Bonus Caps, Deferrals, and Bankers' Risk-Taking[*]

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Abstract

Regulators restrict bankers' risk-taking incentives by using a bonus cap or by extending the effective bonus accrual period. We build a structural model to assess the effect of these bonus restrictions. The calibrated model suggests that extended bonus accrual periods alone do not lead to lower risk-taking while a sufficiently tight bonus cap does. A bonus cap that equals fixed salary (as in the EU) reduces risk on average by 13%.

Keywords: banking, bonuses, regulation, compensation, Dodd-Frank Act

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1 Introduction

In the aftermath of the global financial crisis that started in 2007, bankers' compensation has become a major issue both for banks' corporate governance and for regulation. The main question is whether large short-term bonuses spurred too much risk-taking that partly caused the crisis. For instance, Rajan (2005), who foresaw some of the key developments that eventually led to the crisis, emphasizes the role of short-term compensation. In response to the compensation concerns, both regulators and banks themselves have started to take restrictive measures on compensation. For instance, the European Union has imposed a bonus cap by limiting the bonus-per-salary ratio to one, subject to some flexibility, and is imposing guidelines for bonus deferrals with the possibility of maluses and clawbacks. In the United States, the Dodd-Frank Act introduces the possibility of clawbacks on bonuses.

Our contribution in this paper is to provide a quantitative assessment of the effectiveness of the adopted bonus restrictions on reducing bank risk. First, we develop a structural model for the value of a banker's future cash bonuses and derive her bonus-induced risk-taking incentives, both in the absence and in the presence of a bonus cap and a bonus deferral. Our model follows the line of research that takes the compensation contract as given and focuses on its effect on risk-taking (cf. Ross (2004)). Second, using data on US banks and their CEOs' compensation, we calibrate the model and simulate the effect of a bonus cap and a bonus deferral on the bankers' risk-taking. We show both theoretically and numerically that bonus deferrals may not lead to lower risk-taking while a sufficiently tight bonus cap does for many banks.

In the following we discuss our contributions in more detail. We use a standard continuous-time asset pricing framework to derive the theoretical value of a banker's future cash bonus stream, assuming no bonus caps or bonus deferrals beyond the standard one-year bonus accrual and payment period. We assume that the banker is risk neutral and has a fixed tenure.[1] For robustness, we also extend the model to consider a risk averse banker, and show that our results remain qualitatively the same under this extension. We measure the banker's risk-taking incentive by the derivative of the present

[1] Thanassoulis (2012) provides a thorough argumentation for the risk neutrality assumption.

value of the bonuses with respect to the bank's earnings volatility.[2] As bonuses are only paid out of positive earnings, they are like call options, and hence, the present value of future bonuses is a series of sequential call options on the bank's earnings. Further, since the call options are convex with respect to the earnings, a risk neutral banker would prefer to increase the earnings volatility as much as possible, by raising leverage or by buying riskier assets, if there were no costs to do that.

We show that bonus-induced risk-taking incentives depend on the size of the bonuses and the length of the bonus accrual period at the end of which the bonus is paid.[3] The latter determines the bonus frequency, that is, the number of bonuses paid out during the banker's tenure. Normally, bonuses are paid annually, but in our model, the bonus frequency can be chosen arbitrarily. Bonus size can be constrained by a bonus cap and bonus frequency by setting a minimum length to the bonus accrual period. We define this as the bonus deferral.[4]

We obtain three key theoretical results under risk-neutrality. First, we show that the series of cash bonuses are worth more the higher the bonus frequency is. In other words, it is more valuable to the banker to receive, say, 10 annual bonuses over a 10-year horizon than one bonus over a 10-year accrual period. Figure 1 illustrates the situation. This result is analogous to Merton (1973), who shows that a portfolio of options on individual stocks is worth more than an option on the basket consisting of those stocks.

[2]We define earnings as net income so that earnings volatility can be increased by increasing the bank's leverage and increasing the volatility of the bank's assets.

[3]In our baseline model, we assume that bonuses are paid as a fixed fraction of the bank's earnings if earnings are positive; for negative earnings, the bonus is zero. Murphy (1999) provides a detailed survey of compensation practices in the United States, where our data for banks come from. In Section 6 we extend the baseline model.

[4]The actual regulatory arrangements to decrease the bonus frequency seem to differ somewhat from the straightforward way that we model them. Deferral literally refers to the postponing of the bonus payment date, which may be beyond the end of the bonus accrual period. However, if losses result before the payment date, a malus may be imposed to cut the promised bonus (see e.g. Leisen (2014)). The term *bonus-malus* (which is Latin and means "good-bad") is used for a number of business arrangements, not only in banking, that alternately reward (bonus) or penalize (malus). Similarly, in case of wrongdoing being revealed, a clawback may be imposed, perhaps even on already-paid bonuses. Moreover, the bonus plus potential malus may apply specifically to transactions that were made during the bonus accrual period, but whose cash flows, including potential losses, may extend beyond the bonus accrual period. Hence, if a new bonus accrual period starts every year, there may be several overlapping bonus deferral periods active at the same time. Although we do not explicitly include such structures in our model, given the robustness of our results, our approach to model bonus deferrals gives the basic insights, and captures the essence of the effect on bankers' risk-taking of bonus deferrals.

Both Merton (1973) and our result are based on the convexity property of an option's payoff function. This result suggests that bankers, and similarly, for example, hedge fund and private equity managers, have a strong incentive to negotiate compensation contracts with short accrual and payment horizons.[5]

Second, we show that the higher the bonus frequency is, the higher the banker's risk-taking incentive is in terms of increasing her bank's earnings volatility. This formalizes the common notion that short-term bonus contracts can spur risk-taking. An immediate corollary of this result is that imposing a bonus deferral can help contain risk-taking. However, we also show that a deferral of any length maintains a positive risk-taking incentive for a risk-neutral banker. This implies that if there are nonnegative adjustment costs from reducing the bank's risk, a bonus deferral never leads to a lower risk-taking. However, in one of the model extensions we show that for a risk averse banker, a bonus deferral can induce an incentive to reduce risk if the (nonnegative) adjustment cost is sufficiently low.

Third, we show the rather obvious result that a bonus cap decreases the value of future bonuses by cutting the "upside" of a bonus above the threshold defined by the cap. More precisely, the bonus cap can be modeled as a short call option with an exercise price determined by the bonus cap rule. As a result, our baseline model for the present value of the banker's future cash bonus stream is augmented by a series of short calls, representing the bonus caps on the future bonus payments. We show that for a sufficiently tight cap the risk-neutral banker has an incentive to reduce risk even under a nonnegative adjustment cost.

The costs of changing the bank's risk position stem from several sources, such as compliance with current capital and liquidity regulations, market discipline, risk culture of the bank, the banker's risk aversion, other compensation components such as equity, and the cost of additional effort. Moreover, an obvious cost of increasing risk is due to

[5]In the hedge fund industry, the effect on risk-taking incentives of short payment horizons is at least partially controlled by the so-called high-water marks (see, e.g., Panageas and Westerfield (2009)). For instance, investor group AOI recommends that performance fees be paid not more frequently than once a year, rather than on a monthly or quarterly basis, as they are in many hedge funds (see Bloomberg, December 4, 2014, "Hedge Funds Urged to Beat Benchmarks Before Charging Fees," available at http://www.bloomberg.com/news/2014-12-03/hedge-funds-urged-to-beat-benchmarks-before-charging-fees.html).

a higher probability that the banker will lose her job as a result of poor performance. Because the various costs of changing the risk level are not fully observed, we model them with generic cost functions that we calibrate to our sample data.[6] In order to quantitatively assess the effect of bonus restrictions on bankers' risk-taking, in the policy simulations we calibrate the parameters of the cost functions in the context of the baseline model, excluding bonus caps and bonus deferrals. In the calibration of the cost functions, we use data from the period just before the global financial crisis. More specifically, we use a sample of 85 US banks and data on their balance sheets and CEOs' compensation during the period 2004–2006.[7] The pre-crisis data should be unaffected by any major expectations concerning possible bonus restrictions, which became a possibility soon after the crisis. We use the data on the eve of the crisis also because this gives us an idea of how bonus restrictions, had they been introduced then, might have affected the bankers' risk-taking.

In the model calibration, we assume that the historically estimated earnings volatility of each bank is at the optimal level for each bank CEO. The level of earnings volatility of each bank is such that the bank CEO does not want to change it, given the present value of her bonuses and the costs of changing the risk level. By assuming this optimality condition at the end of 2006, we get bank-specific cost parameters for both a piecewise linear cost function and a quadratic cost function. With the calibrated model, we then run the counterfactual analysis of a bonus cap and bonus deferral for each bank. Regarding the bonus cap, we limit the cash bonus to be no greater than the CEO's fixed salary. This case is motivated by the recent EU regulation.[8]

We find that on average bonus caps reduce banks' earnings volatility by 13% relative

[6]We believe that our approach of using the generic cost functions to model the cost of changing risk level is well suited for calibrating the model and then running the policy simulations. For instance, as other forms of compensation such as equity shares and option grants can have either negative or positive effects on risk-taking incentives, and since they are not explicitly included in our baseline model, our approach implicitly subsumes their net effect into the parameters of the cost function, which we calibrate. However, for robustness we also explicitly model option grants by extending our baseline model, adding them together with cash bonuses, and recalibrating the model to show that our results are qualitatively the same in both the settings.

[7]The sample is almost the same as the one used in Fahlenbrach and Stulz (2011). However, we have a few banks less than what they have because of the zero cash bonuses of some banks during the period 2004–2006 (we consider only banks with nonzero bonuses since they are affected by bonus regulations) and because of missing CEO tenure information or data points used to estimate earnings volatility.

[8]See Official Journal of the European Union, 27.6.2013, Article 94.

to the pre-crisis earnings volatility, depending on the calibration. We consider these estimates conservative because they are based on the assumption that the cost of increasing and decreasing risk is symmetric; i.e., like a switching cost. If the cost of reducing risk were lower than increasing risk, the effect of a bonus cap would be more pronounced. The bank-specific effect varies widely, from 0% to 100%, which is due to the nonlinear effect of the bonus cap. For instance, if the bank originally pays high bonuses, the pre-bonus cap risk-taking incentive is high, and, hence, a bonus cap of 100% of fixed salary can cut deep into the banker's risk-taking incentive and even turn it negative. On the other hand, if original bonuses are at the moderate level, a cap may have no effect. We also find that a bonus cap alone is not necessarily enough to reduce risk-taking in the riskiest banks because the high cost of changing risk in these banks may nullify the effect of the cap. Thus, in order to target the riskiest banks more effectively, our results suggest that a bonus cap would have to be complemented with measures that make sure the costs of reducing risk within a banking organization are not too high.

