Risk-taking Incentives and Losses in the Financial Crisis *

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Abstract

Empirical studies on incentives and risk-taking typically consider incentives to take equity risk, and they assume that risk-taking incentives due to stock holdings are negligible. We instead focus on incentives to take asset risk. We first document that risk-taking incentives from stock holdings can add substantially to those from options, and that overall incentives to take asset risk can be large relative to incentives to increase firm value. Second, we find evidence suggesting that incentives of CEOs of U.S. financial institutions to take asset risk (incentives to increase the firm value) in a range of years prior to the recent financial crisis were significantly positively (negatively) associated with write-downs during the crisis.

JEL-Classification: G01, G28, G34

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1 Introduction

Even as market participants are struggling with what appears, at the time of this writing, to be another significant disruption of the global economy, policymakers and scholars are still trying to sort out what factors were responsible for the crisis of 2007/08. Surely, many elements contributed to the worst economic crisis in three generations. However, some aspects have received particularly heightened attention. Among them is the assertion that governance systems of banks failed. In particular, compensation systems and their inherent incentives for risk-taking have received tremendous criticism and are subject to new regulatory oversight in most countries. The Board of Governors of the Federal Reserve System (2011) begins its recent review of incentive compensation practices with the simple statement: "Risk-taking incentives provided by incentive compensation arrangements in the financial services industry were a contributing factor to the financial crisis that began in 2007" (p. 1). Even some of those, whose pay is now being heavily regulated, seem to agree that compensation systems are to be blamed partially.[1]

A long-standing literature considers managerial incentives, risk-taking, and outcomes in firms in general (see, for example, Coles, Daniel, and Naveen (2006), Guay (1999), and Knopf, Nam, and Thornton (2002)) as well as in banks in particular (see, for example, Laeven and Levine (2009) and Saunders, Strock, and Travlos (1990)). Moreover, a growing academic literature deals with incentives, broadly defined, and performance specifically in the context of the financial crisis (Faulkender, Kadyrzhanova, Prabhala, and Senbet, 2010). Fahlenbrach and Stulz (2011) analyze,

[1]For example, in May 2008, PricewaterhouseCoopers and the Economist Intelligence Unit conducted a global survey of financial services industry executives and commentators. Asked which factors have created the conditions for the credit/banking crisis, only 31% of survey participants put the blame on "monetary policy," 58% on "ineffective regulatory oversight," but an impressive 70% on "reward systems" and 73% on "culture and excessive risk-taking." See PricewaterhouseCoopers (2008).

for U.S. banks, the relation between CEO equity incentives in 2006 and bank performance in 2007/08. In global samples covering some of the largest financial institutions, Erkens, Hung, and Matos (2009) consider the relation between corporate governance and various measures of risk-taking and performance, and Beltratti and Stulz (2009) investigate governance and stock returns. Cheng, Hong, and Scheinkman (2010), DeYoung, Peng, and Yan (2009), and Ellul and Yerramilli (2009) study the association between certain governance features and specific measures of risk-taking, such as risky mortgage-backed securities involvement.

The present paper makes four contributions to the literature on risk-taking in general and the literature on incentives in financial institutions in the context of the financial crisis in particular.

First, we consider a different measure of CEO risk-taking incentives than the prior empirical literature on incentives and risk-taking. Virtually all of the existing literature measures risk-taking incentives of the CEO by *Equity Volatility Vega*[2], that is, the incentives of the CEO to increase *stock return volatility*, thereby mixing asset risk and financial risk (leverage). Moreover, relying on results from Guay (1999) for an average of firms over a broad range of industries, the existing literature argues that the incentives embedded in stock holdings to increase equity volatility are very negligible. Thus, the literature effectively assumes that risk-taking incentives are due *only* to stock options.

We instead employ measures of incentives which are directly linked to the underlying firm asset value and the asset return volatility. Considering measures of the CEO to influence the asset value and its volatility allows for a more direct and intuitive understanding of the incentives to engage in asset risk-taking as opposed to equity based incentive measures. To be consistent, we treat stocks as options and stock options as compound options on the underlying firm asset value, a novelty

[2]Specifying this term helps distinguish this incentive measure from the one the further analysis focuses on.

in the incentives literature.

Following this approach, we calculate *Asset Volatility Vega*, defined as the sensitivity of the CEO's wealth to the company's asset return volatility and *Asset Delta*, defined as the sensitivity of the CEO's wealth to the company's asset value. In our sample, the average CEO has an Asset Volatility Vega of around US$3.5 million and an Asset Delta of around US$6 million dollars. Although the Asset Volatility Vega and the Equity Volatility Vega are related, we document (in addition to the obvious methodological differences) that there are substantial quantitative differences between these measures of risk-taking incentives. For instance, for the main parameter choice in our sample of financial institutions, the ratio of Asset Volatility Vega to Asset Delta[3] is, at the mean, around 50% larger than the ratio of Equity Volatility Vega to Equity Delta[4]; for other reasonable parameter values, the difference can be much larger. These results suggest that asset-based measures indicate relatively stronger risk-taking incentives than equity-based measures. Also, the correlation between the (logarithm of) Asset Volatility Vega and the (logarithm of) standard Equity Volatility Vega (calculated as in Core and Guay (2002) and assuming that Vega due to stock holdings is zero) is on average only about 0.60 in our sample of financial institutions. For a significant number of firms in the sample, incentives to take asset risk emanating from stock-holdings are non-negligible, thus challenging the common belief that options, not stocks, are the dominating driver of risk-taking behavior by CEOs.

Second, while several studies focus on bank performance during the crisis, we are instead interested in studying the degree of ex-ante risk-taking by financial institutions. We use *write-*

[3]Asset Delta is the dollar change in the CEO's wealth with respect to a one percent change in the firm value.

[4]Equity Delta is the dollar change in the CEO's wealth with respect to a one percent change in the stock price. By virtue of working with equity as the underlying variable, the literature operates with an *Equity Delta* (incentives to increase the stock price) equal to one.

downs in 2007/08 (more specifically: the logarithm of write-downs as well as write-downs scaled by total assets) as the dependent variable. The motivation for using this dependent variable is that the financial crisis essentially exposed the downside of the investments that banks undertook in prior years eventually leading to large asset write-downs on their balance sheets. As such, the write-downs form a natural indication of the degree of asset risk-taking by financial institutions in years prior to the crisis financial crisis. (Other studies (Coles, Daniel, and Naveen, 2006; Guay, 1999; Hayes, Lemmon, and Qiu, 2011; Sanders and Hambrick, 2007) also use ex-post outcomes to proxy for ex-ante risk-taking.) The write-downs variable covers write-downs specifically due to the crisis, loan loss provisions and credit losses, subprime losses, and impairment charges (such as losses on trading securities). By hand-collecting these data from 10-K and 10-Q company filings, we construct the largest data set on write-downs of U.S. financial institutions to date, covering not only the largest institutions, but also smaller, though still important institutions. In the data section, we discuss issues such as the discretion companies have in setting the level of write-downs, as well as the benefits and challenges of using alternative measures such as returns on assets and stock returns.

A third distinctive feature of our analysis is that, while existing work on the association between bank performance and incentives focuses exclusively on incentives in 2006, we take into account that many of the deals that resulted in write-downs during the crisis were taken on in earlier years. Therefore, we consider (separately) incentives in 2003-2006. A side advantage of this approach is that a potential reverse causality concern (occurring when stock and options were granted as a reward for risk-taking) is likely to be less severe for heavily lagged explanatory variables.

Our fourth contribution is that we uncover a relationship between incentive systems and write-downs. By and large, Asset Volatility Vega and write-downs (both in absolute terms and scaled by total assets) were generally significantly positively associated, while Asset Delta and write-downs were generally significantly negatively associated. In other words, incentives explained variation in risk-taking. Interestingly, Equity Volatility Vega and Equity Delta were not associated with write-downs, confirming the intuition that it is important to use asset-based risk-taking incentives to explain asset risk-taking. These results complement those of Fahlenbrach and Stulz (2011) who find that equity-based incentives were not significantly associated with stock returns. (We confirm their findings in our sample, but in the robustness analysis, we also find that the asset-based incentive measures are significantly associated with stock returns, too.) Moreover, we find some evidence indicating that the relationship between incentives and write-downs was particularly strong in highly leveraged institutions. (We discuss in detail in the empirical strategy section in which ways our analysis may be subject to endogeneity concerns, and the extent to which these concerns are ameliorated by the way we set up our analysis.)

The finding that the CEO's option and stock holdings imply incentives both to take risk and to avoid risk and that Vega and Delta are, therefore, associated with write-downs with opposite signs is fully consistent with earlier work, outside of the literature on the financial crisis. For example, the sensitivity to stock return volatility and the sensitivity to stock price have countervailing effects on firms' hedging activities (Knopf, Nam, and Thornton, 2002). However, we are not aware of any papers dealing with incentives and the financial crisis (or in general) that explicitly consider the incentives to take asset risk and their relation to asset risk-taking.

The paper proceeds as follows. Section 2 presents the data. Section 3 shows the results. Section 4 offers concluding remarks.

2 Data

The following subsections detail the time horizon (section 2.1), the sample of companies (section 2.2), the dependent variable (section 2.3), and the explanatory variables (section 2.4).

2.1 Time Horizon

We define, in line with existing studies, the financial crisis period to be 2007Q3-2008Q4, and we construct our dependent variable for this time period. As for when to measure incentives, existing work (Erkens, Hung, and Matos, 2009; Fahlenbrach and Stulz, 2011) focuses on CEO incentives in the year immediately before the crisis, namely 2006. In addition, we also consider information from prior years, spanning also the time-segment 2003 to 2005. (Using data from 2002 reduces the number of observations, but yields event stronger findings than in the later years.) This approach is motivated by three considerations.

First, the vast majority of deals related to the subprime and mortgage backed security market originated in the early part of the decade, not in 2006. relevant perhaps similarly been requirements which illustrated in Figure 1. While subprime mortgages have been used for a long time, the "take-off" of the market occurred around 2002/3. (See, for example, Hässig (2009) for the case of UBS.) Second, considering both explicit compensation systems and features of board governance over a range of years prior to the actual crisis helps to see which associations in the relation between risk-taking incentives and write-downs are particularly robust. Third, lagging incentives and governance variables helps to mitigate (though certainly not eliminate) endogeneity problems. It is possible that incentive packages of the year 2006 include options given as a reward for undertaking, in earlier years, some of the risky deals that later led to write-downs. This endogeneity concern is much less likely to hold for incentives given in 2003 because before these years the subprime market was far less developed.

FIGURE 1 ABOUT HERE

2.2 Company Selection

Table 1 displays the industry classification we consider in the analysis. We require a company to have compensation data available in the ExecuComp database.[5] Our sample includes depository institutions, non-depository credit institutions, and investment banks and some brokerage firms.[6] We refer to all companies in our sample as *financial institutions*. We also require that the company is alive at the beginning of the third quarter of 2007. Companies which did not have a stock price observation in CRSP for July 2007 are deemed inactive and excluded from our analysis. However, companies remaining on this list are allowed to subsequently default, be taken over by or merged with another company during the crisis period.

We identify sub-industries with dummies in our regressions.

TABLE 1 ABOUT HERE

[5] Some companies were too small to remain in the ExecuComp database for all years 2003 to 2006 but were still alive going into July 2007. Their compensation information is included into the analysis for the year(s) when they are covered in the ExecuComp database.

[6] SIC code 6211 includes some well-known investment banks and some brokers. For our main analysis, we keep these brokerage firms in the sample but exclude those brokers listed in the same SIC code as exchanges, SIC code 6200. While engagement in the subprime mortgage business may not have been at the core of the business strategy of those brokers in the SIC 6211 code, these companies nonetheless often did engage in activities that resulted in write-downs. An understanding of how incentives and governance features where associated with the degree of risk-taking in financial institutions prior to the crisis cannot neglect firms that "should not" have engaged in businesses that ultimately resulted in write-downs. In any case, our results generally speaking hold also if we exclude all SIC 6211 firms, but this then also excludes firms such as Bear Stearns, Goldman Sachs, Merrill Lynch, and Morgan Stanley, clearly an undesirable sample restriction. We exclude investment advisors (SIC code 6282). For other finance SIC codes that are not shown, we do not have companies with compensation data.

2.3 Dependent Variable

An overview of all dependent and explanatory variables is contained in Table 2.

TABLE 2 ABOUT HERE

2.3.1 Write-downs

Like other studies (Coles, Daniel, and Naveen, 2006; Guay, 1999; Hayes, Lemmon, and Qiu, 2011; Sanders and Hambrick, 2007), our empirical tests rely upon ex-post evidence of risk-taking. The idea we appeal to is that for a given expected project value, a CEO with higher incentives to take risk will be willing to tolerate a greater spread in potential outcomes. Because the financial crisis exposed the downside of the investments that banks undertook in prior years, the *write-downs* form an indication of the degree of risk-taking.[7] Because we aim to capture as broadly as possible the potential downsides, we focus on write-downs during the period 2007Q3-2008Q4.

