha_k$$

$$Bank-type_i^k + \sum_{y=2006}^{2010} \omega_y Year_i^y + \varepsilon_{i,t}$$

where the dependent variable $SRISK_{i,t}$ is the systemic risk for firm i at time t calculated as the is the expected capital shortfall in a crisis scenario. $Incentives_{i,t}$ is either the *Delta* which is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes or *Vega* which is the sensitivity of manager's portfolio to changes in equity volatility. The control variables are defined as follows: *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t-1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income. $Bank-type_i^k$ is a dummy variable for type of financial institution i and $Year_i^y$ is a dummy variable for fiscal years. The *t*-statistics (reported in parentheses) are based on robust standard errors which are adjusted for heteroskedasticity and within-firm clustering

***, **, and *Significance at the 0.01, 0.05, and 0.10 levels, respectively

about USD 16 billion, these 25–40 basis point increases in *MES* are economically highly significant.

With respect to the control variables, the regression results in Table 4 show that systemic risk as measured by *MES* is statistically significantly positively associated with *Size* and *Non-interest income* and negatively associated with *Return on assets*. Thus, our estimates suggest that larger financial institutions which are more involved in non-traditional banking activities and institutions with weaker financial performance are associated with higher levels of systemic risk.

Table 5 reports the regression results with systemic risk, *SRISK*, as the dependent variable. Similar to Table 4, CEO risk-taking incentives are used as the independent variables of interest in Models 1–3, while CFO incentives are used in Models 4–6. As can be noted from Table 5, the *F*-statistics for all six model specifications are statistically significant at the 1% level and the adjusted R^2s of the estimated regressions range from 31 to 57%.

Overall, the estimates of the *SRISK* regressions in Table 5 are very similar to the *MES* regressions reported in Table 4. The most notable differences between the two sets of results are the statistically significant coefficients for *CEO vega* in Model 1 and *CFO vega* in Model 4. These negative and highly significant coefficients indicate that financial institutions with greater risk-sensitivities of the top executives are generally associated with lower levels of systemic risk. The coefficient estimates indicate that a 10% increase in *CEO vega* would decrease *SRISK* by 0.7%, while a corresponding increase in *CFO vega* is associated with a 1.2% decrease in *SRISK*. Furthermore, one standard deviation increases in *CEO vega* and *CFO vega* would decrease *SRISK* by approximately 6.0%. The average *SRISK* for the institutions included in our sample is about USD 4.1 billion, and therefore, these reductions in *SRISK* can be considered economically significant. The documented negative linkage between CEO and CFO vegas and *SRISK* contrasts with the hypothesis that higher managerial risk-taking incentives would contribute positively to the level of systemic risk. Consistent with the agency theory (Jensen and Meckling 1976), this negative association between vegas and systemic risk may suggest that the top executives of financial institutions tend to be risk averse.

Similar to Table 4, the coefficient estimates for the interaction variables $Delta \times Year^{2008}$ and $Vega \times Year^{2008}$ are positive and statistically significant at the 1% level in all four interaction regressions. Thus, consistent with our *MES* regressions, the regressions in Table 5 suggest that financial institutions with greater risk-taking incentives of the top executives prior the financial crisis were associated with higher levels of systemic risk during the crisis. Nevertheless, the magnitudes of the coefficients indicate that the positive association between managerial risk-taking incentives and *SRISK* in the midst of the financial crisis is rather marginal. The estimates of Models 2 and 3 imply that a 10% increase in pre-crisis *CEO delta* and *CEO vega* would increase *SRISK* by less than 0.10% during the financial crisis. With respect to CFO incentives, the estimates of Model 5 and 6 suggest that 10% increases (one standard deviation increases) in pre-crisis *CFO delta* and *CFO vega* are associated with 0.6% (4.7%) and 0.3% (1.4%) increases in *SRISK*, respectively. With average *SRISK* of about USD 4.1 billion, these increases in *SRISK* during the crisis can be considered economically significant.