The results are qualitatively robust with respect to earnings volatility estimates and several extensions of the model, such as skewness of bank earnings, banker's risk aversion, banks' voluntary bonus caps, and explicit inclusion of option grants. Contrary to a common notion,[9] we find that a bonus cap remains effective, even if banks increase the CEO's fixed salary in response to a bonus cap to keep the expected value of the CEO's compensation unchanged, which in principal dilutes the effect of the bonus cap.

Regarding the bonus deferral, we consider cases where the bonus accrual period is two or five years, instead of the one-year standard, such that the bonus is paid out of the bank's cumulative earnings over the two-year or five-year period at the end of the two years or five years.[10] As already predicted by our theoretical result under risk-neutrality, in the presence of risk adjustment costs, bonus deferrals have no effect on the bankers' risk-taking, regardless of the length of the deferral. Under the calibrated adjustment

[9] See, e.g., Financial Times, March 30, 2016, "Fears over impact of cap on bankers' bonuses 'unfounded' ".

[10] See Official Journal of the European Union, 27.6.2013, Article 94(m), which says that "at least 40%, of the variable remuneration component is deferred over a period which is not less than three to five years." This rule could be interpreted as producing an approximately two-year bonus payment deferral. In practice, the amount of bonus may still be determined for each year based on that year's performance, but the actual payment is made only after two years. The deferred payment makes it possible to cancel the bonus if major losses materialize or; some wrongdoing is revealed ex post.

costs, which are quite high for most banks, the same applies also when the banker is risk averse. These findings cast doubt on the effectiveness of deferrals in reducing risk-taking.

Overall, our results suggest that a bonus cap as implemented in the European Union can be effective in reining in risk-taking, whereas bonus deferrals with the possibility for maluses and clawbacks as envisaged in the US Dodd-Frank Act seem ineffective. It is important to note that our analysis is mute on how much risk-taking is desirable and what should be considered excessive. Our aim in this paper is simply to assess the effectiveness of the various bonus restrictions in limiting risk-taking.

The paper is organized as follows. After a literature review in Section 2, the model setup is presented in Section 3. The value of the future bonus stream, considering also the effects of bonus caps and bonus deferrals, is derived in Section 4. Section 5 introduces the costs of changing risk and then the condition for determining the level of optimal risk-taking. Section 6 presents the bonus regulation analyses by using the calibrated model. Section 7 concludes.

2 Literature review

In this section, we briefly review the literature on risk-taking incentives related to compensation in corporations and banks. Some relevant studies also focus on the effect of ownership and the role of the board on risk-taking. We then discuss a selection of recent papers that are more directly related to our work.

Some studies find that the aggressiveness of managerial compensation does increase risk-taking in corporations (e.g., Coles et al. (2006) and Low (2009)). The reason to design such contracts is that managers are inherently too risk averse (e.g., Beatty and Zajec (1994)), which may, however, depend on the amount and composition of their personal wealth (see Korkeamaki et al. (2013)). Cheng et al. (2015) emphasize that risk can cause pay, not the other way round. High and performance-based compensation may simply be a way to attract managers to work in banks with high-risk strategies, and exert themselves to meet high performance targets. Interestingly, Houston and James (1995) do not find bankers' compensation to promote more risk-taking than in other industries, but they note that it is possible that in banks, risk-taking incentives are more hidden. Cain and McKeon (2014) show that risk-taking in corporations depends also on the CEO's personal risk preferences on top of the compensation-based risk-taking incentives. Hagendorff et al. (2015) show evidence that management style also affects risk-taking in banks. Leisen (2015) studies dynamic risk-taking incentives and a bonus scheme that gives a socially optimal level of risk-taking.

Related to bankers' compensation, Anderson and Fraser (2000) find that managerial ownership in banks is positively related to risk-taking, but that this relationship became negative (managerial ownership reduces risk-taking) in conjunction with regulatory changes in the United States around 1990. However, Westman (2014) finds that managerial ownership in European banks that benefit from government safety net had a negative impact on the banks' performance during the recent financial crisis. Leaven and Levine (2009) and Pathan (2009) show that banks' risk-taking may be determined at the level of a board that strongly represents shareholders' interests.

We next consider studies that are more directly related to our paper. The link between bankers' risk-taking incentives and the timing of their compensation is analyzed in several papers. The paper that provides most direct evidence that shorter-term compensation contracts increase risk-taking is Gopalan et al. (2014). Using a carefully constructed measure of executive compensation duration for both financials and non-financials, they show that CEOs with shorter pay durations are more likely to engage in myopic investment behavior. The average CEO pay duration of the 109 US banks in their sample is little more than one year. Makarov and Plantin (2015) study the incentive of fund managers to hide their risk-taking (by taking tail risk) and suggest long-term contracts that can discourage such behavior. Thanassoulis (2013) studies the emergence of a bonus deferral as a trade-off between motivating effort and managing myopia in managerial actions. However, not all papers agree that compensation duration is crucial for risk-taking. Acharya et al. (2014) show in a theoretical model that the impact of pay duration is minor. Their model is set in the context of a labor market competition for managerial talent. Our results are supportive of this view because we find that bonus deferrals are ineffective in incentivizing risk reduction if there are positive costs of changing the bank's risk position.

Thanassoulis (2012) considers the effect of bankers' compensation structure on the banks' default probabilities. Bonuses are valuable as a risk-sharing tool, but a bank-specific limit on the maximum share of bonuses of the balance sheet can reduce banks' default risk. Interestingly, he finds that stringent banker-specific bonus caps can also increase banks' default risk. In a subsequent paper, Thanassoulis (2014) argues that bonus caps can be a better regulatory device to reduce bank risk than a higher capital requirement, which would reduce bank lending to borrowers.

Fahlenbrach and Stulz (2011) show that "banks with higher option compensation and a larger fraction of compensation in cash bonuses for their CEOs did not perform worse during the crisis." This is consistent with our model since CEOs' risk-taking incentives depend not only on compensation but also on the costs related to risk-taking.[11] Unlike Gopalan et al. (2014), Fahlenbrach and Stulz do not use data on the actual vesting periods in CEOs' compensation packages. However, Fahlenbrach and Stulz find some evidence that CEOs with incentives better aligned with those of shareholders took more risks prior to the crisis. They conjecture that these CEOs took risks bona fide, believing that these risks looked profitable for shareholders. This could also give additional evidence reported in Leaven and Levine (2009) and Pathan (2009) that banks' risk-taking may be determined at the level of the board that strongly represents shareholders' interests, and as discussed in Haldane (2009), bank shareholders have incentives to increase risks because of deposit insurance and other government support mechanisms. Also, Murphy (2012) finds only little evidence that the pay structures provide incentives for risk-taking among top-level banking executives. According to Ellul and Yerramilli (2013), risk-taking among US banks depends on the strength and independency of risk management function.

Recent empirical papers that find that compensation-based risk-taking incentives in banks do increase risk-taking include Bhagat and Bolton (2013) and DeYoung et al. (2013) (see also Bhattacharyya and Purnanandam (2011), Balachandran et al. (2010), and Tung and Wang (2012)). Bhagat and Bolton (2013) study the development of total compensation of a sample of large US bank CEOs over the period 2000–2008 and find a link between compensation and risk-taking. DeYoung et al. (2013) measure a bank

[11] We obtain consistent results with Fahlenbrach and Stulz (2011) when we use similar data, ignore the costs of changing risk, and use our model's bonus-induced risk-taking measure (not reported for brevity).

CEO's contractual risk-taking incentives in the years preceding the crisis, ending their sample in 2006, and relate risk-taking incentive measures with the bank's future stock price volatility. They find evidence that stronger contractual risk-taking incentives for CEOs lead to higher risks. The effects are largest and most persistent in the biggest banks. Further, they argue that deregulation around 2000 was the reason contractual risk-taking incentives were raised, especially in the biggest banks. These results partly contrast with the empirical results of Fahlenbrach and Stulz (2011). The different conclusions may reflect the fact that, while DeYoung et al. (2013) use stock return data until 2006 to measure banks' risk, Fahlenbrach and Stulz (2011) focus precisely on the crisis time banks' stock returns. The advantage of focusing on the crisis returns is that, almost by definition, they capture the tail risks that materialized in the crisis. Exposures to these risks may not have been fully reflected in banks' stock return variation prior to the crisis. Another reason for the different results may be the different ways they measure compensation-based CEOs' risk-taking incentives.

More generally, our paper is also related to principal-agent models (see, e.g., Grossman and Hart (1983), Holmstrom (1979, 1982, 1983, 1999), Holmstrom and Milgrom (1991, 1994), Myerson (1982), Rogerson (1985), and Sannikov (2008)).[12] Hakanes and Schnabel (2014) and Thanassoulis and Tanaka (2015) analyze the various principle-agent problems and compensation structures within banks that operate under implicit government guarantees. Further, they consider the role of bonus restrictions such as caps, maluses, and clawbacks in solving the incentive problems. In the present paper, we do not use the principal-agent modeling framework, but take the bankers' compensation contracts as given and calibrate the costs of changing risk from banks' actions. We then focus on counterfactual analysis of changes in risk-taking due to regulatory changes. We believe our framework is well suited to assess the effectiveness of the various bonus regulation policies. Further, since we model also the cost of changing risk, our approach implies that one cannot make predictions of a bank's risk level and/or performance during the crisis solely on the basis of the compensation contracts the bank offers to its top management; the cost of changing risk matters as well. Acharya et al. (2014) show ev-

[12]See also Inderst and Mueller (2004) and Mueller and Inderst (2005) for models in which convex pay components, such as stock options and bonuses, can be used to solve for various efficiency problems arising in the principal-agent setting.

idence that risk-taking incentives of nonexecutives ("middle-managers") are important for understanding banks' risk-taking. Our model could well be applied to nonexecutive risk-taking as well if data were available to calibrate the model for that case.