We collect write-downs data for all U.S. financial institutions for which they are available and for which we have compensation data from ExecuComp. For the largest U.S. financial institutions these write-downs are available from Bloomberg, covering write-downs, losses, and loan-loss provisions. For the smaller U.S. financial institutions for which Bloomberg does not record write-downs we consult the companies' proxy filings (10-K and 10-Q). In particular, we identify the following components from the SEC filings in order to be as consistent as possible with the figures reported

[7] Write-downs, of course, also cover simply bad business choices, even those that were not considered risky ex-ante. For example, the practice of making "Ninja" (no income, no job, no asset) loans on the sheer hope that real estate prices would continue climbing was arguably ex-ante questionable. But not all risks that were taken can be labeled as ex-ante bad. Related to this question, there is some discussion as to just how much CEOs suffered from the crisis. On the one hand, Bebchuk, Cohen, and Spamann (2010) show that management teams in the case of Bear Stearns and Lehman Brothers were able to cash out large amounts of bonus compensation before the crisis. On the other hand, some evidence suggests that in general CEOs did not take actions they thought would be on average value-destroying and that they did not, on average, anticipate the crisis. For example, they did not sell their own shares prior to the crisis, see Fahlenbrach and Stulz (2011).

by Bloomberg:

Write-downs which are explicitly referred to as such. They cover charge-offs on loans (conditional on the fact that these are not included in the loan loss provisions). Furthermore, as a consequence of the financial crisis, some companies had to abandon certain development projects which led to rising severance charges. These are typically reported as specific write-downs related to the crisis.

Loan loss provisions are charges or expenses against income and loans which are deemed to be uncollectible due to the impact of the credit deterioration during the crisis period.

Subprime losses appear when companies directly state that certain losses have occured specifically due to, e.g., investments in the subprime mortgage backed security market or due to the bankruptcies of Fannie Mae and Freddie Mac.

Impairment charges (or impairment on securities) are non-temporary impairments on held to maturity and available for sale securities. This is sometimes referred to as losses on trading securities or impairment on real estate investments.

Credit losses which are directly referred to as such but are not included in the loan loss provisions.

2.3.2 Advantages and Disadvantages of Write-downs and Alternative Measures

Write-downs form a natural proxy for the ex-ante risk-taking of financial institutions precisely because they are not only realized losses, but also unrealized losses. Even if assets that are held to maturity in the end do not lead to an actual loss, the fact that banks had to take write-downs on them indicates their ex-ante riskiness. Nonetheless, write-downs bring with them some limitations which need to be borne in mind. First, write-downs are accounting data. They are not always completely clearly and unambiguously described in company reports. Naturally, one can debate in each and every case which parts of the announced overall write-downs should be included in the analysis, and it can be difficult to precisely disentangle some of the above categories from each other. For instance, credit losses, subprime losses and write-downs are ultimately closely connected. In our analysis we have chosen to use the sum of all losses associated to the crisis, but future research could presumably be profitably conducted on specific subsets of these data.[8]

Second, and related, firms have discretion of when to announce which write-downs. Also, in October 2008, the SEC allowed banks to switch from mark-to-market accounting to hold-to-maturity accounting. We cover a relatively wide data period, but it is still possible that some write-downs that were announced were not "fair value" losses, or that some losses have not yet been recorded as write-downs. For example, write-downs may be overestimated because some firms may have been pushed by government authorities to "come clean." Conversely, write-downs may be underestimated due to the fact that some financial institutions were bailed out just for the bailout funds to flow through indirectly to other banks which could otherwise have ended up in deep trouble.[9] If management perceives its institution to be too close to a capital adequacy boundary, write-downs may be kept low. Some studies report that banks use accounting discretion to understate the impairment of their real estate related assets (Huizinga and Laeven, 2009). Others find that poorly-performing banks overstate unrealized losses ("take a bath") in order to

[8]For a discussion of the challenges and opportunities of accounting in the financial crisis, see Ryan (2008).

[9]The government bailout of the insurance company AIG resulted in funds being channeled through to major U.S. financial institutions including Goldman Sachs and Merrill Lynch and a series of European banks which we do not consider in this analysis. See AIG's press release of March 15, 2009, available at: http://www.aig.com/aigweb/internet/en/files/Counterparties150309RELonly_tcm385-155648.pdf.

show higher earnings the following year (Fiechter and Meyer, 2009). Yvas (2011) documents that higher corporate governance quality was associated with timelier write-downs in the time period 2007/08. His study takes it as given that the cumulated actual write-downs and those implied by benchmarking devaluations to credit indices are identical per the end of 2008. Certainly, investors demonstrated a particularly keen interest in write-downs during the financial crisis, which, together with accounting standards (in particular, FAS 157 - Fair Value Measurement which became effective for annual periods beginning on or after November 15, 2007) requiring detailed disclosure, is likely to have reduced opportunities for manipulation. In the light of these considerations, it seems likely that some measurement error is present in write-downs, but it is less obvious in which direction a bias, if any, would go.

The fact that financial institutions have some discretion over where in their statements to show write-downs has another implication: It is possible that despite diligent reading of the proxy statements available, we missed some write-downs in our data collection. If all institutions report truthfully the losses must ultimately show up in net income. Therefore, an alternative dependent variable would be to use net income scaled by total assets. (For example, Fahlenbrach and Stulz (2011) use returns on assets and on equity.) The drawback of using this dependent variable is that it is a more noisy measure of ex-ante risk-taking, as it also comprises a lot of other activities of the financial institutions, including gains and losses from other business lines unrelated to the crisis. Indeed, the correlation between the reported log write-downs and returns on assets during the crisis is around (minus) 0.4, suggesting that write-downs capture more specifically the elements of financial institutions' risk-taking that we are interested in. (Nonetheless, the overall results with net income over assets as the dependent variable are similar to those for write-downs.)

Finally, market-based dependent variables have also been used. Investigating, for example, stock returns, as several of the cited studies have, is certainly an essential element of the overall picture. A potential drawback of this measure is that the informational efficiency of stock prices is arguably low precisely in the time of the crisis, being contaminated by actual or hinted-at government interventions, short-selling restrictions that apply to some companies, and so on. Also, during the financial crisis, stock prices in the entire financial services industry were negatively impacted by the general uncertainty surrounding the banking sector. We expect write-downs to more clearly reflect idiosyncratic risk-taking and performance as they are less affected by the general market sentiment. (That said, we obtain similar overall results with stock returns as the dependent variable.)

Distance to default would be another potentially interesting market-based measure. While these data surely offer some important insights, especially in the present context it seems that market-based measures underestimated the risks that banks undertook.

We use both the logarithm of write-downs to study the absolute (dollar level) of risk-taking (controlling, of course, for firm size in various ways) and write-downs scaled by total assets to investigate the relative level of risk-taking.

2.4 Explanatory Variables

2.4.1 Incentives

We compute two sets of measures.

Equity Volatility Vega and Equity Delta. The standard approach in the literature is to measure managerial incentives by the sensitivities of CEO wealth to the stock price level and stock return volatility, respectively. We follow Core and Guay (2002) in calculating these quantities;

see Appendix A for details. *Equity Delta* is the sensitivity of a CEO's wealth with respect to a one percent change in the company's underlying stock price. *Equity Volatility Vega* is the change in the dollar value of CEO wealth in response to a one percentage point change in stock return volatility based on the Black-Scholes option pricing formula. Following Core and Guay (2002) and most of the existing literature, we assume that the Equity Volatility Vega from shares of stock equals zero.

Asset Volatility Vega and Asset Delta. Our dependent variable captures asset risk-taking. Therefore, we wish to use a more direct measure of asset risk-taking incentives of CEOs than is offered by Equity Volatility Vega and Equity Delta. To measure incentives to take asset risks, we appeal to the idea, dating back to Merton (1974), that equity and debt can be viewed as contingent claims on the firm value. This idea also applies to banks. Liabilities of banks come in the form of both deposit liabilities and non-deposit liabilities where deposits essentially can be seen as debt with very high priority for this purpose.

Using this framework, we calculate, as our primary measures of incentives, *Asset Volatility Vega* – capturing the incentives to increase the standard deviation of firm value – and *Asset Delta* – capturing the incentives to increase the firm value. Guay (1999) also relies on the contingent claims idea to calculate, for a sample of firms including both financial and non-financial companies, the Equity Volatility Vega of stock. However, Guay (1999) then goes on to calculate Equity Volatility Vega from stock options in the usual way, relying on the Black-Scholes formula, treating equity as the primitive, and then adds to this the Equity Volatility Vega from stocks obtained by relevering his Asset Volatility Vega of stocks. We instead treat equity options as compound options (Geske, 1979). Using this approach, we express the risk-taking incentives directly in terms of incentives to take asset risk, and we treat stock holdings and stock options in a coherent way.

Appendix B provides a detailed exposition of these calculations. In particular, it explains how we calculate the sensitivity of a compound option with respect to the volatility of the underlying asset value, i.e., Asset Volatility Vega of options. Contrary to the result presented in Geske (1979), our formula for the derivative of the compound option value with respect to the asset return volatility converges to the Black-Scholes Vega as the debt converges to zero. Indeed, this appears to be the intuitive benchmark result. We demonstrate that using our formula not only obtains the expected result in the limit, but also that for typical parameter values there is a substantial difference in the magnitude of the calculated risk-taking incentives. This is shown in Figure B-2 in Appendix B. For instance, at the mean asset return volatility 5.7% and other average parameters (see Table B-1) we observe an Asset Volatility Vega in Figure B-2 of around 1.75 based on the formula we derive, whereas the equivalent Asset Volatility Vega based on the formula in Geske (1979) is only around 0.10. Once we multiply with the number of options held by the CEOs, this translates into very large differences in the potential measures of risk-taking incentives we use in the analysis. Figure B-2 also shows that Asset Volatility Vega is monotonically increasing in the underlying asset volatility, suggesting that for non-financial firms, which typically have higher asset volatilities, this way of looking at risk-taking incentives can also provide new insights.

Inputs. Information about executive compensation pay packages is available annually for U.S. entities in Standard & Poor's ExecuComp database. We collect information on executive compensation for the years 2003 to 2006. We focus our analysis on the CEO.[10] Consistent with existing

[10] Fahlenbrach and Stulz (2011) find that the relation between executive equity incentives and the performance of the banks in their sample is driven by the equity incentives of the CEO. For years with missing CEO information and where the dates at which the CEO assumed office is prior to the particular year, we classify the executive as the CEO accordingly. If the CEO is not recorded and the necessary information is not accessible from the SEC Edgar database, we do not include the respective firm in the analysis.

literature, we define the inputs for all these calculations as follows: (1) The stock options exercise prices and (2) maturities are taken from ExecuComp to the extent these are available. If the exercise price for granted stock options is not available, we assume they were granted at-the-money. To obtain the stock option maturity for missing grant dates, we follow Guay (1999) and calculate the maturity of the stock options by assuming that the stock options were granted on July 1 of the year in which the stock options were granted. (3) We use the fiscal year end closing price of the given year as the current stock price. (4) The stock return volatility is calculated (from CRSP data) as the annualized standard deviation of daily log-returns over the past three years by assuming 250 trading days in the year. (5) We use the U.S. Treasury yields obtained from the Fed's webpage as proxies for the risk-free interest rate. (6) The annual cash dividend paid by the company over the fiscal year end closing price is used to calculate the dividend yield. This information is also from CRSP.

For the asset-based measures, we follow Guay (1999) in the calculations of the implied firm value and other parameters needed for the calculation of incentives. In particular, (7) the firm value (return) volatility is determined through a portfolio relationship with stock volatility and debt volatility, thus allowing us to back out the asset volatility from the data. For the standard deviation of debt returns, we use the annualized standard deviation calculated on monthly (log) returns using the Merrill Lynch Bank of America corporate financial bond index using a five year period.[11] As in Guay (1999), (8) the strike price for equity, seen as an option on firm value, is the book value of debt per share. (9) Guay (1999) assumes for financial firms that they have a single

[11]We believe that this index fits our purposes better than the general Merrill Lynch Bank of America corporate bond index that matches the S&P senior debt rating which Guay (1999) uses. With the index used in Guay (1999), we obtain stronger results both in terms of the importance of risk-taking incentives and the statistical significance in our write-down regressions. Finally, the approach used in Gropp and Heider (2010), just delevering stock return volatility, yields very similar overall results, too.

debt obligation with time to maturity equal to 7.5 years (as for most financial firms maturity data is unavailable). We use the same baseline assumption. Core deposits (in addition to long-term debt as funding channels in financial institutions) have no explicit maturity and are often referred to as non-maturity debt. As pointed out by Sheehan (2004) such deposits often remain within the financial institution for significant periods of time, often longer than 10 years. Thus, 7.5 years seems like a reasonable approximation. Note that the debt maturity needs to be longer than the stock option maturity in order for the compound option approach to apply. In cases where the stock option maturity is longer than 7.5 years, we set the maturity of debt equal to the stock option maturity plus two years. That is, for a stock option with a 10 year maturity, we effectively assume that the debt maturity is 12 years. However, the results do not appear to be sensitive to the particular assumption concerning debt maturity. Together with the observation that the stock can be considered as a call option on the firm value, one can finally back out (10) an implied firm value per share.