The coefficient estimates for the control variables in Table 5 indicate that systemic risk is significantly negatively related to *Return on assets*, *Loans to assets*, and *Non-interest income*, while being positively associated with *Size*. This suggests that systemically more risky financial institutions are larger and have lower profitability, lower amounts of outstanding loans, and less income diversification.

In general, the regression results reported in Tables 4 and 5 provide mixed evidence about the linkage between top executive risk-taking incentives and the systemic risk of financial institutions. Specifically, our findings indicate that the relationship between managerial risk-taking incentives and banks' systemic risk is not stable over time. On the one hand, our results indicate that the sensitivities of CEO and CFO compensation to stock return volatility are negatively associated with the systemic risk of financial institutions over our sample period 2005–2010. This finding is in stark contrast with the hypothesis that higher managerial risk-taking incentives would increase the level of systemic risk. Nevertheless, the documented negative association between vegas and banks' systemic risk is consistent with the less recognized alternative view that compensation-based risk-taking incentives may induce risk-averse executives to adopt less risky policies (e.g., Carpenter 2000; Meulbroek 2001; Ross 2004; Hayes et al. 2012). On the other hand, our regressions also demonstrate that financial institutions with greater managerial risk-taking incentives were associated with significantly higher levels of *MES* and *SRISK* in the midst of the global financial crisis in 2008. Taken as a whole, the regressions in Tables 4 and 5 together with the univariate tests in Table 3 do not generally provide support for the view that the risk-taking incentives of the top executives contribute positively to the level of systemic risk.

4.4 Additional tests

We perform several additional tests to investigate the robustness of our findings. Given that managerial risk-aversion may obviously influence the relation between CEO and CFO vegas and systemic risk, we first aim to control for the level of executive risk aversion. Following Guay (1999), Coles et al. (2006), DeYoung et al. (2013), and Croci and Petmezas (2015), we use executives' cash compensation as a proxy for managerial risk-aversion. The prior studies posit that executives with higher total cash compensation are less risk averse. Thus, we estimate regressions with the logarithm of the sum of executive salaries and cash bonuses as an additional control variable. The estimates of these regressions are reported in Table 6. Consistent with our main results, the coefficient estimates for *CEO vega* and *CFO vega* are negative and statistically highly significant in 10 out of 12 alternative specifications, and the coefficients for the interaction variables $Vega \times Year^{2008}$ are positive and statistically significant in all four interaction regressions. Thus, we conclude that our main findings are robust to the inclusion of a proxy for managerial risk-aversion. The estimated coefficients for CFO cash compensation are positive and statistically significant in the regressions with *SRISK* as the dependent variable, suggesting that institutions with higher CFO cash compensation are associated with greater risk-taking.

Second, we acknowledge that *SRISK* is dominated by the size of the institution, and moreover, that our managerial risk-taking incentive variables are strongly positively correlated with institution size. To further examine the robustness of our findings, we scale *SRISK* by total assets and re-estimate the regressions tabulated in Table 5 with *SRISK* as the dependent variable. The results of these additional regressions are reported in Table 7. As can be noted from the table, the coefficient estimates for *CEO vega* and *CFO vega* are negative and statistically significant. Nevertheless, in contrast to our main *SRISK* regressions reported in Table 5, the coefficients for the interaction variables $Delta \times Year^{2008}$ and $Vega \times Year^{2008}$ are insignificant with the only exception being the positive coefficient estimate for $CEO\ vega \times Year^{2008}$ in Model 3. Overall, the additional regressions in Table 7

Table 6 Managerial risk-taking incentives, managerial risk-aversion, and systemic risk