3 Model

We consider a risk-neutral banker who receives bonuses with a certain frequency during her tenure $[0, T]$. Thanassoulis (2012) provides a thorough discussion on the plausibility of the risk neutrality assumption, and uses that assumption also in his model of banker pay. Further, in Section 6 we consider a risk averse banker in one of our model extensions, and find our main results to be robust. The banker's bonuses are paid as a fixed fraction of the bank's earnings. The earnings equal the change in the bank's equity value; hence, earnings depend on the change of the bank's asset value and its leverage.

There are two assets: a risk-free asset and a risky asset. The risky asset is the bank's main business, that is, its loan portfolio, and the risk-free asset is a source of leverage. The bank debt is risk-free in our model, and its dynamics are given by

$$B(t) = \exp(rt),$$

where r is the risk-free rate and $r > 0$. Thus, when the bank borrows money from the market, it sells bonds, so that the holding is negative and its borrowing cost is the risk-free rate.[13]

Under the risk-neutral probability measure Q (for more on risk-neutral pricing, see,

[13] This is approximately correct due to deposit insurance and other government support mechanisms; see for example, Haldane (2009). Further, the CDS spreads of our sample banks depend on the bank size, indicating that big banks have a lower funding cost. This could be due to their too-big-to-fail status.

e.g., Duffie (2001)), the risky asset follows[14]

$$dS(t) = S(t)rdt + S(t)\sigma dW(t), \tag{1}$$

where $S(t)$ is the risky asset value and $S(0) > 0$, σ is the volatility and it satisfies $\sigma > 0$, and $W(t)$ is a standard Wiener process under Q. We denote by $\{F_t\}$ the information filtration generated by the Wiener process. Thus, F_t is the information at time t. If the bank has a highly risky loan portfolio, then σ is high. Further, the loan portfolio dynamics are after all operational costs. In one of our robustness checks in Section 6 we consider a situation where the expected return of the risky asset is twice the risk-free rate indicating a high alpha for the loan portfolio, and show that our main results are qualitatively unchanged.

The banker selects the fractions invested in the risk-free and risky assets, and after that, the bank controls its asset holdings in continuous time in such a way that it keeps the fractions constant. Since the bank uses leverage, it has a negative holding in the risk-free asset. Then it invests all its equity and debt into the risky asset which comprises its loan portfolio. Therefore, under the risk-neutral probability measure Q, the bank's net portfolio value, that is, its equity value, evolves according to (see, e.g., Merton (1971))

$$dA(t) = A(t)rdt + A(t)\sigma_\theta dW(t), \tag{2}$$

where $A(t)$ is the equity value and $A(0) > 0$, the earnings volatility $\sigma_\theta = (1+\theta)\sigma$,[15] and

[14] The continuous time process can be viewed as an approximation of the discrete time process: $S(t+\Delta t) - S(t) = S(t)\left(\hat{\imath}\Delta t - \sum_{z=1}^{N(\Delta t)} L_z\right)$, where $\hat{\imath}$ is the interest rate paid by the bank's customers and $\hat{\imath} > r$, $N(\Delta t)$ is the number of customers defaulted in the Δt period, and it follows a Poisson process with parameter ν, $\{L_z\}$ represents losses in case of default, and they are i.i.d. positive random variables with mean $E[L_z] = \mu_L$ and standard deviation $\sigma_L = \sqrt{E[L_z^2] - E[L_z]^2}$ for all z. By time change, normalization of the state space, and the central limit theorem, compound Poisson process $\sum_{z=1}^{N(\Delta t)} L_z$ converges in distribution to a standard normal random variable (see, e.g., Durrett (1996)), and therefore, we model the risky asset dynamics as in (1), with $r = \hat{\imath} - \nu\mu_L$ and $\sigma = \sqrt{\nu}\sigma_L$. For robustness, we also consider a jump-diffusion process in Subsection 6.2, and show that our main results are qualitatively unchanged.

[15] Note that the equity volatility equals the earnings volatility, as we have assumed that the change of equity value equals earnings and the asset return volatility equals the unlevered earnings volatility.

θ is the bank debt relative to the equity value. Thus,

$$\theta = -\frac{n_B(t)B(t)}{A(t)},$$

where $n_B(t)$ is the bond holding (negative) at time t. This gives $n_B(t) = -\theta A(t)/B(t)$; the bank adjusts its borrowing all the time to keep θ constant.[16] For instance, when the equity $A(t)$ falls, then the bank borrows less. Note that this model structure implies that the bank cannot go bankrupt since the equity is positive. By the model structure, the bank is able to continuously adjust its leverage in response to changes in the equity value (so that θ is constant), and this guarantees that the bank is always able to pay to the bond holders in full.[17]

We analyze how the earnings volatility σ_θ affects the compensation value. Note again that σ_θ rises in θ and σ; the banker can increase risk by increasing the leverage and/or the risky asset volatility, and here we do not focus on the mechanism of how the banker changes σ_θ (but clearly, there are two ways).

From (2) we get

$$A(t) = A(0)\exp\left(\left(r - \tfrac{1}{2}\sigma_\theta^2\right)t + \sigma_\theta W(t)\right) \tag{3}$$

or

$$A(t_2) = A(t_1)\exp\left(\left(r - \tfrac{1}{2}\sigma_\theta^2\right)(t_2 - t_1) + \sigma_\theta[W(t_2) - W(t_1)]\right),$$

where $t_2 > t_1$ and, by the definition of the Wiener process, $W(0) = 0$.

For calculating the banker's compensation, tenure $[0, T]$ is divided into n equal length intervals, where n is bounded. That is, $\Delta = T/n$, where Δ is the length of the interval, and n is the number of bonus payout periods. At the end of each interval, the bank pays a bonus to the banker, and the bonus depends on the change of the equity value during the time period. More specifically, at the end of i'th interval, the bonus payoff is given

[16] The equity and risky asset are related through $A(t)(1 + \theta) = n_S(t)S(t)$, where $n_S(t)$ is the holding of risky asset, which is adjusted continuously so that θ is constant.

[17] Allowing for the possibility of the banks bankruptcy would affect our model because the bankers bonus stream would be discontinued after the bankruptcy. We considered this by using a Merton (1974) style model with a fixed level of debt and found that, given the empirical parameters we use to calibrate our model in Section 6, the probability of bankruptcy is very low and does not materially affect our quantitative results in Section 6.

by

$$\Pi(A(i\Delta), A((i-1)\Delta)) = k \max[A(i\Delta) - A((i-1)\Delta), 0] \tag{4}$$

for all $i \in \{1, 2, \cdots, n\}$, where $k \in (0, 1)$, and it represents the fraction of earnings paid out as compensation to the banker. Thus, at the end of each time interval, the bank pays bonus to the banker if the equity value has risen. Further, we assume that the banker's compensation is so small relative to the earnings that we can ignore its effect on the equity dynamics (see Table 1 and the statistics for k there). However, in one of our robustness checks, we relax this assumption (see Subsection 6.2) and show that our main results are qualitatively unchanged.

For example, if $n = 1$, then we have just one payoff, and this happens at time T:

$$\Pi(A(T), A(0)) = k \max[A(T) - A(0), 0].$$

4 Value of the compensation

In this section, we first analyze how the bonus frequency affects the compensation value and the banker's risk-taking incentives.[18] More specifically, in Subsection 4.1 we model the incentives given the equity dynamics (2) and the bonuses (4). After that, we extend the model to include a bonus cap in Subsection 4.2.

Let us define the following Black and Scholes (1973) call option price with strike price K:

$$\begin{aligned} C(\Delta, K) &= E\left[\exp(-r\Delta) \max\left(\tfrac{A(\Delta)}{A(0)} - K, 0\right)\right] \\ &= \Phi(d_1(\Delta)) - K \exp(-r\Delta)\Phi(d_2(\Delta)), \end{aligned} \tag{5}$$

where $\Phi(x) = \int_{-\infty}^{x} \phi(y)dy$ is the standard cumulative normal distribution function, and

[18]The bonus frequency is defined as the reciprocal of the bonus accrual period during the banker's tenure $[0, T]$. In other words, given the banker's tenure T, the higher the number of bonus payment periods n is, the shorter the bonus accrual period, and the higher the bonus frequency. Since the banker's tenure depends on the compensation contract, which is fixed in our model, we refer to n as the bonus frequency implicitly.

$\phi(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$ is the standard normal density function,

$$d_1(\Delta) = \frac{1}{\sigma_\theta\sqrt{\Delta}}\left[\ln\left(\frac{1}{K}\right) + \left(\frac{1}{2}\sigma_\theta^2 + r\right)\Delta\right], \quad d_2(\Delta) = d_1(\Delta) - \sigma_\theta\sqrt{\Delta}.$$

Thus, $C(\Delta, K)$ is Δ-maturity European call option on $\frac{A(\Delta)}{A(0)}$ with strike price K. Our model can be extended to more complicated asset processes, such as a jump-diffusion process for the assets (see, e.g., Merton (1976) and Kou (2002)), and then this changes the pricing of $C(\Delta, K)$, and the rest of our analysis is the same. In Subsection 6.2, we indeed apply Merton's jump-diffusion model to analyze the robustness of our results.

4.1 Compensation value without bonus cap

By the risk-neutral pricing and (4), the present value of the banker's compensation package is given by

$$\begin{aligned} \pi_n &= \sum_{i=1}^{n} E\left[\exp(-ri\Delta)\Pi(A(i\Delta), A((i-1)\Delta))\right] \quad (6) \\ &= \sum_{i=1}^{n} E\left[\exp(-ri\Delta)k \max[A(i\Delta) - A((i-1)\Delta), 0]\right]. \end{aligned}$$

Thus, the compensation package is a series of sequential call option contracts. The number of contracts in the sequence depends on Δ. For instance, if $\Delta = T$, then π_1 equals one call option with maturity date T. By (6) and iterated expectation, we get the following result:

Proposition 1 *The value of the compensation package with n payout periods on $[0, T]$ is given by*

$$\pi_n = nkA(0)C(T/n, 1),$$

where $C(T/n, 1)$ is the call option price in (5), k is the fraction of earnings paid out as compensation, and $A(0)$ is the initial equity value in (2).