Delta and Vega for previously granted options (i.e., exercisable and un-exercisable options) and current year granted options are then multiplied by the amount of options held by the CEO in each of these dimensions to form the final Vega and Delta measures we use in the analysis.

2.4.2 Corporate Governance Features

We also control for a set of corporate governance variables including (a) *CEO Tenure* which measures the number of years the CEO has been in office and (b) *Percentage of independent directors* which is the fraction of directors on a board classified as independent. These data are from ExecuComp and Riskmetrics, supplemented by hand-collected data where possible. (c) The *Governance index* is the number of anti-takeover provisions a company has in place (Gompers, Ishii, and Metrick, 2003). A higher value of the Governance index is regarded as less shareholder-friendly governance.

2.4.3 Company Characteristics

We obtain company-specific information from the Compustat Fundamental and Bank Annual databases. As control variables in the main analysis we include proxies for firm size (the logarithm of market capitalization), the ratio of the book value of assets over the market value of assets (as a proxy for the companies potential investment opportunities), and market and book leverage.

3 Results

We first show some summary statistics for write-downs (section 3.1) and data that provide insight into the potential relevance of risk-taking incentives (section 3.2). We then discuss our hypotheses for relating write-downs with incentives and our empirical strategy to test these hypotheses (section 3.3). Sections 3.4 to 3.7 report the corresponding regression results.

3.1 Write-downs

During the credit crisis period, the companies in our sample had on average write-downs of around US$6.6bn, which implies write-downs of around 5.5% of their total assets (averaging assets over the years). See Table 3; all monetary values are in 2008 dollars. The heterogeneity in the sample also shows in the absolute standard deviation of write-downs, approximately US$16.7bn. This large standard deviation is also due to the fact that in our analysis we include financial institutions with small write-downs. Existing work on write-downs by Erkens, Hung, and Matos (2009) has only considered financial companies that have reported large losses and hence due to the extensive media coverage have been collected by Bloomberg. In our regressions, we use several approaches to deal with the presence of outliers. First, we winsorize all variables at the 2nd and 98th percentiles. Second, we take the logarithm of potentially skewed variables. Third we also consider write-downs scaled by total assets.

TABLE 3 ABOUT HERE

3.2 Incentives

As seen in Table 3, the average Equity Volatility Vega implies that a one percentage point increase in the company's stock price volatility was associated with an increase of around US$301,000 in CEO wealth. This number is comparable in size with that of other studies on risk-taking incentives in banks. While Equity Volatility Vega in financial institutions is about double the size of Equity Volatility Vega in the Coles, Daniel, and Naveen (2006) sample of industrial firms, it still seems modest, in particular compared to Equity Delta. A 1% increase in the company's stock price resulted in an increase of around US$1,131,000 in the CEO's wealth on average.

However, it would be wrong to conclude, on the basis of evidence from *equity*-risk taking incentives, that more generally the wealth-driven incentives of CEOs to engage in risky activities, such as investing in sub-prime products, were small. To see this, consider the results for Asset Volatility Vega and Asset Delta. The absolute numbers for Asset Volatility Vega cannot be directly compared with Equity Volatility Vega, because one refers to the increase in asset return volatility and the other to the increase in stock return volatility. However, Dittmann and Yu (2010) argue that an appropriate measure of the intensity of risk-taking incentives is the ratio of Vega to Delta (although they consider Equity Volatility Vega). Averaging over the years, for our main parameter choice, the ratio of Asset Volatility Vega to Asset Delta equals 0.44 at the median and is, as such, about 50% larger than the ratio of Equity Volatility Vega to Equity Delta, which equals 0.30.[12] At higher asset volatilities, these effects are even more pronounced. This is important because it is often argued that in recessions asset volatilities increase, suggesting particularly powerful asset risk-taking incentives of managers in bad times, relative to incentives to increase firm value. For instance, using debt volatilities proposed by Guay (1999) in his analysis (which covers both financials and industrial firms) yields somewhat higher asset volatilities and, consequently, ratios of Asset Vega Volatility to Asset Delta that are easily twice or three times as large as the ratios of Equity Volatility Vega and Equity Delta. (This second version is shown as "V2" in Table 3.)

TABLE 4 ABOUT HERE

Table 4 confirms that the result holds across the years under consideration. It also shows that, as expected, a large part of risk-taking incentives continues to come from stock options, but it is clear that stock holdings can also imply significant risk-taking incentives. For the median CEO, risk-taking incentives due to options dominate those due to stock, but for the mean CEO, (only) about half of the total incentives to increase the asset return volatility are due to options.

Interestingly, the correlation of the standard Equity Volatility Vega with the Asset Volatility Vega is far from perfect, at 0.5 to 0.7 across the years. This confirms two points. First, it is conceptually intuitive to focus on the asset risk-taking incentives of the CEO, allowing risk-taking incentives also to emanate from stock-holdings, rather than on the equity risk-taking incentives that are due only to options. Second, this focus yields a different picture of risk-taking incentives in the sample and may, therefore, imply a different relationship of incentives with risk-taking.

[12] Intuitively, the two ratios are not identical because leverage and volatilities enter highly non-linearly into the option pricing formulas.

3.3 Hypotheses and Empirical Strategy

We now turn to the relation between incentives of CEOs and write-downs. To understand this relation, it is important to note at the outset that shareholders in principle (ex-ante) welcomed the risk-taking that later turned out to be harmful to the health of their financial institutions. For example, holding AAA tranches of securitized loans was appealing to shareholders for two reasons. First, these tranches paid extra yields over and above the typical AAA investments. Second, whether held on or off the balance sheet (by way of so-called conduits and other vehicles), these investments did not require backing by enhanced equity capital.[13] Thus, to the extent that there are factors apart from material rewards that make CEOs act in the interest of shareholders, part of the risk-taking in banks, as in other corporations, will not be explained by direct monetary incentives of CEOs. For example, by doing as shareholders want, a CEO increases his chances to keep his job. Functioning alignment of CEO actions with shareholder interests in financial institutions thus generates a baseline amount of risk-taking.

What we are interested in is whether part of the variation in risk-taking beyond this baseline level can be explained by incentives. We test two main hypotheses regarding this relation.

Hypothesis 1: Higher incentives to take asset risk (higher Asset Volatility Vega) are positively associated with write-downs.

Hypothesis 2: Higher incentives to increase firm value (higher Asset Delta) are negatively associated with write-downs.

[13] Whether equity is "expensive" is debated hotly. Practitioners as well as some academics tend to think it is; see, for example, Acharya and Richardson (2009). Others appeal to the Modigliani-Miller theorem and argue that with lower leverage the cost of equity should go down; see, for example, Admati, DeMarzo, Hellwig, and Pfleiderer (2011). This of course matters greatly for regulation and for understanding the present and the future, but really does not matter for understanding the past financial crisis. It is simply a fact that most practitioners did believe that holding more equity was not desirable.

Hypothesis 1 is self-evident. The rationale behind Hypothesis 2 is that a risk-averse CEO wishes to avoid fluctuations in the asset value, and this desire is more pronounced the more he participates in any upward or downward movement of firm value.

Our empirical strategy to test these hypotheses is straightforward: We run cross-sectional regressions with log write-downs and write-downs scaled by total assets on the left-hand side and our explanatory variables, in particular risk-taking incentives, leverage governance features, and other firm-specific variables, on the right-hand side.

It is important to understand the potential limitations of this approach. Quite simply, we do not offer identification of a causal effect in this study. Our results are correlations, and we interpret them as such. As in other studies of governance and firm behavior, two types of endogeneity concerns exist: omitted variable bias and reverse causation.

We control for important firm-level variables as well as industry dummies in order to ensure that our results are not driven by unobserved industry fixed-effects.

However, we cannot rule out the possibility that a positive association between risk-taking incentives and write-downs could arise because of omitted factors. For instance, board competence is unobserved. Some may argue that less competent boards are more easily captured by the CEO and may, therefore, grant an excessive number of options to CEOs. Moreover, less competent boards are less able to monitor investments and may provide worse advice to the CEO. These two factors may combine into a cross-sectional positive relationship between risk-taking incentives and write-downs. Or, the least talented CEOs (who choose the worst projects on average) may be inclined to self-select into the firms with the highest risk-taking incentives, to occasionally "hit the jackpot." Note, however, that it is equally possible that we are underestimating the relationship between risk-taking incentives and poor outcomes. For example, if a company has a culture of risk-taking, it may attract risk-seeking individuals and may, thus, need to provide incentives with lower Vega than other firms. At the same time, these companies may, indeed, engage in a lot of risk-taking simply because the manager likes risk, which, in the case of the subprime crisis resulted in large write-downs.

One of our control variables is leverage, which itself is endogenous. (Existing work on the financial crisis also uses leverage and related measures as control variables.) The ideal situation would be to jointly model the setting of incentives and the choices of the CEO to take asset risk through increasing the firm value return volatility and financial risk through higher firm leverage (in the spirit of Coles, Daniel, and Naveen (2006)). Unfortunately, we cannot do this in our cross-sectional setup. Market leverage may, however, be subject to fewer concerns because it fluctuates passively simply because of changes in stock price performance (Welch, 2004). Thus, the endogeneity of leverage may be less of a concern given that we use market leverage throughout. All our results hold more strongly with book leverage.

As for reverse causation, we are considering the relationship between incentives in the years 2003-2006 and outcomes over the years 2007-2008. We do not have information on the decision criteria boards used to allocate incentive packages in a given year. It is conceivable that incentive packages of a given year include options given as a reward for undertaking risky deals in earlier years; this would imply an upward bias in the respective estimates. However, this concern is much less likely to apply to incentives in 2003. Incentive packages relevant for that year may, of course, include stock and options given as a reward for other risk-taking in prior years, but these potential earlier risky activities do not include the investments that led to write-downs in the financial crisis.

3.4 Main Regression Results

Table 5 presents the main results. The left-hand side of Table 5 shows that Asset Volatility Vega is significantly positively associated with log write-downs in two out of four years, and more weakly (but insignificantly so) in a third one. A similar picture holds for Delta, with reversed signs: Asset Delta is generally negatively associated with write-downs.

TABLE 5 ABOUT HERE

The right-hand side of Table 5 shows results for write-downs scaled by total assets. The overall results are quite similar, though somewhat stronger than those for log write-downs. Despite the small sample size, we obtain (almost) significant associations in the predicted directions for three out of four years for Asset Volatility Vega and for two years for Asset Delta. One difference between the results for absolute risk-taking (log write-downs) and relative risk-taking (write-downs scaled by firm size) is that the regressions for the former generally show greater explanatory power than for the latter, in terms of R-squared.

Columns (1)-(3) of Table 6 add governance variables. For space reasons, we only show the findings for 2006 and only for log write-downs. Asset Volatility Vega and Asset Delta are now often significant even for the year 2006. When including board independence, they are not significant in 2006, but highly significant in two other years. Moreover, the incentive measures in the regression with board independence are highly significant also for 2006 when using the Guay (1999) assumptions for debt volatility (not shown). Finally, the results for the other years and for write-downs scaled by total assets also remain as strong as before. The stronger results for 2006 are due to sample composition, as a separate analysis reveals. It is interesting that incentives mattered more for write-downs in the bigger and more widely known firms that tend to be covered by governance indices.

TABLE 6 ABOUT HERE

Overall, Asset Volatility Vega generally, though not in each and every regression, appears positively related to risk-taking, in absolute and in relative terms, and CEOs with high Asset Delta were more careful in selecting investments. That is, the findings broadly provide support for Hypotheses 1 and 2.

These results are similar to what Knopf, Nam, and Thornton (2002) find for corporate hedging activities. In their study, managers with a high sensitivity of wealth to stock price volatility engaged in less hedging while those with a high sensitivity of wealth to stock price engaged in more hedging. As such, our findings confirm that incentives were related to risk-relevant activities in the time ahead of the financial crisis just like in other times.

Notably, the results for the asset-based incentive measures are different than those for the equity-based measures; see, e.g., columns (4)-(6) of Table 6. Neither for log write-downs nor for write-downs scaled by total assets (not shown) do we find a significant relationship between equity-based incentives and risk-taking. This implies that when trying to explain asset risk-taking, it can be important to use incentives defined in terms of asset values and asset risk.