Variable	CEO incentives			CFO incentives		
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Panel A: Marginal expected shortfall (MES) regressions						
Delta	−0.013*			−0.072**		
	(−1.72)			(−2.10)		
Vega	−0.018	−0.039***	−0.060**	−0.009	−0.082**	−0.118**
	(−1.14)	(−2.97)	(−2.55)	(−0.14)	(−2.15)	(−2.11)
Vega×Year^{2008}			0.109***			0.201***
			(5.20)			(5.97)
Managerial risk-aversion	−0.018	−0.014	−0.013	0.039	0.039	0.044
	(−1.48)	(−1.01)	(−0.92)	(1.11)	(1.13)	(1.14)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Bank-type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	72.00%	73.06%	73.87%	67.29%	66.76%	67.76%
F-stat.	28.43***	33.05***	32.27***	19.8***	20.76***	20.23***
Panel B: Systemic risk (SRISK) regressions						
Delta	0.002			0.010		
	(0.51)			(0.58)		
Vega	−0.078***	−0.083***	−0.103***	−0.134***	−0.124***	−0.157***
	(−4.06)	(−5.48)	(−6.29)	(−11.21)	(−5.73)	(−10.29)
Vega×Year^{2008}			0.104***			0.182***
			(3.92)			(16.26)
Managerial risk-aversion	−0.019	−0.016	−0.015	0.053**	0.053**	0.058**
	(−0.91)	(−0.76)	(−0.70)	(2.38)	(2.28)	(2.32)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Bank-type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	40.10%	43.44%	46.28%	59.79%	59.74%	63.19%
F-stat.	7.4***	9.36***	9.83***	14.31***	15.33***	16.52***

The table reports the estimates of six alternative regressions. In Panel A, the dependent variable is the marginal expected shortfall ($MES_{i,t}$) for firm i at time t calculated as the expected daily percentage decrease in equity value of a financial institution when the aggregate stock market falls more than 2%. In Panel B, the dependent variable is the systemic risk ($SRISK_{i,t}$) for firm i at time t calculated as the is the expected capital shortfall in a crisis scenario. Managerial risk-taking incentives are measured with *Delta* which is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes and *Vega* which is the sensitivity of manager's portfolio to changes in equity volatility. *Managerial risk-aversion* is proxied by executives' cash compensation. The control variables are defined as follows: *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t−1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income. $Bank − type_i^k$ is a dummy variable for type of financial institution i and $Year_i^y$ is a dummy variable for fiscal years. The *t*-statistics (reported in parentheses) are based on robust standard errors which are adjusted for heteroskedasticity and within-firm clustering

***, **, and *Significance at the 0.01, 0.05, and 0.10 levels, respectively

Table 7 Managerial risk-taking incentives and systemic risk (*SRISK*) scaled by total assets

Variable	CEO incentives			CFO incentives		
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Delta	0.001	−0.002***		0.006*	−0.005	
	(0.73)	(−3.13)		(1.84)	(−1.17)	
Delta×Year^{2008}		0.001			−0.008	
		(0.09)			(−1.26)	
Vega	−0.010*		−0.009**	−0.023**		−0.016**
	(−1.95)		(−2.20)	(−2.29)		(−2.21)
Vega×Year^{2008}			0.001*			−0.003
			(1.90)			(−1.23)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Bank-type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	35.74%	29.74%	30.07%	39.78%	34.19%	39.09%
F-stat.	6.5***	4.95***	6.61***	6.74***	5.3***	6.55***

The table reports the estimates of six alternative regressions with systemic risk (*SRISK*) scaled by total assets as the dependent variable. $SRISK_{i,t}$ for firm i at time t calculated as the is the expected capital shortfall in a crisis scenario. Managerial risk-taking incentives are measured with *Delta* which is the sensitivity of a manager's portfolio to stock price and measures the dollar gain or loss in manager's wealth if the firm's stock price changes and *Vega* which is the sensitivity of manager's portfolio to changes in equity volatility. The control variables are defined as follows: *Size* is measured as the logarithm of total assets, *Capital ratio* is the ratio of equity to total assets, *Return on assets* is the ratio of net income to total assets, *Loans to assets* is the ratio of net loans to totals assets, *Loan growth* is the percentage change in loans from year $t−1$ to year t, *Deposits to assets* is the ratio of deposits to total assets, and *Non-interest income* is the ratio of non-interest income to total income. $Bank−type_i^k$ is a dummy variable for type of financial institution i and $Year_i^y$ is a dummy variable for fiscal years. The *t*-statistics (reported in parentheses) are based on robust standard errors which are adjusted for heteroskedasticity and within-firm clustering

***, **, and *Significance at the 0.01, 0.05, and 0.10 levels, respectively

provide further evidence that the sensitivities of CEO and CFO compensation to stock return volatility are negatively associated with systemic risk.