Proof: By (6) and iterated expectation, we get

$$\begin{aligned}\pi_n &= \sum_{i=1}^{n} E\left(\exp(-ri\Delta)kA((i-1)\Delta)\max\left[\frac{A(i\Delta)}{A((i-1)\Delta)}-1,0\right]\right) \\ &= \sum_{i=1}^{n} E\left[E\left(\exp(-ri\Delta)kA((i-1)\Delta)\max\left[\frac{A(i\Delta)}{A((i-1)\Delta)}-1,0\right]|F_{(i-1)\Delta}\right)\right] \\ &= \sum_{i=1}^{n} E\left[\exp(-r(i-1)\Delta)kA((i-1)\Delta)E\left(\exp(-r\Delta)\max\left[\frac{A(i\Delta)}{A((i-1)\Delta)}-1,0\right]|F_{(i-1)\Delta}\right)\right] \\ &= \sum_{i=1}^{n} \exp(-r(i-1)\Delta)kC(\Delta,1)E\left[A((i-1)\Delta)\right]\end{aligned}$$

and, since $E\left[A((i-1)\Delta)\right] = A(0)\exp(r(i-1)\Delta)$, we get the result. □

Thus, the value of the compensation equals the sum of $nkA(0)$ many call options with maturity $\Delta = T/n$ and strike price $K = 1$. From Proposition 1, we get the following corollary:

Corollary 1 *Let* $0 < r < \sigma_\theta^2\left(1+\sqrt{\frac{5}{4}+\frac{1}{\sigma_\theta^2 y}}\right)$ *for all* $y \in \left(0, \frac{T}{n}\right]$*. Then* π_n *rises in* n*, i.e.,* $\pi_{n+1} \geq \pi_n$*.*

Proof: By Boyle and Scott (2006), the constraint on r gives a sufficient condition for $C(y,1)$ being increasing and concave in y for all $y \in \left(0, \frac{T}{n}\right]$. Let us set $n = k$, and then, since π_n is continuous in n, we have

$$\begin{aligned}\pi_{k+1}-\pi_k &= \int_k^{k+1}\frac{\partial \pi_n}{\partial n}|_{n=i}di = kA(0)\int_k^{k+1}\left(C(T/i,1)-\frac{T}{i}\frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=T/i}\right)di \\ &= kA(0)\int_k^{k+1}\left(\int_0^{\frac{T}{i}}\frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=y}dy-\frac{T}{i}\frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=T/i}\right)di \geq 0,\end{aligned}$$

where $k \in \{1,2,\cdots\}$. The inequality holds because $C(y,1)$ is concave for all $y \in \left(0, \frac{T}{k}\right]$, and thus, we have $\frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=y} \geq \frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=T/i}$ for all $y \in \left(0, \frac{T}{i}\right]$, which gives $C(T/i,1)-\frac{T}{i}\frac{\partial C(\Delta,1)}{\partial \Delta}|_{\Delta=T/i} \geq 0$. □

Corollary 1 is a sufficient condition for $C(\Delta,1)$ being increasing and concave for all $\Delta \in \left(0, \frac{T}{n}\right]$, and this guarantees $\pi_{n+1} \geq \pi_n$. Even though it is possible to find parameter values, where $C(\Delta,1)$ is locally convex in Δ,[19] all the compensation contracts analyzed

[19]For instance, $A(0) = 100$, $r = 0.06$, $\Delta = 0.2$, and $\sigma_\theta = 0.02$ (see Boyle and Scott (2006)).

in this paper have $\pi_{n+1} \geq \pi_n$ since the opposite result would require convexity for a wide range of Δ values.

Since the compensation value is a series of sequential call options, the value rises in the earnings volatility σ_θ, such that $\frac{\partial \pi_n}{\partial \sigma_\theta} > 0$, and by Proposition 1 and Black and Scholes (1973), we get the formula for the bonus vega:

$$\frac{\partial \pi_n}{\partial \sigma_\theta} = nkA(0)\frac{\partial C(T/n,1)}{\partial \sigma_\theta} = nkA(0)\exp(-rT/n)\sqrt{T/n}\phi(d_2(T/n)), \tag{7}$$

where $\phi(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$ is the standard normal density function. Now we can state the following corollary that gives how the vega changes with respect to n.

Corollary 2 *The sensitivity of the compensation value with respect to the earnings volatility σ_θ rises in the number of payout periods n:*

$$\frac{\partial \pi_{n+1}}{\partial \sigma_\theta} \geq \frac{\partial \pi_n}{\partial \sigma_\theta} > 0.$$

Proof: Since $r > 0$, $\sigma_\theta > 0$, and $\Delta > 0$, we have

$$\begin{aligned}
\frac{\partial^2 \pi_n}{\partial \sigma_\theta \partial n} &= kA(0)\left[\frac{\partial C(\Delta,1)}{\partial \sigma_\theta} - \frac{\partial^2 C(\Delta,1)}{\partial \sigma_\theta \partial \Delta}\Delta\right] \\
&= kA(0)\left[\frac{\sqrt{\Delta}}{8\sigma_\theta^2\sqrt{2\pi}}\exp\left(-\frac{\Delta(2r+\sigma_\theta^2)^2}{8\sigma_\theta^2}\right)\left(4r^2\Delta + 4\sigma_\theta^2 + 4r\Delta\sigma_\theta^2 + \Delta\sigma_\theta^4\right)\right] > 0.
\end{aligned}$$

This gives

$$\frac{\partial \pi_{n+1}}{\partial \sigma_\theta} - \frac{\partial \pi_n}{\partial \sigma_\theta} = \int_n^{n+1} \frac{\partial \pi_k}{\partial \sigma_\theta \partial k}|_{k=i} di > 0.$$

By (7), $\frac{\partial \pi_n}{\partial \sigma_\theta} > 0$ for all $n > 0$. □

By Corollary 2, the shorter the time period $\Delta = T/n$ is, the stronger the effect of the earnings volatility on the compensation value. This implies that bankers with short-term compensation packages have a high incentive to increase leverage and/or their business risk if the cost of changing the risk level is not considered. This is consistent with Gopalan et al. (2014; see prediction 2), who find that the pay duration is shorter for firms with more volatile cash flows.

Figure 2 illustrates the compensation value (Corollary 1) and risk-taking incentives (7), that is, bonus vega ($\frac{\partial \pi_n}{\partial \sigma_\theta}$) with respect to the number of bonus payout periods for an example bank when the cost of changing the risk level is not considered. Note that the higher the number, the shorter the compensation time interval Δ. As can be seen, both the compensation value and the vega are positive and increasing in the number of periods. Thus, by our model and the numerical example of Figure 2, the higher the bonus payment frequency is, the higher the compensation value and the risk-taking incentives. However, vega is substantially higher only if the payment interval is shorter than one year, that is, for n larger than 10.

Figure 3 illustrates the compensation value and risk-taking incentives with respect to the earnings volatility. As can be seen, the compensation value rises in the earnings volatility, while the risk-taking incentive is low at very small volatility values but rises rapidly.

4.2 Compensation value with bonus cap

We next extend the model to include a bonus cap. Let M be the bonus cap for each Δ-period; M is the maximum bonus during the Δ-period. Then from Proposition 1, we get the following result:

Corollary 3 *The value of the compensation package with n payout periods on $[0, T]$ and bonus cap M in each payout period is given by*

$$\tilde{\pi}_{n,M} = nkA(0) \left\{ C(\Delta, 1) - \frac{1}{n} \sum_{i=1}^{n} E \left[C \left(\Delta, 1 + \frac{M}{kA(0)} \exp \left(\left(\tfrac{1}{2}\sigma_\theta^2 - r \right) (i-1)\Delta + \sqrt{(i-1)\Delta}\sigma_\theta \varepsilon_i \right) \right) \right] \right\}$$

where $\Delta = T/n$, $A(0)$ is the initial equity value in (2), σ_θ is the earnings volatility, r is the risk-free rate, k is the fraction of earnings paid out as compensation, $\{\varepsilon_i\}$ are independent standard normal random variables, and $C(\Delta, K)$ is the call option price in (5).

Proof: Let us consider i'th Δ-period. By (4) and the definition of the bonus cap, if $k[A(i\Delta) - A((i-1)\Delta)] \geq M$, then the bonus is capped at M. Therefore, we have the following bonus payoff:

$$\tilde{\Pi}\left(A(i\Delta), A((i-1)\Delta)\right) = k \max\left[A(i\Delta) - A((i-1)\Delta), 0\right] - k \max\left[A(i\Delta) - \left(\chi + A((i-1)\Delta)\right), 0\right],$$

where $\chi = M/k$ and M is the maximum bonus during the Δ-period.[20] By Proposition 1, the compensation value is the sum of expected discounted payoffs:

$$\begin{aligned}\tilde{\pi}_{n,M} &= \sum_{i=1}^{n} E\left[\exp(-ri\Delta)\tilde{\Pi}\left(A(i\Delta), A((i-1)\Delta)\right)\right] \\ &= \pi_n - k \sum_{i=1}^{n} E\left[\exp(-ri\Delta) A((i-1)\Delta) \max\left[\frac{A(i\Delta)}{A((i-1)\Delta)} - \frac{\chi + A((i-1)\Delta)}{A((i-1)\Delta)}, 0\right]\right]\end{aligned}$$

which, with iterated expectations, (3), and (5), gives the result. □

Next, we consider the bonus vega of the compensation package with the bonus cap, and give the following result:

Corollary 4 *The sensitivity of the compensation value under a bonus cap with respect to the earnings volatility can be negative; that is,* $\frac{\partial \tilde{\pi}_{n,M}}{\partial \sigma_\theta} < 0$ *for sufficiently low* M*.*