3.5 Results for Other Governance Variables

As can be seen in Table 6, we find no robust association of any of the governance characteristics with write-downs, controlling for incentives to take asset risk. That we detect no significant, robust relationship between director independence and write-downs may be the result of several countervailing factors. On the one hand, boards acting more strongly on behalf of shareholders may have pushed CEOs to engage in more risk-taking (thus implying a positive relationship).[14] On the other hand, such boards may also have been more prudent in avoiding the worst investments. Moreover, board independence does not directly capture board competence. Speaking to the latter, Fernandes and Fich (2009) document that banks with boards of higher financial literacy performed better during the crisis in terms of stock returns. There is also an intense debate about whether board independence can be expected to be associated with better performance to begin with; see Adams, Hermalin, and Weisbach (2010) for a survey. Erkens, Hung, and Matos (2009) find a positive relationship between write-downs and board independence for large international firms, but they do not control for the same types of incentives as we do as they are using an international sample where the needed data are not available.

3.6 The Role of Leverage

The results so far also show that leverage is positively related to write-downs. It appears that to some extent agency costs of poor balance sheets (Bernanke and Gertler, 1989) may have played a role in explaining risk-taking.[15] However, this result only holds for absolute risk-taking (in terms of log write-downs), not for relative risk-taking (in terms of write-downs scaled by assets).

Column (7) of Table 6 shows an additional result. There is some evidence that Asset Volatility Vega was more strongly related to write-downs in highly leveraged financial institutions, as can be

[14]It is also possible that more independent boards forced executives to disclose write-downs earlier or higher. This argument only holds if one posits that despite the strict accounting regime and the eagerness of investors to monitor developments at financial institutions, some banks were able to manipulate the total amount of write-downs in the six quarters considered here upwards or downwards.

[15]It seems somewhat less likely that "gambling for resurrection" (Bebchuk and Spamann, 2010) was a major issue in the early 2000s – financial institutions were not in financial distress and bank managers were not desperate at the time.

seen from the positive and significant interaction term between Vega and Leverage. The main effect of Vega turns negative in these regressions, but at high enough leverage (roughly starting from the 25th percentile of leverage), the interaction effect dominates so that an overall significantly positive effect of Vega results for most firms, and this effect is increasing in leverage. (Similar findings also obtain in variations of these regressions for log write-downs, but the interaction terms are not significant for write-downs scaled by assets; see column (8).) Note also that when the interaction of leverage with incentives is included, leverage becomes insignificant. This is consistent with Gorton and Rosen (1995) who found that it was mostly the manager-shareholder conflict (incentives) that was responsible for excess risk-taking and the ensuing decline of the U.S. banking sector in the 1980s, rather than the implicit put option the Federal Deposit Insurance Corporation (FDIC) offers.

There are several potential explanations for the interaction effect result. One explanation draws on career concerns of CEOs. In particular, at high leverage, top management is, ceteris paribus, less eager to take additional asset risk, as CEOs perceive the danger that the company will enter financial distress and in the worst case will go bankrupt, which is an extremely costly event in terms of the reputation of a CEO. Therefore, if CEOs do take asset risk, it is more likely that they do so when their asset-risk-taking incentives specifically induce them to do so. In other words, for CEOs in banks with high leverage, the direct monetary incentives related to the value and risk of the assets a bank invests in, play a bigger role than for CEOs of banks with low leverage.[16] Another explanation may be that high leverage may also identify the sample of particularly aggressive firms in general, or particularly innovative firms that had the easiest access

[16] A select few managers of large, highly levered financial institutions may have regarded their banks as "too big to fail." For them, the concern that their career would be negatively affected by an adverse turn of events may not have been so powerful. This would mitigate the argument that incentives played a greater role at higher leverage.

to the new products on the sub-prime market that later resulted in write-downs. These firms may have attracted individuals as CEOs who reacted more strongly to monetary incentives. The CEOs of less innovative firms (which had lower leverage) may have acted as followers with respect to investing in subprime related products largely irrespective of their direct monetary incentives but more driven by the pressure to be involved in "hot" products.[17]

3.7 Additional Results

Here we discuss some additional robustness results which are not tabulated to conserve space.

First, we consider the same regression specification across years as in Table 5 but with buy-and-hold stock returns during the crisis period as the dependent variable. We find that financial institutions with higher Asset Volatility Vegas had lower stock returns, whereas those with higher Asset Deltas had higher returns. This adds to the results obtained in Fahlenbrach and Stulz (2011) for equity-based incentives measures and reflects the fact that asset-based incentives measures capture different features than the equity-based ones. (For Equity Volatility Vega and Equity Delta, we also find no relation with stock returns, like they do.)

Second, turning to the explanatory variables, the regression results (both those in Table 5 and those involving interaction terms in Table 6) continue to hold when we consider book leverage instead of market leverage. Also, including total assets into the regression instead of market capitalization does not change much. Including either measure of squared firm size terms does not materially affect the results. In the spirit of Edmans, Gabaix, and Landier (2009), we scaled Delta by total compensation. The results continue to hold.

[17] Although these economic explanations are appealing, it is also possible that we are simply picking up a non-linear effect, as incentives are also correlated with leverage.

Finally, another measure of the capital strength of an institution is the tier-1 ratio. (Investment banks did not have to report tier-1 ratios until 2008.) Financial institutions with a lower tier-1 ratio in 2006 tended to have higher write-downs. While the findings here are not strongly statistically significant, this is consistent with the argument that these institutions, knowing that the market was monitoring their tier-1 ratios, may have searched for investment opportunities offering a risk premium that did not require coverage with equity. Investments in CDOs and related structures offered just this opportunity.

4 Concluding Remarks

In corporate finance, it is common to think of the value and risk of a firm's assets as the fundamental parameters a manager can influence through his decisions. Interestingly, this idea has hitherto been rarely employed when considering managerial incentives in empirical studies. We show that this notion can help shed new light on the relationship between incentives and risk-taking. Our analysis explicitly recognizes that asset risk-taking incentives are also embedded in stock holdings, and we view stock options as compound options on the firm's asset value. While the existing literature finds that incentives to take equity risk are small compared to incentives to maximize the stock price, we document that incentives to take asset risk can be large compared to incentives to increase the value of assets. Moreover, only when using asset-based incentives measure do we find substantial evidence of an association between incentives and risk-taking in our setting; using equity-based measures, there is no significant relation. We suggest that these results may also inform future studies on incentives and risk-taking (where researchers often use asset-based proxies such as R&D investments as risk-taking measures).

We conclude by commenting on implications of the present findings for future research and policy, noting carefully that our results are based on a relatively small sample and statistically significant in many, but not all regressions presented. First, the finding that Asset Delta was overall significantly negatively associated with write-downs is consistent with the notion that a high sensitivity of managerial wealth to firm value movements reduces risk-taking, potentially favoring stock over stock options as a compensation tool. However, once one recognizes that stock-holdings can also induce substantial asset risk-taking incentives, the proposal to compensate CEOs mostly with stock does not apply so cleanly anymore.

Second, there is some evidence that in highly leveraged financial institutions, incentives were particularly strongly associated with risk-taking. This effect does not feature in existing models that consider the effects of leverage levels for the shareholder–debtholder problem (Merton, 1977) and for incentives of creditors to monitor and discipline managers (Acharya, Mehran, and Thakor, 2011). Future research may profitably explore whether leverage regulations need to differentiate between the roles of managerial incentives at different leverage levels.

Finally, from society's point of view, the relationship between write-downs and compensation structures was accentuated because the downsides of financial institutions' investments resulted in significant external costs presumably not taken into account by shareholders. Thus, a natural future research question is whether and how incentive systems at financial institutions may encourage managers of these companies to take into account (to a greater extent than is arguably common today) the external effects of their actions.[18]

[18]Some work exists that has begun addressing related issues. For example, on optimal incentive design in the presence of government guarantees see John, Saunders, and Senbet (2000), John, Mehran, and Qian (2008), Bebchuk and Spamann (2010), and Bolton, Mehran, and Shapiro (2011).

References

Acharya, Viral, Hamid Mehran, and Anjan Thakor, 2011, Caught between Scylla and Charybdis? Regulating bank leverage when there is rent-seeking and risk-shifting, *Mimeo*.

Acharya, Viral, and Matthew Richardson, 2009, Causes of the financial crisis, *Critical Review* 21(2-3), 195–210.

Adams, René, Benjamin Hermalin, and Michael Weisbach, 2010, The role of boards of directors in corporate governance: A conceptual framework and survey, *Journal of Economic Literature* 58, 58–107.

Admati, Anat R., Peter M. DeMarzo, Martin F. Hellwig, and Paul Pfleiderer, 2011, Fallacies, irrelevant facts, and myths in the discussion of capital regulation: Why bank equity is not expensive, *Stanford University Working Paper*.

Bebchuk, Lucian A., Alma Cohen, and Holger Spamann, 2010, The wages of failure: Executive compensation at Bear Stearns and Lehman 2000-2008, *Yale Journal on Regulation* 27, 257–282.

Bebchuk, Lucian A., and Holger Spamann, 2010, Regulating bankers' pay, *Georgetown Law Journal* 102, 957–993.

Beltratti, Andrea, and René Stulz, 2009, Why did some banks perform better during the credit crisis? A cross-country study of the impact of governance and regulation, *Mimeo*.

Bernanke, Ben, and Mark Gertler, 1989, Agency costs, net worth, and business fluctuations, *American Economic Review* 79, 402–23.

Black, Fischer, and Myron Scholes, 1973, The pricing of options and corporate liabilities, *Journal of Political Economy* 81, 637–654.

Board of Governors of the Federal Reserve System, 2011, Incentive Compensation Practices: A Report on the Horizontal Review of Practices at Large Banking Organizations, *October 2011*.

Bolton, Patrick, Hamid Mehran, and Joel Shapiro, 2011, Executive compensation and risk taking, *Mimeo*.

Cheng, Ing-Haw, Harrison Hong, and Jose Scheinkman, 2010, Yesterday's heroes: Compensation and creative risk-taking, *Mimeo*.

Coles, J., N. Daniel, and Lalitha Naveen, 2006, Managerial incentives and risk-taking, *Journal of Financial Economics* 79, 431–468.

Core, John E., and Wayne R. Guay, 2002, Estimating the value of employee stock option portfolios and their sensitivities to price and volatility, *Journal of Accounting Research* 40, 613–629.

DeYoung, Robert, Emma Y. Peng, and Meng Yan, 2009, Executive compensation and business policy choices at U.S. commercial banks, *Mimeo*.

Dittmann, Ingolf, and Ko-Chia Yu, 2010, How important are risk-taking incentives in executive compensation?, *Mimeo*.

Edmans, Alex, Xavier Gabaix, and Augustin Landier, 2009, A multiplicative model of optimal CEO incentives in market equilibrium, *Review of Financial Studies* 22, 4881–4918.

Ellul, Andrew, and Vijay Yerramilli, 2009, Stronger risk controls, lower risk: Evidence from U.S. bank holding companies, *Mimeo*.

Erkens, David, Mingyi Hung, and Pedro Matos, 2009, Corporate governance in the 2007-2008 financial crisis: Evidence from financial institutions worldwide, *Mimeo.*

Fahlenbrach, Rüdiger, and René Stulz, 2011, Bank CEO incentives and the credit crisis, *Journal of Financial Economics* 99, 11–26.

Faulkender, Michael, Dalida Kadyrzhanova, N. Prabhala, and Lemma Senbet, 2010, Executive compensation: An overview of research on corporate practices and proposed reforms, *Journal of Applied Corporate Finance* 22, 107–118.

Fernandes, Nuno, and Eliezer M. Fich, 2009, Does financial experience help banks during credit crises?, *Mimeo.*

Fiechter, Peter, and Conrad Meyer, 2009, Big bath accounting using fair value measurement discretion during the financial crisis, *Mimeo.*

Geske, Robert, 1979, The valuation of compound options, *Journal of Financial Economics* 7, 63–81.

Gompers, Paul A., Joy L. Ishii, and Andrew Metrick, 2003, Corporate governance and equity prices, *Quarterly Journal of Economics* 118, 107–156.

Gorton, Gary, and Richard Rosen, 1995, Corporate control, portfolio choice, and the decline of banking, *Journal of Finance* 50, 1377–1420.

Gropp, Reint, and Florian Heider, 2010, The determinants of bank capital structure, *Review of Finance* 14, 257–282.

Guay, Wayne, 1999, The sensitivity of CEO wealth to equity risk: An analysis of the magnitude and determinants, *Journal of Financial Economics* 53, 43–71.

Hässig, Lukas, 2009, *Der UBS-Crash* (Hoffmann und Campe: Hamburg).

Hayes, Rachel M., Michael Lemmon, and Mingming Qiu, 2011, Stock options and managerial incentives for risk-taking: Evidence from FAS 123R, *Journal of Financial Economics* forthcoming.

Huizinga, Harry, and Luc Laeven, 2009, Accounting discretion of banks during a financial crisis, *Mimeo*.