Third, in order to ensure that the high correlations between the managerial risk-taking incentive variables do not affect our results, we re-estimate Models 1 and 4 in Tables 4 and 5 using only one incentive variable at a time (results not tabulated). Similar to Model 1 in Table 4, the coefficients for *CEO delta* and *CEO vega* with *MES* as the dependent variable are statistically insignificant even when these variables are not used simultaneously in the regression. In contrast to our main analysis, the coefficient estimates for *CFO delta* and *CFO vega* are negative and statistically significant in the *MES* regressions (Model 4 in Table 4) and the coefficients for *CEO delta* and *CFO delta* are negative and significant at the 1% level in the *SRISK* regressions (Models 1 and 4 in Table 5). The coefficients for *CEO vega* and *CFO vega* in the regressions with *SRISK* as the dependent variable are negative and highly significant consistent with Models 1 and 4 in Table 5. Thus, these additional regressions strongly suggest that financial institutions with greater compensation-based managerial risk-taking incentives are generally associated with lower systemic risk.

Fourth, despite the severe multicollinearity concerns, we also experiment by estimating regressions in which we simultaneously use the deltas and vegas and their respective

interactions with the crisis year 2008 dummy variable. The estimates of these regressions (not tabulated) are very similar to the interaction regressions reported in Tables 4 and 5. Specifically, the coefficients for *CEO vega* are negative and statistically highly significant both in the *MES* and *SRISK* regressions, and the coefficient for *CFO vega* is negative and significant at the 1% level in the regression with *SRISK* as the dependent variable. Consistent with our main analysis, the coefficient estimates for *CEO vega* $\times$ *Year*^{2008} and *CFO vega* $\times$ *Year*^{2008} are positive and highly significant throughout the alternative regression specifications. The coefficient estimates for *CEO delta* and *CEO delta* $\times$ *Year*^{2008} are insignificant, while the coefficient for *CFO delta* is negative and the coefficient for *CFO delta* $\times$ *Year*^{2008} positive in the regression with *MES* as the dependent variable.

Fifth, following Fahlenbrach and Stulz (2011), we re-estimate all our regression specifications by using the sums of CEO and CFO deltas and CEO and CFO vegas as the incentive variables. Fahlenbrach and Stulz (2011) use the combined incentives of the top five highest-paid executives, whereas we only combine the deltas and vegas of the CEOs and CFOs. The estimates of these additional regressions (not tabulated) are very similar to the estimates reported in Table 4 and 5. The coefficients for the combined deltas and vegas as well as for the interaction variables have the same signs and also largely the same significance levels as in our main analysis.

Sixth, we winsorize all the variables at the 2.5th and 97.5th percentiles to examine whether our findings are affected by outliers or extreme observations. When the regressions are re-estimated with the winsorized variables (not tabulated), the coefficients for the risk-taking incentive variables remain virtually unchanged. Once again, the estimates indicate that *CEO vega* and *CFO vega* are significantly negatively associated with *SRISK*, and the positive and significant coefficients for the interaction variables demonstrate that financial institutions with greater managerial risk-taking incentives in 2007 were associated with higher *MES* and *SRISK* amidst the financial crisis in 2008. We therefore conclude that our empirical findings are not driven by outliers.

Seventh, we re-estimate the regressions by using firm fixed-effects instead of bank-type fixed-effects to control for omitted variables and unobserved heterogeneity. The estimation results with firm fixed-effects (not tabulated) are broadly consistent with our main regressions. Specifically, the coefficient estimates for the interaction variables *Delta* $\times$ *Year*^{2008} and *Vega* $\times$ *Year*^{2008} are always positive and statistically significant, and therefore suggest that the level of systemic risk during the financial crisis was higher for financial institutions with greater managerial risk-taking incentives.