Proof: We consider a special case with $n = 1$. Then the bonus vega is given by

$$\frac{\partial \tilde{\pi}_{1,M}}{\partial \sigma_\theta} = kA(0)\left[\frac{\partial C(\Delta, 1)}{\partial \sigma_\theta} - \frac{\partial C(\Delta, 1 + \frac{M}{kA(0)})}{\partial \sigma_\theta}\right] = kA(0)\left[\phi(d_2(\Delta)) - \phi(d_3(\Delta))\right],$$

where

$$d_2(\Delta) = \frac{1}{\sigma_\theta\sqrt{\Delta}}\left[\left(r - \frac{1}{2}\sigma_\theta^2\right)\Delta\right], \quad d_3(\Delta) = \frac{1}{\sigma_\theta\sqrt{\Delta}}\left[\ln\left(\frac{1}{1 + \frac{M}{kA(0)}}\right) + \left(r - \frac{1}{2}\sigma_\theta^2\right)\Delta\right].$$

[20] Thus, when earnings $A(i\Delta) - A((i-1)\Delta) < \chi$, then the bonus equals

$$\tilde{\Pi}\left(A(i\Delta), A((i-1)\Delta)\right) = k \max\left[A(i\Delta) - A((i-1)\Delta), 0\right] < M,$$

and when earnings $A(i\Delta) - A((i-1)\Delta) \geq \chi$, then

$$\tilde{\Pi}\left(A(i\Delta), A((i-1)\Delta)\right) = k\left[A(i\Delta) - A((i-1)\Delta)\right] - k\left[A(i\Delta) - (\chi + A((i-1)\Delta))\right] = M.$$

Therefore, if $r - \frac{1}{2}\sigma_\theta^2 > 0$ and $-\left(r - \frac{1}{2}\sigma_\theta^2\right)\Delta < -\ln\left(1 + \frac{M}{kA(0)}\right) + \left(r - \frac{1}{2}\sigma_\theta^2\right)\Delta$, so that if

$$0 < M < kA(0)\exp\left(2\left(r - \frac{1}{2}\sigma_\theta^2\right)\Delta\right) - 1,$$

we have $\phi(d_2(\Delta)) - \phi(d_3(\Delta)) < 0$, which implies $\frac{\partial \tilde{\pi}_{1,M}}{\partial \sigma_\theta} < 0$. □

This result is important since it indicates that bonus caps alone can create incentive to decrease the risk level. Note that, by Corollary 2, bonus deferrals alone cannot do that.

5 Optimal risk level

In this section, we solve the banker's optimal level of risk by including the costs of changing the risk level to our model. As discussed in the introduction, the costs of increasing risk may arise from several sources, such as market discipline, regulatory capital requirements, other forms of compensation such as equity that may make the banker more risk averse, and the banker's own career concerns as a result of poor performance.[21] Similarly with risk reduction, the stronger the risk-taking culture within the bank, the more "costly" it is to reduce risks. Overall, there may be costs from adjusting a bank's risk strategy one way or another, arising from changing the overall portfolio that includes illiquid assets and from a need to adjust internal systems and processes. To assess the total effect of bonus regulations, both the costs of changing the bank's risk position and the effect on bonus-induced risk-taking incentives need to be considered. So far in this paper we have focused on the incentives, but in order to do the counterfactual analysis for changes in bonus regulations, we need to include the cost of changing the bank's risk position. We do not explicitly model the sources of those costs; instead, we use generic cost functions.

By (2), the banker takes risk with high leverage θ and/or with low asset quality which we define as a high volatility, σ, of the risky asset. The costs of changing the risk position are a function of the change of the earnings volatility σ_θ. Further, we use a

[21] Interestingly, Savaser and Ciamarra (2015) find that corporate managers take less risk, given their pay for performance, in recessions than in macroeconomic expansions. They argue that this is consistent with their changing risk aversion. In our framework, this would imply that the cost of changing the bank's risk level depends on the macroeconomic state of the economy.

common form for the cost function but with individual cost parameters for each bank. Thus, given the bonus compensation, the banker's objective is to maximize her net value which is the value of the compensation minus the cost:

$$\max_{\Delta\sigma_\theta \geq -\sigma_\theta} \{\tilde{\pi}_{n,M}(\sigma_\theta + \Delta\sigma_\theta) - F(\Delta\sigma_\theta)\}, \tag{8}$$

where we write $\tilde{\pi}_{n,M}$ explicitly as a function of earnings volatility $\sigma_\theta = (1+\theta)\sigma$, $\Delta\sigma_\theta$ is the change of current σ_θ, and $F(\cdot)$ is the cost of changing the earnings volatility.[22] The optimization constraint in (8) means that the earnings volatility cannot be negative.

We use two alternative cost functions:

- piecewise linear: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$
- piecewise quadratic: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$

where c_+ and c_- are cost parameters for volatility increase and decrease, and $I\{\cdot\}$ is an indicator function, i.e.,

$$I\{Y\} = \begin{cases} 1 & \text{if } Y \text{ is true} \\ 0 & \text{otherwise.} \end{cases}$$

The higher the c_+ parameter is, the more the volatility increase is penalized. On the other hand, the smaller the c_- parameter is, the less costly it is to reduce the risk.

By our model, the total risk-taking incentive depends on the banker's compensation and the costs of changing risk. Therefore, measures of compensation-induced incentives alone do not predict the bank's risk level or changes of that. This is consistent with Fahlenbrach and Stulz (2011), who show that the ratio of US bank CEOs' bonuses relative to fixed salaries at the end of 2006 does not predict the banks' stock price performance during the crisis of 2007–2008. Using almost the same data, we replicate their result by ignoring the cost of changing risk: the CEO's risk-taking incentive (vega) derived from Proposition 1 from the model without the cost of changing risk, does not predict the banks' stock price returns during the crisis (not reported for brevity). Hence,

[22] The reason to specify the cost function in terms of the change in the risk level rather than in the level of risk is to use more general functions that have different costs for risk increases and decreases. Further, this simplifies the optimality condition in (11) since when σ_θ is optimal then $\Delta\sigma_\theta$ is zero.

this and the results in Fahlenbrach and Stulz (2011) are consistent with our model with the cost of changing risk.

By (8), regulators have in principal three ways to affect bankers' risk-taking: (*i*) limit compensation and in this way decrease bankers' incentive for risk-taking (lower M and/or decrease n), (*ii*) increase the cost of increasing risk-taking (increase c_+), and (*iii*) decrease the cost of decreasing risk-taking (decrease c_-). An example of (*i*) is bankers' bonus cap in EU (European Union, 2013). Trading book's market risk requirement within the Basel capital adequacy framework is an example of (*ii*) since the more a bank trades or, more specifically, the higher its trading book's value at risk is, the more it should finance itself with equity capital. Basel II's risk weights represent an example of (*iii*) since lowering the risk weights of certain asset classes rewards banks to hold more those assets.

Here we focus on (*i*) and analyze the earnings volatility changes under the two cost functions above and different bonus caps and bonus frequencies. By Corollary 3, the bank regulators can limit bankers' risk-taking by introducing a bonus cap (parameter M) and the frequency of bonuses (parameter n). More specifically, let $\hat{\sigma}$ be regulators' upper bound on the earnings volatility σ_θ. Then the regulators face the following problem: find the range of bonus cap M and bonus frequency n values such that

$$\hat{\sigma} \geq \sigma^*_{n,M}, \tag{9}$$

where the optimal earnings volatility is given by

$$\sigma^*_{n,M} = \sigma_\theta + \arg\max_{\Delta\sigma_\theta \geq -\sigma_\theta} \left\{ \tilde{\pi}_{n,M}(\sigma_\theta + \Delta\sigma_\theta) - F(\Delta\sigma_\theta) \right\}. \tag{10}$$

Since we do not know $\hat{\sigma}$ or the parameters of the cost function F, we analyze (9) as follows. We use a sample of US banks' CEO bonuses and accounting data from 2004 to 2006. The data are introduced in Subsection 6.1. We calculate the cost function parameters for each bank using one of the alternative cost functions and assuming that at the end of 2006, each bank's risk level is optimal in the sense that the banker does not want to change its earnings volatility σ_θ. The cost function parameters are such that the earnings volatility in 2006 of each bank equals the model's $\sigma^*_{T,\infty}$ in (10), i.e.,

$$\arg \max_{\Delta\sigma_\theta \geq -\sigma_\theta} \{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - F(\Delta\sigma_\theta)\} = 0, \tag{11}$$

where σ_θ is the earnings volatility at the end of 2006. This condition gives a range of cost function parameter values. For both cost functions above, we have three methods to select the parameters from this set: (i) common estimate for c_+ and c_- by a max-min method: we first select the smallest c_+ and c_- parameter values that satisfy (11), and then select the maximum among these two and set both c_+ and c_- equal to that; (ii) different c_+ and c_- estimates: we simply select the smallest c_+ and c_- parameter values that satisfy (11); and (iii) c_- equals zero: c_+ is as in (ii) but c_- is set to zero. We have the following result:

Lemma 1 *If there are no bounds on the cost parameters and if initially there are no bonus caps, then the smallest cost parameter c_- that satisfies the optimality condition (11) is negative.*

Proof: By the optimality condition (11), for the quadratic cost function we have,

$$c_- \geq \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2},$$

and by Corollary 2, $\frac{\partial \tilde{\pi}_{T,\infty}(\sigma_\theta)}{\partial \sigma_\theta} > 0$, we have

$$\max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2} < 0.$$

This implies that the smallest value of $c_- < 0$ that satisfies (11) is negative. The case for the linear cost function is similar, which is omitted here. □

Thus, if c_- is not bounded to be positive, and if there is no bonus cap initially, then $c_- < 0$. However, this is not realistic but rather illustrative since most likely there are substantial costs in changing banks' asset portfolios or business lines. Therefore, we use cost parameter selections (ii) and (iii) above as robustness checks for our results. To gain more realistic estimates of risk reductions due to bonus caps, we mostly use (i) under which the cost of changing risk, either increasing or decreasing, is symmetric.

Given the cost function parameters, in the next section, we study the effect of bonus caps and deferrals on the bank CEO's optimized σ_θ. Intuitively, the effect of a bonus restriction (either a bonus cap or a deferral) works as follows. When the restriction is imposed, the banker reduces risk only if the marginal increase in the value of her future bonuses exceeds the marginal cost of reducing risk. She continues to reduce risk until the marginal gain in the value equals the marginal cost. It is also possible to have a corner solution in which the banker loads off all risk implying that the marginal gain in value minus the marginal cost stays positive until zero-risk level is reached.