John, Kose, Hamid Mehran, and Yiming Qian, 2008, Outside monitoring and CEO compensation in the banking industry, *Mimeo*.

John, Kose, Anthony Saunders, and Lemma W. Senbet, 2000, A theory of bank regulation and management compensation, *Review of Financial Studies* 13, 95–112.

Knopf, John D., Jouahn Nam, and John H. Thornton, 2002, The volatility and price sensitivities of managerial stock option portfolios and corporate hedging, *Journal of Finance* 57, 801–813.

Laeven, Luc, and Ross Levine, 2009, Bank governance, regulation and risk taking, *Journal of Financial Economics* 93, 259–275.

Merton, Robert, 1974, On the pricing of corporate debt: the risk structure of interest rates, *Journal of Finance* 3, 449–470.

Merton, Robert C., 1977, An analytic derivation of the cost of deposit insurance and loan guarantees: An application of modern option pricing theory, *Journal of Banking and Finance* 1, 3–11.

PricewaterhouseCoopers, 2008, Reward: A new paradigm?, *PwC*.

Ryan, Stephen G., 2008, Accounting in and for the subprime crisis, *Accounting Review* 83, 1605–1638.

Sanders, WM. Gerard, and Donald C. Hambrick, 2007, Swinging for the fences: The effects of CEO stock options on company risk taking and performance, *Academy of Management Journal* 50, 1055–1078.

Saunders, Anthony, Elizabeth Strock, and Nickolaos G. Travlos, 1990, Ownership structure, deregulation, and bank risk taking, *Journal of Finance* 45, 643–654.

Sheehan, Richard G., 2004, Valuing core deposits, *Working paper, Department of Finance, University of Notre Dame*.

Welch, Ivo, 2004, Capital structure and stock returns, *Journal of Political Economy* 112, 106–131.

Yvas, Dushyantkumar, 2011, The timeliness of write-downs by U.S. financial institutions during the financial crisis of 2007-2008, *Journal of Accounting Research* forthcoming.

Please note: This comprehensive Appendix can be made available on a website upon publication.

Appendix A Equity Delta and Equity Volatility Vega

In this section we start by assuming that the stock price, S, follows a geometric Brownian motion

$$\frac{dS_t}{S_t} = \mu_S dt + \sigma_S dW_t \tag{1}$$

under the historical measure. The parameters μ_S and σ_S are assumed constant and we also assume that there exists a bank account which yields a constant interest rate r.

Following Core and Guay (2002), we calculate Equity Delta and Equity Volatility Vega using the derivatives of the Black-Scholes formula (see Black and Scholes (1973)) with respect to the underlying stock and the stock return volatility respectively. Recall that the value of a plain vanilla call is given by

$$BS = Se^{-\delta T} N(d_1) - Ke^{-rT} N(d_2) \tag{2}$$

with

$$d_1(S, K, r, T, \sigma_S) = \frac{\ln(S/K) + ((r - \delta) + \sigma_S^2/2)T}{\sigma_S \sqrt{T}} \tag{3}$$

$$d_2(S, K, r, T, \sigma_S) = d_1(S, K, r, T, \sigma_S) - \sigma_S \sqrt{T}, \tag{4}$$

where N denotes the cumulative distribution function of a standard normal random variable. S denotes the stock, K denotes the strike, σ_S is the return volatility, r represent the risk-free rate, δ denotes the dividend yield and T represents the maturity of the option.

The *Equity Delta* of a single option can be computed according to

$$\text{Equity Delta} = \frac{\partial BS}{\partial S} \cdot (S/100) = e^{-\delta T} N(d_1) \cdot (S/100), \tag{5}$$

which measures the sensitivity of the option value with respect to a one percent change in the stock price.

The *Equity Volatility Vega* of a single option can be computed according to

$$\text{Equity Volatility Vega} = \frac{\partial BS}{\partial \sigma_S} \cdot (1/100) = e^{-\delta T} \varphi(d_1) S \sqrt{T} \cdot (1/100) \tag{6}$$

which measures the sensitivity of the option value with respect to a 0.01 change in the underlying stock return volatility and φ denotes the density of a standard normal random variable.

As is standard in the literature, we assume that Equity Delta from stocks is equal to one (by construction) and that Equity Volatility Vega from stocks equals zero; see Guay (1999).

Appendix B Asset Delta and Asset Volatility Vega

To motivate the notion of asset-based measures of risk-taking incentives we consider a company's equity as a contingent claim on its firm value (Merton, 1974). Within this framework, we are able to compute incentive measures similar to those traditionally used in the literature, with the central difference being that we express them with respect to the underlying firm value parameters. In addition to considering a CEO's stock holdings as a call option on the firm value, we view a CEO's option holdings as a compound call option on the firm value (Geske, 1979). The idea of considering stock options as compound options on the firm value is new to the literature on risk-taking, but a natural step in order to operate within a coherent framework.

We assume that the firm value, V, follows a geometric Brownian motion

$$\frac{dV_t}{V_t} = \mu_V dt + \sigma_V dW_t \tag{7}$$

under the historical measure. The parameters μ_V and σ_V are assumed constant. We also assume that there exists a bank account which yields a constant interest rate r.

Asset Delta is the first derivative of the stock and option price, respectively, with respect to changes in the firm value, V.

Asset Volatility Vega is the first derivative of the stock and option price, respectively, with respect to changes in the underlying asset return volatility, σ_V.

Once we have computed the measures for individual stocks and options, we multiply them with the CEO's holdings of stock and options (current granted, previously granted exercisable, previously granted un-exercisable) and add them to obtain our final measures of incentives.

The remainder of this Appendix explains how we obtain Asset Delta and Asset Volatility Vega. Section B.1 conducts preliminary calculations, yielding the implied per share firm value and other quantities needed for the calculation of incentives in the asset-based framework. In Section B.2 we briefly review the compound call option pricing formula as presented in Geske (1979) since this lays the groundwork for our derivation of the Asset Delta and Asset Volatility Vega measures. In Section B.3 we compute Asset Delta from stocks, in Section B.4 Asset Delta from options, in Section B.5 Asset Volatility Vega from stocks, and in Section B.6 Asset Volatility Vega from options.

Appendix B.1 Preliminaries

Guay (1999) develops an approach to measure the incentives to take risks inherent in a CEO's stock holdings. The preliminary calculations used in this approach are also needed for the calculation of incentives inherent in option holdings, so we first describe them here.

We begin by computing the implied per share firm value, V, as the implicit solution to the Black-Scholes equation,[19]

$$S = VN(d_1) - De^{-rT}N(d_2) \tag{8}$$

with

$$d_1 = \frac{\ln(V/D) + (r + \sigma_V^2/2)T}{\sigma_V\sqrt{T}} \tag{9}$$

$$d_2 = d_1 - \sigma_V\sqrt{T}. \tag{10}$$

That is, we assume that Black-Scholes model is the correct one to value equity as a call option on the firm value. In the above equation, S denotes the stock price (which is observable), D is book value of debt per share (which is observable), T is the maturity of long-term debt (we follow Guay (1999) and set it equal to 7.5 years for our sample of financial institutions) and r is the yield on Treasury bonds with time to maturity of 7 years (which is the closest yield we had to 7.5 years as possible).[20] To obtain an estimate of the firm value return volatility, σ_V, Guay (1999) proposes to rely on portfolio theory. Thus, the variance of the firm value can written as

$$\sigma_V^2 = X_{\text{debt}}^2\sigma_{\text{debt}}^2 + X_{\text{equity}}^2\sigma_{\text{equity}}^2 + 2X_{\text{debt}}X_{\text{equity}}\text{Cov}(\sigma_{\text{debt}}, \sigma_{\text{equity}}), \tag{11}$$

where X_{debt} and X_{equity} are the weights of debt and equity in the firm's capital structure and $\sigma_{\text{equity}} \equiv \sigma_S$

[19] We exclude dividends for simplicity and from option pricing theory there is no reason to expect that omitting this component will result in substantially different outcomes.

[20] As pointed out by Guay (1999), in principle, when a firm has outstanding debt with different times to maturity, common stock is technically a compound option. Like him, we make the simplifying assumption that the firm has a single debt obligation with a time to maturity of 7.5 years.

is the annualized standard deviation of daily log stock returns. We use the same σ_{equity} as we have used for computing Equity Volatility Vega and Equity Delta as outlined in Appendix A. For σ_{debt}, we use the annualized standard deviation of monthly (log) returns using the Merrill Lynch Bank of America corporate financial bond index using a five year period. Moreover, we follow Guay (1999) and set the correlation between equity and debt returns equal to one, $\text{Corr}(\sigma_{\text{debt}}, \sigma_{\text{equity}}) = \frac{\text{Cov}(\sigma_{\text{debt}}, \sigma_{\text{equity}})}{\sqrt{\sigma^2_{\text{debt}}\sigma^2_{\text{equity}}}} = 1$, which implies that $\text{Cov}(\sigma_{\text{debt}}, \sigma_{\text{equity}}) = \sigma_{\text{debt}}\sigma_{\text{equity}}$ and, therefore,

$$\sigma^2_V = X^2_{\text{debt}}\sigma^2_{\text{debt}} + X^2_{\text{equity}}\sigma^2_{\text{equity}} + 2X_{\text{debt}}X_{\text{equity}}\sigma_{\text{debt}}\sigma_{\text{equity}}. \tag{12}$$

Table B-1 shows descriptive statistics for all the relevant variables.

TABLE B-1 ABOUT HERE

Appendix B.2 The Compound Option Pricing Formula

In order to compute the derivative of the option value with respect to the firm value return volatility, σ_V, and the firm asset value, V, we start from the compound call option pricing formula presented by Geske (1979). For completeness, we review the formula here. The price of a compound call (CC) option is given by the expression

$$\begin{aligned} \text{Compound Call}(V, D, r, \tau_1, \tau_2, \sigma_V, K) &= VN_2(h + \sigma_V\sqrt{\tau_1}, k + \sigma_V\sqrt{\tau_2}; \sqrt{\tau_1/\tau_2}) - De^{-r\tau_2}N_2(h, k; \sqrt{\tau_1/\tau_2}) \\ &- Ke^{-r\tau_1}N_1(h), \end{aligned} \tag{13}$$

where $N_2(\cdot)$ represents the bivariate cumulative normal distribution function, $N_1(\cdot)$ represents the standard normal cumulative distribution function, τ_1 denotes the expiration of the stock option and τ_2 denotes the maturity of the debt.[21] The remaining terms are given as

$$h = \frac{\ln(V/\bar{V}) + (r - \frac{1}{2}\sigma_V^2)\tau_1}{\sigma_V\sqrt{\tau_1}} \quad (14)$$

$$k = \frac{\ln(V/D) + (r - \frac{1}{2}\sigma_V^2)\tau_2}{\sigma_V\sqrt{\tau_2}} \quad (15)$$

and $\bar{V}$ is the value of V which is the solution to the equation

$$VN_1(k + \sigma_V\sqrt{\tau_2 - \tau_1}) - De^{-r(\tau_2-\tau_1)}N_1(k) - K = 0, \quad (16)$$

where K denotes the strike price of the option and D denotes the face value of debt per share, so that $\bar{V}$ denotes the firm value where the option is just at the money at time τ_1.

Appendix B.3 *Asset Delta* from stocks

In this section we calculate the sensitivity of a stock in a CEO's stock holdings with respect to changes in the firm value. In contrast to the traditional approach, the Asset Delta is no longer equal to one. By relying on the Black-Scholes model we obtain

$$\begin{aligned} \text{Asset Delta from stocks} &= \frac{\partial \text{BS}(V, D, r, T, \sigma_V)}{\partial V} \cdot (V/100) \\ &= N(d_1(V, D, r, T, \sigma_V)) \cdot (V/100), \end{aligned} \quad (17)$$

where the variables are defined above.

To keep an interpretation similar to the one for Equity Delta, we multiply the Asset Delta from stocks

[21] Thus, the model requires that $\tau_2 > \tau_1$. In practice, stock option maturities typically range from 3 to 10 years. Therefore, this sometimes can conflict with the assumption of having the maturity of debt equal to 7.5 years. In these cases, we set, for simplicity, the maturity of debt equal to the option maturity plus two years. However, consistent with Guay's (1999) assessment of the sensitivity of his results for Asset Volatility Vega from stocks to assumptions about debt maturity, we find that for Asset Volatility Vega from options, the results do not appear sensitive to how we adjust the debt maturity either.

and options with $V/100$.

Appendix B.4 ***Asset Delta*** from options

Analogously, we can compute Asset Delta coming from options by relying on the compound option pricing formula derived by Geske (1979). Thus,

$$\begin{aligned}\text{Asset Delta from options} &= \frac{\partial \text{Compound Call}(V, D, r, \tau_1, \tau_2, \sigma_V, K)}{\partial V} \cdot (V/100) \\ &= N_2(h + \sigma_V\sqrt{\tau_1}, k + \sigma_V\sqrt{\tau_2}, \sqrt{\tau_1/\tau_2}) \cdot (V/100), \qquad (18)\end{aligned}$$

where the variables similarly are defined above.[22] Also here we multiply the Asset Delta from stocks and options with $V/100$ to keep the same interpretation.