Eight, we estimate parsimonious versions of the regressions with *Size*, *Capital ratio*, and *Return on assets* as the only control variables to ascertain that our findings are not driven by spurious correlations between the variables used in the regressions. Again, the coefficients for the variables of interest (not tabulated) are consistent with our main analysis. Our parsimonious regressions indicate that managerial risk-taking incentives are generally negatively associated with systemic risk, while being significantly positively associated with the level of risk during the severe financial market turmoil in 2008.

Ninth, we investigate whether our findings are affected by firm-size effects. For this purpose, we divide our sample into two subsamples based on firm-size and then re-estimate the regressions (not tabulated). We exclude either the largest 10% or the smallest 10% of the financial institutions from the sample. The regressions results based on these two subsamples are very similar to the results reported in Tables 4 and 5 and the coefficients for the deltas and vegas as well as for the crisis interaction variables have the same signs and mostly the same significance levels as in our main regressions. This suggests that our

empirical findings are not driven by the largest or the smallest institutions included in the sample.

Tenth, we examine the sensitivity of our results to the sample period used in the regressions. Specifically, we re-estimate the regressions using three different truncated subsamples (not tabulated). The first truncated subsample excludes the first sample year 2005, the second subsample excludes the crisis year 2008, and the third excludes the last sample year 2010. When either year 2005 or 2010 is excluded, the results are broadly consistent with the estimates reported in Table 4 and 5, and indicate that financial institutions with greater managerial risk-taking at the onset of the financial crisis incentives were associated with higher *MES* and *SRISK* during the crisis in 2008. When we exclude the crisis year 2008 from the sample, the coefficient estimates for *CEO vega* and *CFO vega* are negative and statistically highly significant both in the *MES* and *SRISK* regressions, and the coefficients for *CEO delta* and *CFO delta* are statistically insignificant. This provides additional evidence that the sensitivities of top executive compensation to stock return volatility are negatively associated with the systemic risk of financial institutions, at least outside crisis periods.

Eleventh, in order to further examine the effects of the financial crisis on our findings, we exclude "troubled" financial institutions from the sample and then re-estimate the regressions (not tabulated). We define "troubled" financial institutions as those institutions that either failed or reported losses in excess of 2% of total assets during the crisis. The regression results without the "troubled" institutions are very similar to the estimates reported in Tables 4 and 5. The overall association between managerial risk-taking incentives and systemic risk is negative, and the positive and statistically significant coefficients for $Delta \times Year^{2008}$ and $Vega \times Year^{2008}$ indicate that financial institutions with greater managerial risk-taking incentives were positively associated with systemic risk amidst the crisis in 2008.

Finally, given that our sample contains different types of financial institutions, we examine the robustness of our results by restricting the sample to commercial banks and other lending institutions with a net loans to total assets ratio of at least 30%. When the regressions are re-estimated with this restricted sample (not tabulated), the results are similar to our main analysis. Once again, the coefficients for the interaction variables $Delta \times Year^{2008}$ and $Vega \times Year^{2008}$ are positive and statistically significant both in the *MES* and *SRISK* regressions, and therefore suggest that the pre-crisis risk-taking incentives of the top executives are positively association with systemic risk during the crisis. Thus, we conclude that our results are robust to the exclusion of investment banks and non-bank financial services firms from the sample.

5 Conclusions

Politicians, regulators, and bank supervision authorities have emphasized the focal role of executive compensation policies at banking organizations in the development of the global financial crisis of 2008–2009. Moreover, the financial crisis highlighted the importance of systemic risk and the fact that risk-taking of individual institutions may create substantial negative externalities on the financial system. In this paper, we examine the linkage between systemic risk and compensation-based risk-taking incentives of the top executives. The risk-taking incentives generated by executive compensation programs are generally designed to maximize shareholder value by mitigating managerial risk aversion. However,

given the moral hazard problems caused by the too-big-to-fail phenomenon, implicit and explicit government guarantees, and deposit insurance systems, greater alignment of incentives between executives and shareholders may encourage excessive risk-taking in the financial industry.