Next, we analyze the effect of bonus caps and bonus deferrals on the optimal earnings volatility. Let σ_θ be the initial optimal earnings volatility in (11), which gives the parameter values in the cost function F. Then regulators introduce a bonus cap and/or a bonus deferral, and the banker reacts by solving a new earnings volatility $\sigma^*_{n,M}$, where M is the positive bonus cap and n is the new bonus frequency and it satisfies $n \leq T$. Thus, we use the cost function parameters from (11), and then, we solve the new optimal risk level $\sigma^*_{n,M}$ from (10) under the calibrated cost parameters, where n is the regulatory number of bonus payments during the banker's tenure T and M is the bonus cap.

By Corollary 4, if regulators introduce a bonus cap, we have the following result and the proof is in Appendix A.1.

Proposition 2 *Even if $c_- \in (0, \bar{c}_-)$, there is bonus cap $M > 0$ such that $\sigma^*_{T,M} < \sigma_\theta$, where T is the initial bonus frequency, σ_θ is the initial earnings volatility in (11), and $\bar{c}_- = \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} > 0$. If $c_- \leq 0$, bonus caps decrease the earnings volatility, i.e., $\sigma^*_{T,M} < \sigma_\theta$ for all bounded bonus caps.*

The above result indicates that a bonus cap alone can cut risk-taking, and in that sense, it is effective if the cost of changing risk is not so high that it exceeds the benefit of reducing risk. This is not the case with bonus deferrals. In particular, we have the following result if there are no bonus caps, and the proof is in Appendix A.2.

Proposition 3 *With bonus deferrals while without bonus caps (i.e., $n < T$ and $M = \infty$), we have the following:*

- *If $c_- \geq 0$, then bonus deferrals do not decrease the earnings volatility, i.e., $\sigma^*_{n,\infty} \geq$*

σ_θ for all $n < T$, where T is the initial bonus frequency and σ_θ is the initial earnings volatility in (11).

- *If $c_- < 0$, then bonus deferrals do not increase the earnings volatility, i.e., $\sigma^*_{n,\infty} \leq \sigma_\theta$ for all $n < T$.*

The above result means that bonus deferrals alone cannot decrease risk if the cost of decreasing risk is nonnegative. Thus, the only way bonus restrictions can be effective is to introduce a bonus cap or to have other incentives to decrease risk that gives $c_- < 0$.

6 Policy simulations

In this section, we use the calibrated model to study the effect of bonus caps and bonus deferrals, applied separately or jointly, on the CEO's optimized risk level in terms of earnings volatility σ_θ. More specifically, we calculate five different cases with the alternative cost functions. The first three cases are as follows. (i) The bonus cap equals the CEO's base salary at 2006; we solve $\sigma^*_{T,S}$ in (10), where S is the annual base salary. (ii) The bonus accrual and payment period is two years; bonuses accrue over a two-year period and are paid at the end of that period, which gives $\sigma^*_{T/2,\infty}$. (iii) The bonus accrual and payment period is two years and the bonus cap equals the CEO's total base salary during those two years, i.e., $\sigma^*_{T/2,2S}$. All these cases are motivated by the current EU regulations on bonus policies (see European Union, 2013). Cases (iv) and (v) simply replicate cases (ii) and (iii) by considering the bonus accrual and payment period of five years. Note that regarding the implementation of the bonus deferral policy, the bonus cap is calculated based on the cumulative base salary over the bonus accrual period: one, two, or five years.[23] Further, note that for simplicity, we ignore salary rises.

In Subsection 6.1, we first describe the data used to calibrate the model parameters, and then in Subsection 6.2, we present the results for cases $(i)-(v)$ above. We also make several important extensions to the baseline model in order to check the robustness of our results based on the baseline cost parameters.[24]

[23]The way we combine a bonus cap and a bonus deferral does not exactly match the details of the EU regulations. However, we consider the bonus cap with several bonus frequencies and find our qualitative results to be robust.

[24]The baseline model refers to the theoretical model presented in Section 4, the baseline cost param-

6.1 Data

To calibrate the parameters of the cost functions introduced in Section 5, we use the US bank accounting and CEO compensation data from Compustat and BankScope. In our sample, we have 85 banks, and the banks are almost the same as in Fahlenbrach and Stulz (2011). Some banks did not pay cash bonuses to their CEOs during the period 2004–2006, and they are not included in our sample, since in our model calibration, parameter k in (4) is zero for these banks (and thus, the risk-taking incentive is also zero). Further, we do not include those banks in Fahlenbrach and Stulz (2011) that did not have CEOs' tenure information in our dataset or data points used to estimate earnings volatility.

Variables needed in calculating bankers' risk-taking incentive measure (the vegas henceforth) are calculated as follows. Parameter k is the average of CEO cash bonus divided by net income in years 2004–2006. We use the average of those years because a large part of the sample banks paid zero bonus in 2006.[25] Asset return volatility is the annualized volatility estimated from the time series of quarterly net income divided by the book value of assets from 2000Q1 to 2006Q4,[26] and θ is the bank debt over equity in book values at 2006Q4. For robustness, we also consider σ-estimate based on data from 2000Q1 to 2008Q4; that is, we include the crisis of 2007–2008 in our sample. This can be viewed as a crude proxy for the possibility that banks had a higher, partly forward-looking earnings volatility estimate at the end of 2006 than just the historical earnings volatility estimate. By equation (2), σ and θ give the earnings volatility σ_θ. Table 1 shows that the estimated earnings volatility for an average bank almost triples when we use data until 2008Q4 instead of 2006Q4. So including the crisis period constitutes an interesting robustness check.

The Δ parameter, measuring the bonus frequency, is set at one year. Parameter T, the remaining tenure of the CEO, is estimated by taking the minimum of 10 years and the difference between the CEO's retirement age and her current age. The retirement

eters refer to the cost parameters with $c_- = c_+$, and the baseline case refers to the calibration of the baseline model with the baseline cost parameters.

[25]This may be a somewhat crude approximation, as a zero bonus in a certain year may result from the bank missing its earnings target before bonuses can be paid (see Murphy, 1999).

[26]Our measure of return on assets is net income over the book value of total assets, which is the same as used, for example, by Fahlenbrach and Stulz (2011).

age is common for all CEOs in the sample and is proxied by the highest CEO age in the data, which is 77 years. Admittedly, this is a crude proxy with which we settled in the absence of more detailed information of individual CEO contracts. The cap of 10 years on the remaining CEO tenure is motivated by studies on average CEOs' tenures.[27] However, as a robustness check, we also calibrate the model by assuming a CEO tenure cap of 15 years.

6.2 Results

6.2.1 Baseline model

Consistent with Lemma 1, in the absence of bonus caps and any cost parameter restrictions, the cost parameter c_- is negative when the model is calibrated according to equation (11). Table 3 shows that in this case both bonus caps and even bonus deferrals would lead to risk reductions, bonus caps having the stronger effect. For comparison, Table 4 presents risk reductions by assuming that c_- is set at zero. Then, as expected by Proposition 3, bonus deferrals alone no longer have any effect, while bonus caps continue to have a sizeable average risk-reducing effect. However, neither of these cases is realistic but rather illustrative since most likely there are substantial costs in changing banks' asset portfolios or business lines. To gain more realistic estimates of risk reductions due to bonus caps, we assume that the cost of changing risk, either increasing or decreasing, is symmetric: we set $c_- = c_+$. The interpretation of this is that there is a switching cost to changing the bank's strategic risk position.

Table 5 provides results for this baseline case. Focusing on Case I, the average risk reduction due to bonus caps varies between 7.68% and 20.06%, depending on the shape of the cost functions. The bank-specific effect varies widely. Some banks have no effect, while others completely off-load the risk. The right panel of Figure 4 illustrates why this happens: the effect of a bonus cap on the risk-taking incentive (vega) is highly nonlinear. Table 6 further indicates that the bank-level risk reduction correlates positively with bank size and the share of bonus from earnings, k. Hence, banks that originally pay high bonuses provide a high risk-taking incentive to the banker. A bonus cap causes a

[27] For instance, Kaplan and Minton (2012) find that CEO turnover for a sample of large US companies was 15.8% from 1992 to 2007, implying an average CEO tenure of less than seven years.

relatively big cut in bonuses in such banks and thereby strongly reduces the banker's risk-taking incentive. However, if the banker's cost of changing risk is high, the bonus cap may remain ineffective under the symmetric cost of changing risk. In banks with only moderate bonuses, a bonus cap does not make a big difference.

If the regulatory aim of a bonus cap is to reduce bank risk-taking, then a bonus cap should be most effective in banks with the highest levels of risk. In Table 6 we measure the correlation between risk reduction and four different measures of risk: a bank's asset return volatility, leverage, crisis time stock return and a simple measure of systemic risk. We do this under two assumptions concerning the cost of reducing risk: $c_- = 0$ and $c_- = c_+$. The correlations are quite weak, sometimes of unexpected sign, and statistically insignificant especially under $c_- = c_+$ (note that the signs for "stock crisis return" and "systemic risk" are as expected).

Table 7 takes a further look on this. It lists the ten most risky banks in our sample, measured either by their earnings volatility or just leverage. The two right-most columns list the corresponding risk reductions under the two assumptions regarding the cost of reducing risk. The results show that if reducing risk is costless, then the bonus cap does induce strong risk reduction in most of the riskiest banks. However, considering the symmetric switching cost of changing risk, the bonus cap has virtually no effect in these banks. Hence, a bonus cap alone is not enough to reduce risk-taking in the riskiest banks when the cost of reducing risk is taken into account.

In general, these results suggest that regulation should focus on risky banks, and use measures that directly target their risks. In our model this means high earnings volatility or just high leverage (which is easier to measure). This could be achieved, e.g., with a bonus cap that applies to banks with tier 1 capital ratio below a certain threshold level (e.g. 10%). Further, to improve the effectiveness of incentive-based regulation such as bonus caps, regulation could also include policies that make sure that the costs of reducing risk within banking organizations are low. This could be achieved, e.g., by reducing excessive regulation for low risk banking businesses.

6.2.2 Extensions

In Appendixes D and E, we consider several extensions of our model. Overall, they confirm the relative effectiveness of bonus caps over bonus deferrals.