Appendix B.5 ***Asset Volatility Vega*** from stocks

Now we compute the incentive, coming from the CEO's stock holdings, to increase the firm value return volatility. Relying on the Black-Scholes formula, we obtain

$$\begin{aligned}\text{Asset Volatility Vega from stocks} &= \frac{\partial BS(V, D, r, T, \sigma_V)}{\partial \sigma_V} \cdot (1/100), \\ &= \varphi(d_1(V, D, r, T, \sigma_V))V\sqrt{T} \cdot (1/100), \qquad (19)\end{aligned}$$

where φ denotes the standard normal probability density. The Asset Volatility Vega from stocks measures the sensitivity of the stock price with respect to a 0.01 change in the underlying asset volatility, σ_V.

[22] The derivative of the compound formula with respect to the underlying asset value, V, converges to the correct Delta for the Black-Scholes model for debt equal to zero.

Appendix B.6 *Asset Volatility Vega* from options

In this section we calculate the sensitivity of the compound option pricing formula for a call option with respect to the underlying asset return volatility. Geske (1979) presents a formula for this derivative, which we denote by "Geske Vega,"

$$\begin{aligned}\text{Geske Vega} &= \frac{\partial CC(V, D, r, \tau_1, \tau_2, \sigma_V, K)}{\partial \sigma_V^2} \cdot \frac{d\sigma_V^2}{d\sigma_V} \\ &= \frac{N_2(h + \sigma_V\sqrt{\tau_1}, k + \sigma_V\sqrt{\tau_2}, \sqrt{\tau_1/\tau_2})}{N_1(k + \sigma_V\sqrt{\tau_2})} De^{-r\tau_2}\varphi(k)\frac{\sqrt{\tau_2}}{2\sigma_V} \cdot 2\sigma_V. \end{aligned} \quad (20)$$

However, we do not rely on this formula for computing the Asset Volatility Vega we use in our analysis. Our motivation not to employ this formula, is that the Black-Scholes model is a special case of the compound option model when the firm's debt, D, goes to zero (this observation is noted by Geske (1979)). Indeed, in the limit as $D \to 0$, the compound option price converges to the Black-Scholes price. Therefore, we would also expect that, for zero debt, the Asset Volatility Vega from the compound option model should collapse into the formula for the Asset Volatility Vega (and, thus, in this special case the Equity Volatility Vega) from the Black-Scholes model. However, the formula for the Geske Vega given in equation (20) would suggest, counter-intuitively, that in the limit when $D \to 0$ the Asset Volatility Vega given by the compound option pricing model would converge to zero.

To resolve the puzzling feature regarding the limit of the compound option pricing vega presented in Geske (1979), we derive a different expression for this sensitivity.

Proposition 1. *The Asset Volatility Vega in the compound option pricing model is given by the* *expression*

$$\begin{aligned}\frac{\partial CC}{\partial \sigma_V} &= V\Bigg[\varphi(h+\sigma_V\sqrt{\tau_1})N_1\left(\frac{k+\sigma_V\sqrt{\tau_2}-\sqrt{\frac{\tau_1}{\tau_2}}(h+\sigma_V\sqrt{\tau_1})}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\sqrt{\tau_1}\\ &+ \varphi(k+\sigma_V\sqrt{\tau_2})N_1\left(\frac{h+\sigma_V\sqrt{\tau_1}-\sqrt{\frac{\tau_1}{\tau_2}}(k+\sigma_V\sqrt{\tau_2})}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V}\Bigg]\\ &- De^{-r\tau_2}\varphi(k)N_1\left(\frac{h-\sqrt{\frac{\tau_1}{\tau_2}}k}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\frac{dk}{d\sigma_V} \qquad (21)\end{aligned}$$

where

$$\frac{dk}{d\sigma_V} = -\frac{k}{\sigma_V} - \sqrt{\tau_2} \quad \textit{and} \quad \frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V} = -\frac{k}{\sigma_V}. \qquad (22)$$

Proof From equation (13), we take the derivative with respect to σ_V, which gives us

$$\begin{aligned}\frac{\partial CC}{\partial \sigma_V} &= V\Bigg(\frac{\partial N_2(x,k+\sigma_V\sqrt{\tau_2};\sqrt{\frac{\tau_1}{\tau_2}})}{\partial x}(h+\sigma_V\sqrt{\tau_1})\frac{d(\sigma_V\sqrt{\tau_1})}{d\sigma_V}\\ &+ \frac{\partial N_2(h+\sigma_V\sqrt{\tau_1},y;\sqrt{\frac{\tau_1}{\tau_2}})}{\partial y}(k+\sigma_V\sqrt{\tau_2})\frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V}\Bigg)\\ &- De^{-r\tau_2}\frac{\partial N_2(h,y;\sqrt{\frac{\tau_1}{\tau_2}})}{\partial y}(k)\frac{dk}{d\sigma_V}\\ &+ \Bigg[V\frac{\partial N_2(x,k+\sigma_V\sqrt{\tau_2};\sqrt{\frac{\tau_1}{\tau_2}})}{\partial x}(h+\sigma_V\sqrt{\tau_1})\\ &- De^{-r\tau_2}\frac{\partial N_2(x,k;\sqrt{\frac{\tau_1}{\tau_2}})}{\partial x}(h) - Ke^{-r\tau_1}\frac{dN(h)}{dh}\Bigg]\frac{dh}{d\sigma_V}. \qquad (23)\end{aligned}$$

This formula can be simplified by realizing that the terms in front of $\frac{dh}{d\sigma_V}$ cancel out. In fact, the terms in the bracket can be written as $\frac{\partial CC}{\partial h}\frac{dh}{d\sigma_V}$. Furthermore, $\frac{\partial CC}{\partial h} = 0$. This is due to the fact that $\frac{\partial BS}{\partial h} = 0$ which can be seen easily from the relation $V\varphi(h+\sigma_V\sqrt{\tau_1}) = Ke^{-r\tau_1}\varphi(h)$ which again implies that we must also have $\frac{\partial CC}{\partial h} = 0$. This leaves us with the formula

$$\begin{aligned}
\frac{\partial CC}{\partial \sigma_V} &= V \Bigg(\frac{\partial N_2(x, k+\sigma_V\sqrt{\tau_2}; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial x} (h+\sigma_V\sqrt{\tau_1}) \frac{d(\sigma_V\sqrt{\tau_1})}{d\sigma_V} \\
&+ \frac{\partial N_2(h+\sigma_V\sqrt{\tau_1}, y; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial y} (k+\sigma_V\sqrt{\tau_2}) \frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V} \Bigg) \\
&- De^{-r\tau_2} \frac{\partial N_2(h, y; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial y} (k) \frac{dk}{d\sigma_V}. \qquad (24)
\end{aligned}$$

Now, by relying on the relation

$$N_2(h, k; \rho) = \int_{-\infty}^{h} \varphi(x) N_1 \left(\frac{k-\rho x}{\sqrt{1-\rho^2}} \right) dx \qquad (25)$$

as given in Geske (1979) and from the symmetry between k and h, we have the following relations:

$$\frac{\partial N_2(x, k+\sigma_V\sqrt{\tau_2}; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial x} (h+\sigma_V\sqrt{\tau_1}) = \varphi(h+\sigma_V\sqrt{\tau_1}) N_1 \left(\frac{k+\sigma_V\sqrt{\tau_2} - \sqrt{\frac{\tau_1}{\tau_2}}(h+\sigma_V\sqrt{\tau_1})}{\sqrt{1-\frac{\tau_1}{\tau_2}}} \right) \qquad (26)$$

and

$$\frac{\partial N_2(h+\sigma_V\sqrt{\tau_1}, y; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial y} (k+\sigma_V\sqrt{\tau_2}) = \varphi(k+\sigma_V\sqrt{\tau_2}) N_1 \left(\frac{h+\sigma_V\sqrt{\tau_1} - \sqrt{\frac{\tau_1}{\tau_2}}(k+\sigma_V\sqrt{\tau_2})}{\sqrt{1-\frac{\tau_1}{\tau_2}}} \right) \qquad (27)$$

and

$$\frac{\partial N_2(x, k; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial x} (h) = \varphi(h) N_1 \left(\frac{k - \sqrt{\frac{\tau_1}{\tau_2}} h}{\sqrt{1-\frac{\tau_1}{\tau_2}}} \right) \qquad (28)$$

and

$$\frac{\partial N_2(h, y; \sqrt{\frac{\tau_1}{\tau_2}})}{\partial y} (k) = \varphi(k) N_1 \left(\frac{h - \sqrt{\frac{\tau_1}{\tau_2}} k}{\sqrt{1-\frac{\tau_1}{\tau_2}}} \right), \qquad (29)$$

where φ denotes the standard normal probability density. Inserting these derivative relations into equation

(24) we obtain the formula

$$\begin{aligned}
\frac{\partial CC}{\partial \sigma_V} &= V\left[\varphi(h+\sigma_V\sqrt{\tau_1})N_1\left(\frac{k+\sigma_V\sqrt{\tau_2}-\sqrt{\frac{\tau_1}{\tau_2}}(h+\sigma_V\sqrt{\tau_1})}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\sqrt{\tau_1}\right. \\
&+ \left.\varphi(k+\sigma_V\sqrt{\tau_2})N_1\left(\frac{h+\sigma_V\sqrt{\tau_1}-\sqrt{\frac{\tau_1}{\tau_2}}(k+\sigma_V\sqrt{\tau_2})}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V}\right] \\
&- De^{-r\tau_2}\varphi(k)N_1\left(\frac{h-\sqrt{\frac{\tau_1}{\tau_2}}k}{\sqrt{1-\frac{\tau_1}{\tau_2}}}\right)\frac{dk}{d\sigma_V},
\end{aligned} \tag{30}$$

where

$$\frac{dk}{d\sigma_V} = -\frac{k}{\sigma_V} - \sqrt{\tau_2} \quad \text{and} \quad \frac{d(k+\sigma_V\sqrt{\tau_2})}{d\sigma_V} = -\frac{k}{\sigma_V}. \tag{31}$$

which is precisely the closed-form expression for the Asset Volatility Vega in the compound option pricing model given in Proposition 1. ■

Remark to the proof of Proposition 1.

In some cases, researchers may be interested in analyzing how the firm value where the option is precisely at the money, $\bar{V}$, varies as the asset volatility varies. That is, we would wish to compute the term $\frac{d\bar{V}}{d\sigma_V}$. Although the term $\frac{dh}{d\sigma_V}$, in which $\bar{V}$ features, plays no role in the proof of Proposition 1 (the terms in front of it cancel out), we present the derivations for computing this derivative here for completeness.

Define the following function

$$f(x,y) = xN_1(k(x,y)+y\sqrt{\tau_2-\tau_1}) - De^{-r(\tau_2-\tau_1)}N_1(k(x,y)) - K, \tag{32}$$

where

$$\tilde{k}(x,y) = \frac{\log(\frac{x}{D}) + (r-\frac{y^2}{2})(\tau_2-\tau_1)}{y\sqrt{\tau_2-\tau_1}}. \tag{33}$$

Now, by relying on equation (16) above we have that

$$f(\overline{V}, \sigma_V) = 0. \tag{34}$$

Since the function f depends on σ_V both through the direct effect but also indirectly through its effect on $\bar{V}$, we can consider the function f as a function in these two variables. Writing up the dynamics using the chain-rule, we have

$$df(\overline{V}, \sigma_V) = \frac{\partial f}{\partial x}(\overline{V}, \sigma_V)d\overline{V} + \frac{\partial f}{\partial y}(\overline{V}, \sigma_V)d\sigma_V = 0, \tag{35}$$

which equivalently can be written as

$$\frac{d\overline{V}}{d\sigma_V} = -\frac{\frac{\partial f}{\partial y}(\overline{V}, \sigma_V)}{\frac{\partial f}{\partial x}(\overline{V}, \sigma_V)}. \tag{36}$$

We obtain

$$\frac{d\overline{V}}{d\sigma_V} \quad = \quad -\frac{De^{-r(\tau_2-\tau_1)}\varphi(\overline{k})\sqrt{\tau_2-\tau_1}}{N_1(\overline{k}+\sigma_V\sqrt{\tau_2-\tau_1})}, \tag{37}$$

where

$$\overline{k} = \tilde{k}(\overline{V}, \sigma_V). \tag{38}$$

Now it is straightforward to compute the term $\frac{dh}{d\sigma_V}$ in equation (23). From,

$$h = \frac{\log(\frac{V}{\overline{V}}) + (r - \frac{\sigma_V^2}{2})\tau_1}{\sigma_V\sqrt{\tau_1}} \tag{39}$$

we obtain

$$\frac{dh}{d\sigma_V} = \frac{\frac{1}{\bar{V}\sqrt{\tau_1}}\frac{De^{-r(\tau_2-\tau_1)}\varphi(\bar{k})\sqrt{\tau_2-\tau_1}}{N_1(\bar{k}+\sigma_V\sqrt{\tau_2-\tau_1})} - h}{\sigma_V} - \sqrt{\tau_1} \tag{40}$$

■

We rely on the formula in Proposition 1 to measure the CEO risk-taking incentives we apply in the analysis. Analogously to the Asset Volatility Vega from stocks we divide the expression in Proposition 1 by 100 so that it measures the sensitivity of the option price with respect to a 0.01 change in the underlying asset return volatility, as we did it with the Equity Volatility Vega.