In our empirical analysis, we use data on large, publicly traded U.S. financial institutions to empirically examine whether systemic risk is associated with the risk-taking incentives generated by executive compensation. We measure the risk-taking incentives of CEOs and CFOs with the sensitivities of their personal compensation to changes in the stock price and stock return volatility of their institutions. Furthermore, we use the marginal expected shortfall (*MES*) and systemic risk (*SRISK*) proposed by Acharya et al. (2012, 2017), and Brownlees and Engle (2017) to gauge the systemic risk of individual financial institutions. *MES* and *SRISK* provide a measure of the exposure of a given financial institution to aggregate tail shocks in the financial system.

We find an ambiguous relationship between managerial risk-taking incentives and systemic risk. Our empirical findings indicate that the sensitivities of top executive compensation to volatility are generally negatively associated with systemic risk, while the relation between executive pay-performance sensitivity and systemic risk is virtually nonexistent. These findings are in stark contrast with the hypothesis that greater compensation-based managerial risk-taking incentives would increase the level of systemic risk. Nevertheless, the documented negative association between vegas and banks' systemic risk is broadly consistent with the less recognized alternative view that compensation-based risk-taking incentives may induce risk-averse executives to adopt less risky policies. Our empirical findings also demonstrate that the relationship between managerial risk-taking incentives and banks' systemic risk is not stable over time. We find that financial institutions with greater managerial risk-taking incentives were associated with significantly higher levels of systemic risk in 2008 during the global financial crisis. Our estimates suggest that one standard deviation increases in the pre-crisis risk-taking incentives increase *MES* by about 25–40 basis points and *SRISK* by several percentage points during the crisis. This positive association between CEO and CFO risk-taking incentives and systemic risk during the severe market turmoil in 2008 may indicate that financial institutions with greater compensation-based risk-taking incentives were taking more risk before the crisis in order to maximize shareholder wealth, and that these risks were then materialized and exposed during the financial crisis.

Appendix 1

List of financial institutions

1	American Express	39	Metlife
2	Associated Banc-Corp.	40	Morgan Stanley
3	Bank of America	41	National City
4	Bank of Hawaii	42	New York Community Bancorp
5	Bank of New York Mellon	43	Northern Trust
6	BB&T	44	PNC Financial Services
7	BBVA Compass Bancshares	45	Principal Financial Group
8	Bear Stearns	46	Prosperity Bancshares
9	BGC Partners	47	Prudential Financial
10	BOK Financial	48	Raymond James Financial
11	Capital One Financial	49	Regions Financial
12	Capitol Federal Financial	50	SEI Investments
13	Charles Schwab	51	Signature Bank
14	Citigroup	52	Sallie Mae
15	City National	53	Sovereign Bank
16	Comerica	54	State Street
17	Commerce Bancshares	55	Stifel Financial
18	Countrywide	56	SunTrust
19	Cullen/Frost Bankers	57	SVB Financial
20	East West Bancorp	58	Synovus Financial
21	Fannie Mae	59	T. Rowe Price Group
22	Fifth Third Bancorp	60	TCF Financial
23	First Citizens BancShares	61	TD Ameritrade
24	First Horizon National	62	TransAtlantic
25	First Niagara Financial	63	UMB Financial
26	Franklin Resources	64	UnionBanCal
27	Fulton Financial	65	US Bancorp
28	Goldman Sachs	66	Valley National Bancorp
29	Hancock	67	Washington Federal
30	Hudson City Bancorp	68	Webster Financial
31	Jefferies Group	69	Wells Fargo
32	JP Morgan Chase & Co.	70	WMI Holdings
33	KeyCorp	71	Zions Bancorporation
34	Legg Mason		
35	Lehman Brothers		
36	M&T Bank		
37	Marshall & Ilsley		
38	Merrill Lynch & Co.		

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