Bonus payments and equity value dynamics

Table 8 reports the results for risk reductions when the value of bank equity drops after a bonus payment. Note that in the baseline model (2) and Table 5, we assume that the banker's compensation is so small relative to the equity value that we can ignore its effect on the equity dynamics (see Table 1 and the statistics for k there). We see that risk reductions of bonus caps (Case I) of Table 8 are quite similar to those in Table 5, although they are somewhat more sensitive to the shape of the cost functions. Interestingly, in the case of linear cost function and 15-year maximum tenure for the CEOs, risk increases as a result of the two-year bonus deferral (Case II). This is because bonus deferrals can raise vega when the equity falls after the bonus payment.

Option grants

Option grants also affect bankers' risk-taking incentives. In the calibrated baseline model, the state variable that determines the amount of bonus paid in each bonus accrual period is earnings. We could use the same model and interpret the state variable as bank equity value, which determines the value of the managerial option grants. However, because bankers take risk in our model by choosing the level of the earnings volatility, we modify the model by using the (equity) price-to-earnings ratio to transform earnings volatility into equity return volatility by using the empirical relationship from Vuolteenaho (2002). Finally, the banker's bonus value function is augmented by the value of the option grants.

Data on option grants are obtained from Equilar. We use the vesting period of a CEO's option grants as the maturity of the options, effectively applying a conservative assumption that the CEO would exercise the options immediately when they vest. Note that in this case, the model has to be recalibrated so that the new cost parameters also reflect the presence of option grants. Tables 9 and 10 report the cost parameters and the risk reductions, respectively, when the option grants are also considered in the bankers' objective function. With bonus caps, the average risk reductions are in some cases even bigger than in Table 5. Bonus deferrals continue to have no effect.[28] Overall, explicitly including option grants in the model does not qualitatively change our baseline results.

Internal bonus caps

Some banks may have applied internal bonus caps voluntarily as a part of their bonus programs (see Murphy, 1999). However, we do not have detailed data on those for years 2006 and earlier to calibrate our model (to keep our calibration independent of possible expectations regarding post-crisis bonus regulations). Gauging bonus per salary ratios in our bank CEO data over the period 2004–2006, we find that the majority of banks have paid bonuses which are at most five times higher than CEOs' fixed salaries. But a few "outliers," especially the big investment banks, have paid bonuses up to 20–30 times the fixed salary. In order to check the robustness of our results against possible internal bonus caps, we do two things. First, we consider our baseline results separately for the subsample of the five big investment banks (which are Merrill Lynch, Bear Stearns, Morgan Stanley, Lehman Brothers, and Goldman Sachs) because their high bonus-per-salary ratios suggest they did not apply internal bonus caps. Second, we recalibrate our model for all banks assuming that the banks with bonus-per-salary ratios higher than five did not have internal bonus caps (i.e., our baseline model applies), while the other banks had a bonus cap of five times their CEOs' fixed salaries. For the latter group, we apply the model with a bonus cap when calibrating their cost parameters. The risk reduction analysis (not reported for brevity) shows that big investment banks are not affected by bonus caps (or bonus deferrals). The reason is that the calibrated costs of changing risk are high for these banks.

Table 12 provides results for the second case in which we assume that some banks applied an internal bonus cap five times the fixed salary. Interestingly, the risk reductions are clearly bigger than those in our baseline case in Table 5. Bonus deferrals in turn lead to risk increases in many banks. This is because the cost parameters calibrated under the internal bonus cap are smaller than those without the cap and bonus deferrals with the time-scaled internal bonus cap due to a longer bonus accrual period can increase the vega.

[28] Note that in our model we have applied deferral only on cash bonuses. In the European Union, deferral applies to all variable pay in a given period, including exercised option grants.

Effect of bonus cap on fixed salary

When bonus caps are introduced, banks could raise fixed salaries to compensate the loss for the managers. One consequence of this might be that the effect of the cap is "diluted" because the cap is defined in relation to the amount of fixed salary. We take this into consideration as follows: In Table 13, we assume that the annual fixed salary is augmented at the end of 2006 in such a way that the present value of the total compensation (salary plus the bonus paid every year without a bonus cap) during the CEO's tenure is equivalent to the expected total compensation after the introduction of the bonus cap (i.e., augmented fixed salary plus bonus paid every year subject to a bonus cap, which is equivalent to the augmented fixed salary).

Somewhat surprisingly, with the augmented fixed salary, the risk reduction for the average bank due to a bonus cap is even higher than that in the baseline model. In other words, the intuition that augmenting fixed salary would dilute the effect of the cap and hence lead to less risk reductions does not hold on average. A closer look reveals, however, that the standard deviation of risk reductions is larger with the augmented fixed salary than in the baseline case, and individual bank results confirm that for some banks, risk reductions are bigger, while for others, smaller than in the baseline case. These results can be explained with Figure 4 (right panel). If the bonus cap (M) is very large and hence not binding, then this situation is close to the baseline case in which the banker's vega is positive (because of the scale of the figure, this is hard to visualize). For smaller caps that become binding, the vega becomes negative, but the effect is not monotone: there is a large negative hump after which vega converges to zero as the cap goes to zero (i.e., the case with no bonuses allowed). Our sample banks are partly scattered around the hump range. This implies that the augmented fixed salary, which does make the bonus cap less binding for all banks, has differential effects on individual banks' vegas. For some banks, vega becomes less negative (those that reduce risk less than in the baseline case with a bonus cap), while for others, vega becomes more negative (those that reduce risk more than in the baseline case with a bonus cap). So on average, even if banks raise fixed salaries in response to a bonus cap, the effect of the bonus cap is not watered down; we find that the average risk reduction is actually higher than in the baseline case.

Effect of skewness

Banks' true return probability distributions may have a substantial negative skewness. We model this by a jump-diffusion process in Merton (1976) for the banks' earnings. To focus on earnings skewness and its implications for the effectiveness of bonus restrictions, we assume that the banker can only change the skewness and the higher-order moments of the earnings while the mean and variance are constant. More specifically, we assume that the equity dynamics follow the jump-diffusion process:

$$\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t),$$

where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. Note that, as in (2), the expected instantaneous earnings equal $A(t)rdt$ (so the mean is constant). The banker can only change the jump size to alter the skewness and the higher-order moments of the bank's earnings, while the probability of the jump (we assume 10% annually) and the mean and standard deviation of the earnings are kept fixed. The second moment is given by

$$\sigma_\theta^2 = \sigma^2 + \lambda u^2,$$

and it is kept constant by changing σ when u changes, where σ is the volatility of the diffusion part in the jump-diffusion process. The cost parameters and risk reduction results with the jump-diffusion model are presented in Tables 14–16. In this case, we measure risk reductions relative to the size of the jump. As expected, the bonus deferrals have no effect on risk-taking, but now the risk reduction effect of bonus caps is also negligible. Thus, we conclude that bonus caps and bonus deferrals do not have substantial effect on the banker's incentive, net of costs, to change the degree of skewness of the earnings distribution.

Alternative earnings volatility estimate

Tables 20–26 in Appendix E replicate the baseline case and the extensions by using systematically higher earnings volatility estimates. These alternative earnings volatility estimates are obtained by including the crisis years 2007 and 2008 in the estimation period. These partly "forward-looking" volatility estimates provide a crude proxy for tail risks that materialized in the crisis but are not captured by the historical estimation period we use from 2006 backward. This is essentially an attempt to control for the possibility that some banks knowingly increased tail risks. The results are again qualitatively the same as in the baseline case in Table 5.

Risk averse banker

Lastly, we consider the extension that the banker is risk averse. So far in this paper we have focused on the case of a risk-neutral banker, and produced a number of both theoretical and numerical benchmark results. The common view often cited in the literature is that bankers (generally, managers) are given bonuses (or options) to increase their risk appetite. Accordingly, they are modeled to be risk averse (see e.g. Ross (2004)). Hence, bonuses can be used to align the risk-taking incentives of the banker with those of the shareholders, if shareholders are more willing to take risk. As in our benchmark model under risk-neutrality, if the regulator prefers a lower level of risk-taking from the viewpoint of financial stability, the regulator can use a bonus cap or bonus deferral (or both) to achieve this lower risk level. The analysis in the following is otherwise the same as in the benchmark model but now the banker's objective function (the present value of her future bonuses minus the cost of changing risk) is the following, reflecting her risk aversion:

$$U_{n,M}(\sigma_\theta + \Delta\sigma_\theta) = E\left[\frac{W_{n,M}^{1-\gamma}(\sigma_\theta + \Delta\sigma_\theta)}{1-\gamma}\right] - F(\Delta\sigma_\theta), \tag{12}$$

where $W_{n,M}(\sigma_\theta) = \sum_i^n \min[k \max[A(i\Delta) - A((i-1)\Delta), 0], M]$, we set $\gamma = 0.5$, and $A(t)$ is the equity process in (2).[29] Note that we maintain the assumption that the bank's asset dynamics are risk-neutral; see (1). However, as a robustness check, we also simulate the loan portfolio dynamics (1) by doubling the expected return, which gives $2r$ and then the expected return of equity value in (2) is higher and rises in the risk level. We find that our results are qualitatively the same under this extension (not reported for

[29]Bankers' risk aversion is captured by $\gamma > 0$, $\gamma \neq 1$. Parameter value $\gamma = 2$ is used, e.g., in Mehra and Prescott (1985) and Keppo and Petajisto (2014). We use $\gamma = 0.5$ instead in order to have a relatively large utility value to avoid the potential numerical errors in the risk reduction simulation. Note that under $\gamma = 0.5$, the utility function is concave and, thus, the banker is risk averse.

brevity).

Since the objective function (12) now considers the banker's risk aversion, we need to re-calibrate the cost parameters for the bonus regulatory analysis. The cost parameters are calibrated such that

$$\arg \max_{\Delta\sigma_\theta \geq -\sigma_\theta} U_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) = 0,$$

where σ_θ is the earnings volatility at the end of 2006. The smallest cost parameters are reported in Table 17. Compared to the cost parameters calibrated freely in the risk-neutral case in Table 2, we see that now for some banks the cost of decreasing (increasing) risk can be positive (negative). The reason is that in the risk averse banker's objective function (12), the utility function is concave, so that the expected utility depends increasingly on the variance of $A(\Delta) - A(0)$ that has a negative impact on the expected utility. Hence, for some bank CEOs the vega of the expected utility of future bonuses has been negative at the end of 2006 under the model with risk aversion.