To confirm the intuitive benchmark result mentioned above, consider the case when the debt, D, tends to zero. Then, since $\bar{V}$ tends to the strike K and k tends to $+\infty$ it is clear that

$$\lim_{D\to 0}\frac{\partial CC}{\partial\sigma_V} = V\varphi(h+\sigma_V\sqrt{\tau_1})\sqrt{\tau_1} \tag{41}$$

which is precisely the vega of a call option in the Black-Scholes model and where h is given in Appendix B.2. The idea that the Vega presented in Geske (1979) (see equation (20)) converges to zero whereas the formula given in Proposition 1 converges to the Black-Scholes vega is illustrated in Figure B-1. There, we plot the Asset Volatility Vega using the formula in Geske (1979) and the formula given in Proposition 1 for typical parameter values that allow a graphical illustration of the differences between the two sensitivities for varying levels of debt.

FIGURE B-1 ABOUT HERE

The figure also shows a discrete difference approximation using the compound option pricing formula derived by Geske (1979). That is, we can approximate the derivative of the compound call option price with respect to the firm's return volatility with a first difference of the compound option pricing formula with respect to σ_V. For this, we consider a sufficiently small change in σ_V in order to approximate the true derivative with a high precision. Notably, this difference approximation agrees with our analytical formula for the Asset Volatility Vega given in Proposition 1.

Figure B-2 shows a comparison of the formulas for the *Asset Volatility Vega* given by the formula in Geske (1979) (see equation (20)) with our Asset Volatility Vega (see Proposition 1) and the one computed by the first difference approximation for parameter values relevant for the analysis conducted in this paper and for varying levels of asset volatilities, σ_V . We make two observations. First, as before, the analytical formula in given in Proposition 1 completely agrees with the first difference approximation. Second, there are substantial differences between the Asset Volatility Vega computed using the formula in Proposition 1 and the formula presented in Geske (1979) at common levels of the asset volatility. The difference (both in absolute and in relative terms) between the two approaches to compute the Asset Volatility Vega is particularly pronounced for moderate and low levels of asset volatility, which is commonly observed for financial institutions, though it remains substantial even at higher levels of asset volatility. That is, if we were to use the formula in Geske (1979), we would substantially underestimate the incentives to take asset risk as compared to our formula (and the difference approximation).

FIGURE B-2 ABOUT HERE

Table B-1. Descriptive statistics of the parameters used in the computations of Asset Volatility Vega and Asset Delta. The summary statistics are average over the years 2003-2006. Per-share stock price denotes the average end-of-year stock price. Per-share book-value of debt denotes the book value of liabilities end-of-year. The risk-free interest rate is the yield on U.S. Treasury bonds with a maturity similar to maturity of the firms liabilities. Standard deviation of debt returns is the annualized standard deviation calculated on monthly (log) returns using the Merrill Lynch Bank of America corporate financial bond index using a five year period. Standard deviation of equity returns is calculated (from CRSP data) as the annualized standard deviation of daily log-returns over the past three years up to each year in our sample by assuming 250 trading days in the year. Est. std. dev. of returns on firm value denotes the estimated standard deviation of returns on the firm value (see Appendix B.1). Weight of equity and Weight of debt are, respectively, the shares of equity and debt in the firm's capital structure. Implied per-share market value of assets is backed out using the Black-Scholes equation (see Appendix B.1). Per-share market value of assets denotes sum of the per share end-of-year stock price and the per share book value of debt. Price-to-strike ratio is the implied per share firm value divided by the per share book value of debt. The variables are winsorized at the 2nd and 98th percentile on an annual basis. The term "q" denotes the quantile, i.e., 10q refers to the 10th percentile in the empirical distribution of the respective variable. All monetary values are expressed in 2008 dollars.

Firm characteristics	Mean	Std. Dev.	10q	25q	50q	75q	90q
Per-share stock price ($)	42.0	22.7	17.9	25.6	37.3	52.8	69.6
Per-share book-value of debt ($)	238.3	254.3	61.2	103.9	160.4	282.4	409.7
Risk-free interest rate (%)	4.1	0.4	3.7	3.9	4.3	4.6	4.6
Standard deviation of debt returns (%)	3.1	0.1	2.9	2.9	3.0	3.2	3.2
Standard deviation of equity returns (%)	27.5	9.5	17.3	21.3	25.8	32.0	37.8
Est. std. dev. of returns on firm value (%)	5.7	2.8	4.0	4.5	5.1	5.9	7.1
Weight of equity (%)	10.4	6.9	5.6	7.4	9.0	10.5	14.3
Weight of debt (%)	89.4	7.9	85.6	89.4	91.0	92.6	94.4
Implied per-share market value of assets ($)	215.6	200.4	67.1	108.1	156.9	256.0	373.3
Per-share market value of assets ($)	280.0	270.4	85.2	134.2	201.4	333.4	476.3
Price-to-strike ratio	1.1	0.8	0.8	0.9	1.0	1.1	1.2

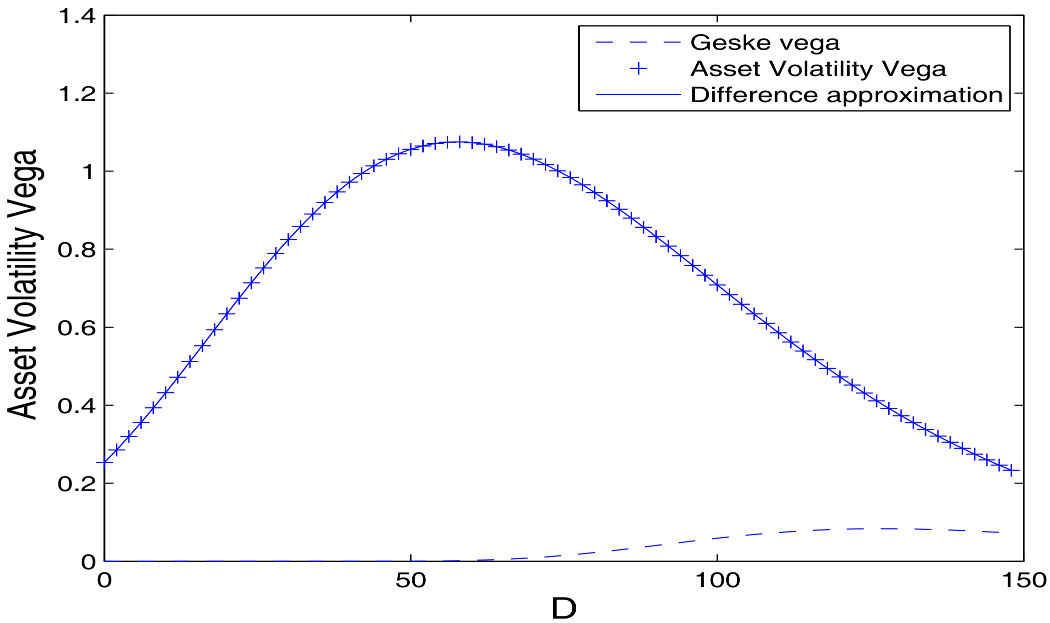

Figure B-1. Comparison of Asset Volatility Vegas for varying levels of debt, D, computed using three different approaches: The Geske (1979) approach (dotted line), our approach ("+") and the difference approximation (solid line). The parameters are $V = 110$, $K = 95$, $r = 0.04$, $\tau_2 = 10$, $\tau_1 = 6$ and $\sigma_V = 0.10$. $\Delta = 10^{-11}$ is used to calculate the difference approximation.

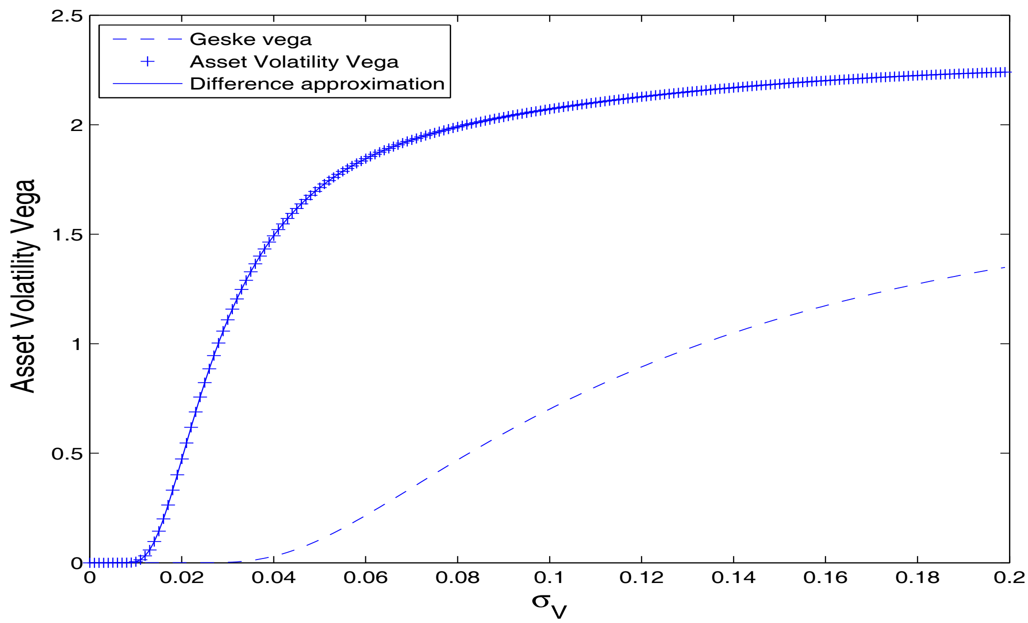

Figure B-2. Comparison of Asset Volatility Vegas for varying asset volatility, σ_V, computed using three different approaches: The Geske approach (dotted line), our approach ("+") and the difference approximation (solid line). The parameters are $V = 215$, $K = 95$, $r = 0.04$, $\tau_2 = 10$, $\tau_1 = 6$ and $D = 238$. $\Delta = 10^{-11}$ is used to calculate the difference approximation.

Figure and Tables for Main Text

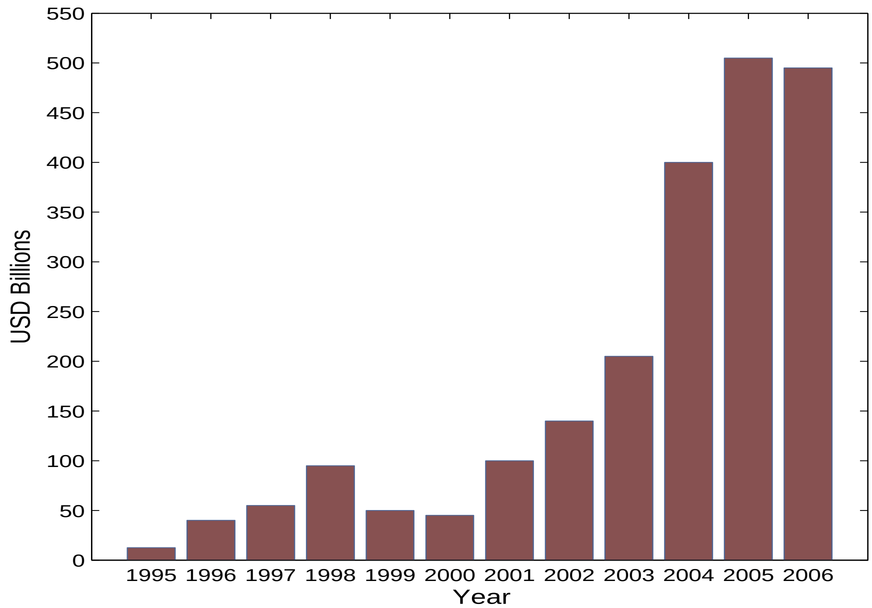

Figure 1. The development in subprime mortgage securitization over the years 1995-2006. Source: www.subprimer.org.

Table 1. Industry classification. A (*) denotes an industry in which financial institutions report a Tier-1 ratio.

Financial institutions	*2-digit SIC*	*SIC Code*	*Financial Service Industry*
Depository Institutions	60	6020	Commercial Banks*
		6035	Federal Savings Institutions*
		6036	Savings Institutions, Except Federal*
		6099	Functions Related to Depository Banking
Nondepository Credit Institutions	61	6111	Federal Credit Agencies
		6141	Personal Credit Institutions
		6159	Miscellaneous Business Credit
		6162	Mortgage Bankers and Loan Correspondents
		6172	Finance Lessors
		6199	Finance Services
Security Brokers and Dealers	62	6211	Security Brokers and Dealers

Table 2. Variable description.

Write-downs	
Write-downs (USD mill.)	The losses incurred by the financial institutions during the financial crisis period 2007Q3-2008Q4.
Write-downs scaled by total assets	Write-downs divided by a company's total assets.
CEO compensation measures	
Equity Volatility Vega (1000 USD)	The dollar change in the CEO's wealth for a 0.01 change in the standard deviation of returns.
Equity Delta (1000 USD)	The dollar change in the CEO's wealth with respect to a one percent change in the underlying stock price.
Asset Volatility Vega (1000 USD)	The dollar change in the CEO's wealth for a 0.01 change in the standard deviation of firm value returns.
Asset Delta (1000 USD)	The dollar change in the CEO's wealth with respect to a one percent change in the underlying firm value.
Total Compensation (1000 USD)	The CEO's total annual compensation (TDC1 in ExecuComp).
Firm Characteristics	
Market Cap. (USD mill.)	The market capitalization of the company
Total assets (USD mill.)	Total assets on the company's balance sheet.
Book-to-Market ratio (%)	Book value of assets over the market value of assets.
Book leverage (%)	Book leverage = 1 - (book value of equity / book value of assets)
Market leverage (%)	Market leverage = 1 - (market value of equity / market value of the financial institution) where market value of equity equals the number of shares times end-of-year stock price and the market value of the financial institution equals the market value of equity plus the book value of liabilities
Governance measures	
Percentage independent directors (%)	The fraction of directors on a board classified as independent.
Tenure	The number of years the CEO has been in office.
Governance index	The number of anti-takeover provisions a company has in place.

Table 3. Summary statistics of company specific variables, write-downs and the risk-incentive measures averaged over the years 2003-2006. All variables are winsorized at the 2nd and 98th percentile on an annual basis. The incentive measures are calculated using the assumptions detailed in the text and in the Appendix. "Asset Volatility Vega over Delta (V2)" denotes a second version of the ratio of Asset Volatility Vega and Asset Delta. In that version, we use Guay's (1999) assumptions for the standard deviation of debt returns, which implies somewhat higher asset volatilities than in our main case. For details, see the text. The regressions in Tables 5 and 6 use the main version of the incentive measures. The term "q" denotes the quantile, i.e., 10q refers to the 10th quantile in the empirical distribution of the particular variable. All monetary values are expressed in 2008 dollars.

	Mean	Std. Dev.	10q	25q	median	75q	90q
Write-downs							
Write-downs (USD mill.)	6644.3	16653.7	18.0	101.9	468.5	2981.1	21736.5
Write-downs scaled by total assets	0.055	0.082	0.003	0.012	0.029	0.066	0.140
CEO risk-taking incentives and compensation measures							
Equity Volatility Vega (1000 USD)	301.5	423.0	5.3	27.9	103.3	403.6	897.1
Equity Delta (1000 USD)	1130.9	1638.5	42.3	171.9	549.0	1264.1	2955.9
Equity Volatility Vega over Delta	0.35	0.30	0.03	0.10	0.30	0.52	0.74
Asset Volatility Vega (1000 USD)	3459.5	6538.0	39.7	161.4	930.9	3039.2	10660.5
Asset Delta (1000 USD)	6054.5	9627.8	203.5	651.5	2446.0	6742.3	17048.7
Asset Volatility Vega over Delta	0.49	0.34	0.10	0.23	0.44	0.67	0.93
Asset Volatility Vega over Delta (V2)	0.90	0.50	0.27	0.57	0.89	1.19	1.57
Total Compensation (1000 USD)	8237.4	10671.7	797.9	1535.8	3176.7	11103.8	23971.8
Firm characteristics							
Market Cap. (USD mill.)	15990.2	29386.6	693.1	1080.5	2811.2	15611.8	55234.6
Total Assets (USD mill.)	109778.4	240345.5	2535.8	5082.5	13798.2	79723.0	350432.6
Book-to-Market Ratio (%)	0.49	0.18	0.25	0.37	0.49	0.60	0.73
Book Leverage (%)	0.90	0.07	0.86	0.90	0.91	0.93	0.94
Market Leverage (%)	0.80	0.11	0.72	0.78	0.82	0.86	0.89
Governance measures							
Percentage independent directors	72.9	12.9	55.6	66.7	75.0	82.4	87.5
Tenure	7.7	5.8	2.0	3.0	6.0	11.0	16.0
Governance index	9.8	2.9	6.0	8.0	10.0	12.0	14.0

Table 4. Summary statistics of Asset Volatility Vega and Asset Delta divided into incentives coming from option and stock holdings, respectively, across the years 2003-2006 for all financial institutions in our sample. "Asset Volatility Vega over Delta" and "Equity Volatility Vega over Delta" represent the Asset Volatility Vega divided by Asset Delta and the Equity Volatility Vega divided by Equity Delta, respectively. The variables are winsorized at the 2nd and 98th percentile on an annual basis. The term "q" denotes the quantile, i.e., 10q refers to the 10th quantile in the empirical distribution of the respective variable. All monetary values are expressed in 2008 dollars.

Year	Variable	Mean	Std. Dev.	10q	25q	median	75q	90q
2003	Asset Volatility Vega							
	due to options	2718.9	4195.1	48.0	218.8	1063.4	3128.7	8908.9
	due to stocks	1526.5	3944.8	8.8	37.2	171.5	777.8	3682.5
	Asset Delta							
	due to options	3555.7	4662.5	135.7	380.1	1888.5	4546.6	10730.2
	due to stocks	2566.2	5046.2	61.1	226.7	769.4	2148.5	5864.3
	Asset Volatility Vega over Delta	0.63	0.37	0.20	0.33	0.61	0.88	1.09
	Equity Volatility Vega over Delta	0.37	0.25	0.05	0.16	0.36	0.52	0.77
2004	Asset Volatility Vega							
	due to options	2461.9	3929.3	53.4	197.7	938.6	2511.4	9498.3
	due to stocks	1754.6	5064.1	8.0	26.8	145.5	751.0	2808.3
	Asset Delta							
	due to options	3686.7	5212.6	136.0	422.7	1745.5	4429.1	10661.7
	due to stocks	2867.8	5939.3	91.5	237.8	848.3	2468.1	6682.0
	Asset Volatility Vega over Delta	0.55	0.32	0.14	0.32	0.52	0.74	0.96
	Equity Volatility Vega over Delta	0.36	0.24	0.05	0.14	0.31	0.57	0.70
2005	Asset Volatility Vega							
	due to options	2299.5	3526.1	91.7	198.3	906.4	2602.8	8460.8
	due to stocks	2045.5	6465.7	6.4	28.7	138.3	1048.5	2391.4
	Asset Delta							
	due to options	3846.3	5181.1	135.9	398.4	1724.0	4321.6	12509.7
	due to stocks	3687.9	9121.7	86.3	370.2	834.1	2411.4	6297.8
	Asset Volatility Vega over Delta	0.51	0.32	0.12	0.28	0.50	0.67	0.95
	Equity Volatility Vega over Delta	0.39	0.30	0.04	0.13	0.33	0.59	0.82
2006	Asset Volatility Vega							
	due to options	1557.9	2728.1	25.5	81.0	410.4	1783.0	3983.3
	due to stocks	879.8	2112.9	2.3	9.7	78.8	448.7	2029.6
	Asset Delta							
	due to options	2954.8	4278.2	75.8	248.6	1058.0	3515.9	11394.3
	due to stocks	2633.9	4307.1	86.6	219.4	792.5	2497.2	7519.0
	Asset Volatility Vega over Delta	0.40	0.30	0.07	0.17	0.37	0.50	0.70
	Equity Volatility Vega over Delta	0.29	0.24	0.03	0.09	0.23	0.42	0.60

Table 5. Regressions of log write-downs (left panel) and write-downs scaled by total assets (right panel) on CEO incentives and firm-level variables for each year for the financial institutions in our sample. All variables are winsorized at the 2nd and 98th percentile. Robust t-statistics are given in the parentheses and ***, ** and *, denote the statistical significance of the parameter estimates at the 1%, 5% and 10% levels, respectively.

	Log write-downs				*Write-downs scaled by total assets*			
	(2003)	(2004)	(2005)	(2006)	(2003)	(2004)	(2005)	(2006)
Log Asset Volatility Vega	0.56***	0.21	0.51**	0.03	0.0206	0.0138*	0.0141*	0.0003
	(3.78)	(1.01)	(2.24)	(0.35)	(1.65)	(1.68)	(1.88)	(0.17)
Log Asset Delta	-0.61***	-0.20	-0.57**	-0.01	-0.0333**	-0.0180	-0.0246	-0.0040
	(-3.13)	(-0.76)	(-2.19)	(-0.05)	(-2.18)	(-1.48)	(-1.65)	(-0.66)
Market leverage	6.06***	5.32***	5.21***	3.77***	0.1752	0.0850	0.0875	0.0417
	(3.99)	(3.47)	(4.11)	(3.28)	(1.27)	(0.74)	(0.68)	(0.59)
Log market cap	1.10***	1.08***	1.15***	1.18***	-0.0044	-0.0073	0.0004	0.0003
	(10.69)	(10.99)	(11.93)	(12.87)	(-0.57)	(-1.19)	(0.08)	(0.06)
Book-to-market	0.58	1.96	0.36	2.18**	-0.0089	0.0596	0.0061	0.0500*
	(0.58)	(1.52)	(0.40)	(2.48)	(-0.17)	(0.89)	(0.17)	(1.66)
Constant	-6.95***	-7.77***	-6.70***	-7.97***	0.0816	0.0682	0.0682	0.0087
	(-4.89)	(-5.46)	(-6.24)	(-7.93)	(0.98)	(1.05)	(1.40)	(0.25)
Industry fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	95	99	99	118	95	99	99	118
Adj. R^2	0.73	0.74	0.75	0.74	0.11	0.12	0.10	0.05

Table 6. Regressions of log write-downs (columns (1)-(7)) and log write-downs scaled by total assets (column (8)) on CEO incentives, firm-level and governance variables for 2006. All variables are winsorized at the 2nd and 98th percentile. Monetary values are measured in 2008 dollars. Robust t-statistics are given in the parentheses and ***, ** and *, denote the statistical significance of the parameter estimates at the 1%, 5% and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Asset Volatility Vega	0.27	0.24***	0.24***				-0.39***	-0.005
	(1.11)	(3.11)	(2.69)				(-3.41)	(-0.87)
Log Asset Delta	-0.38	-0.32*	-0.28*				-0.59	0.029
	(-1.28)	(-1.94)	(-1.72)				(-1.12)	(0.77)
Log Equity Volatility Vega				0.04	-0.01	0.03		
				(0.32)	(-0.05)	(0.24)		
Log Equity Delta				-0.18	-0.06	-0.05		
				(-0.92)	(-0.37)	(-0.35)		
Mkt lev. * Log Asset Vol. Vega							0.75***	0.012
							(3.64)	(1.19)
Mkt lev. * Log Asset Delta							0.40	-0.047
							(0.60)	(-0.86)
Market leverage	3.99*	4.04**	4.42**	5.21***	5.84***	6.25***	-1.15	0.323
	(1.89)	(2.57)	(2.50)	(2.92)	(2.76)	(2.70)	(-0.23)	(0.79)
Perc. Ind. Directors	0.00			0.00				
	(0.29)			(0.47)				
Tenure		0.01			0.01			
		(0.51)			(0.53)			
G-index			0.03			0.04		
			(0.62)			(0.84)		
Log market cap	1.32***	1.26***	1.25***	1.30***	1.23***	1.21***	1.22***	0.002
	(10.21)	(10.83)	(11.08)	(10.03)	(10.33)	(10.25)	(13.47)	(0.38)
Book-to-market	2.15*	1.67	1.81	2.76***	2.31**	2.46**	1.15	0.046
	(1.95)	(1.59)	(1.66)	(2.93)	(2.34)	(2.40)	(1.32)	(1.45)
Constant	-8.06***	-7.62***	-8.29***	-9.74***	-9.73***	-10.43***	-3.17	-0.211
	(-3.68)	(-5.47)	(-4.70)	(-6.03)	(-5.94)	(-5.68)	(-0.79)	(-0.76)
Industry fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	84	89	83	84	89	83	118	118
Adj. R^2	0.78	0.75	0.76	0.78	0.74	0.75	0.76	0.05