We have also analyzed the risk averse banker with the earnings volatility estimate at the end of 2008, and the results are qualitatively the same as with the 2006 earning volatility (not reported for brevity). Table 19 provides the risk reduction results under the different bonus restrictions. This is the case that we consider the more realistic, corresponding to the baseline case in Table 5, in which we assume that the cost of changing risk is symmetric and non-negative. The results are qualitatively the same as in Table 5. With symmetric positive cost of changing the risk level, bonus deferral has no impact while the bonus cap can have a significant impact.

It is possible that with zero cost (or even positive costs of small magnitude) of reducing risk, a bonus deferral can lead to risk reduction when the banker is risk averse. This is demonstrated in Table 18. In some banks a bonus deferral turns the vega of the expected utility of the banker's future bonuses from positive to negative. These numerical results imply that the first result of Proposition 3 does not necessarily hold under a risk averse banker. This is broadly consistent with Ross (2004) who shows that the net effect on risk-taking from the interaction between a convex compensation schedule and concave utility is generally indeterminate, and Leisen (2014) who shows in a somewhat different modelling setup that the effect of a bonus deferral on risk-taking can vary.

7 Conclusions

In this paper, we have modeled a banker's future bonuses as a series of sequential call options on the bank's earnings and show that bonuses provide the higher risk-taking incentive, the shorter the bonus accrual period is and the higher the bonuses relative to fixed salary are. The banker's total risk-taking incentive is a joint effect of compensation, her risk preferences, and the costs of changing risk. With positive risk adjustment costs, bonus deferrals are impotent, while bonus caps can have a sizeable effect. This is because a sufficiently tight cap provides an incentive to reduce risk, which may exceed the cost of reducing risk.

We calibrate our model to a sample of US banks and their CEOs' bonuses, and find that increasing the bonus accrual period to two or five years from the standard one year has no effect on risk-taking. Capping the bonus to be no larger than fixed salary — an equivalent of the new EU regulation — reduces the banker's optimized risk level. The average risk reduction is 13% depending on the model specification, with wide bank-specific variations. These results are qualitatively robust with respect to earnings volatility estimates and several model extensions, such as skewness of bank earnings, banks' voluntary bonus caps, explicit inclusion of option grants, bankers' risk aversion, and allowing for the possibility that banks increase fixed salary in response to a bonus cap. However, a bonus cap alone is not necessarily enough to reduce risk-taking in the riskiest banks because their high cost of changing risk position may nullify the effect of the cap. To improve the effectiveness of incentive-based regulation such as bonus caps, regulation could include policies that make sure that the regulation focuses on risky banks and that the costs of reducing risk within banking organizations are low.

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Appendix A Proofs

A.1 Proof of Proposition 2

Proof: Since c_+ and c_- satisfy (11), for the quadratic cost case, we have

$$
\begin{aligned}
c_+ &\geq \max_{\Delta\sigma_\theta > 0} \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2}, \\
c_- &\geq \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2}.
\end{aligned}
$$

We first argue that $\sigma^*_{T,M} \leq \sigma_\theta$. By Corollary 4, $\frac{\partial\tilde{\pi}_{T,M}(\sigma_\theta)}{\partial\sigma_\theta} \leq \frac{\partial\tilde{\pi}_{n,\infty}(\sigma_\theta)}{\partial\sigma_\theta}$ and, thus for $\Delta\sigma_\theta > 0$ we have

$$
\frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} \leq \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{\Delta\sigma_\theta^2} \leq c_+,
$$

which implies that $\Delta\sigma_\theta > 0$ cannot be optimal if there exists a bonus cap, that is, $\sigma^*_{T,M} \leq \sigma_\theta$. For all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, we have

$$
\frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} \geq \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{\Delta\sigma_\theta^2},
$$

and by Corollary 4, for a certain range of M values,

$$
\frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} > 0,
$$

which implies if

$$
c_- < \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2}.
$$

Therefore, under the above condition, even if $c_- > 0$, there exists the bonus cap $M > 0$, such that $\Delta\sigma_\theta < 0$ is optimal, that is, $\sigma^*_{T,M} < \sigma_\theta$. If $c_- \leq 0$, since c_- satisfies the optimality condition (11), and $M > 0$ is bounded, then by Corollary 4, either for all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$,

$$
\frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} > c_-,
$$

or at least for some $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$,

$$\frac{\tilde{\pi}_{T,M}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,M}(\sigma_\theta)}{\Delta\sigma_\theta^2} > c_-,$$

which implies $\sigma^*_{T,M} < \sigma_\theta$. The linear cost function case can be proved in the same way, which is omitted here. □

A.2 Proof of Proposition 3

Proof: We first prove the first statement. By Corollary 2, in this case $\frac{\partial \tilde{\pi}_{n,\infty}(\sigma_\theta)}{\partial \sigma_\theta} > 0$ for all $\sigma_\theta > 0$ and, therefore, for the linear cost with $c_- \geq 0$, we have

$$\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - F(\Delta\sigma_\theta) = \tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) + c_-\Delta\sigma_\theta \leq \tilde{\pi}_{n,\infty}(\sigma_\theta),$$

for all $\Delta\sigma_\theta \in [-\sigma_\theta, 0]$. This gives the result for the linear cost function. The quadratic cost function case can be proved in the same way (omitted here for brevity).

We then prove the second statement. By Corollary 2, for the quadratic cost case, we have for any $n < T$

$$\frac{\partial \pi_{n,\infty}}{\partial \sigma_\theta} \leq \frac{\partial \pi_{T,\infty}}{\partial \sigma_\theta},$$

which implies if $\Delta\sigma_\theta > 0$, then

$$\frac{\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2} \leq \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2},$$

which implies $\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta) \leq \tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta) \leq c_+(\Delta\sigma_\theta)^2$, where c_+ is defined in the proof of Proposition 2. Therefore, $\Delta\sigma_\theta > 0$ is not optimal for $n < T$. If $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, then

$$\frac{\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2} \geq \frac{\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta)}{(\Delta\sigma_\theta)^2},$$

which implies $\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta) - c_-(\Delta\sigma_\theta)^2 \geq \tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{T,\infty}(\sigma_\theta) - c_-(\Delta\sigma_\theta)^2$. Since by (11) for any $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, $\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) - c_-(\Delta\sigma_\theta)^2 \leq \tilde{\pi}_{T,\infty}(\sigma_\theta)$, one of the three cases holds:

- For all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, $\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta) - c_-(\Delta\sigma_\theta)^2 \geq 0$, under which $\sigma^*_{n,\infty} \leq \sigma_\theta$.
- For all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, $\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta) - c_-(\Delta\sigma_\theta)^2 \leq 0$, under which $\sigma^*_{n,\infty} = \sigma_\theta$.
- For some $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, $\tilde{\pi}_{n,\infty}(\sigma_\theta + \Delta\sigma_\theta) - \tilde{\pi}_{n,\infty}(\sigma_\theta) - c_-(\Delta\sigma_\theta)^2 \geq 0$, under which $\sigma^*_{n,\infty} \leq \sigma_\theta$.

Thus, the optimal earnings volatility under bonus deferral cannot be larger than the initial optimal earnings volatility, that is, $\sigma^*_{n,\infty} \leq \sigma_\theta$ for all $n < T$. The linear cost function case can be proved in the same way, which is omitted here. □

Appendix B Figures

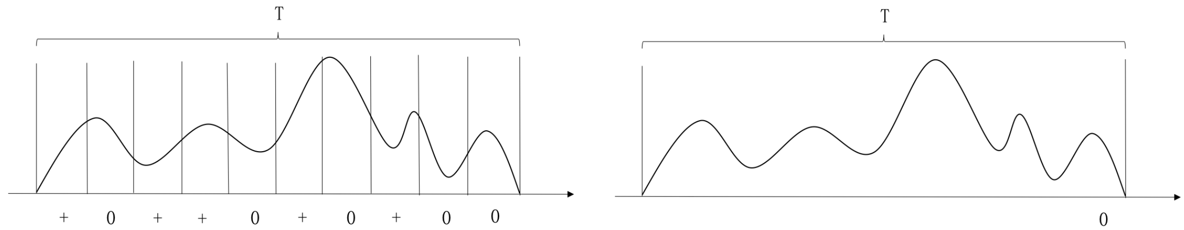

Figure 1: **Two bonus frequency examples.** Solid line depicts cumulative earnings. The left panel is under a high bonus frequency. Plus means positive earnings over the bonus accrual period and, thus, a bonus payment for that period; zeros correspond to negative earnings and thus zero bonuses. The right panel is the corresponding case with only one bonus accrual period.

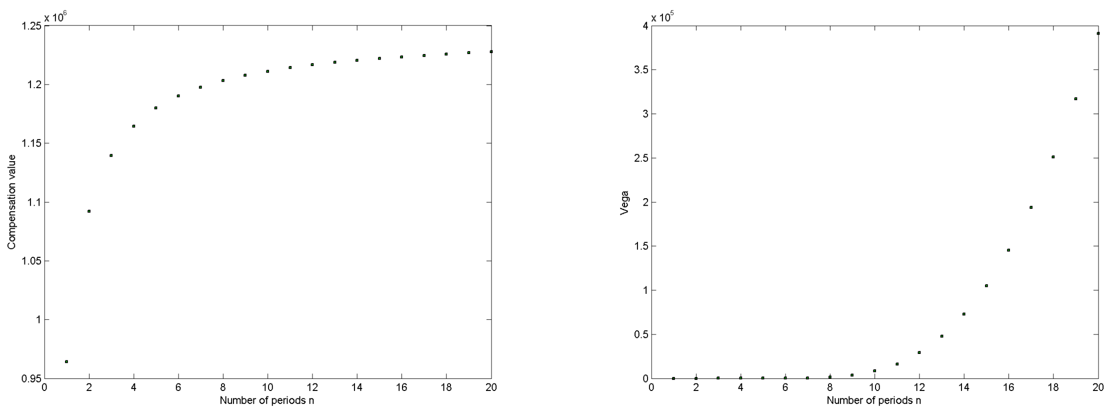

Figure 2: **Compensation value (π_n) and the corresponding risk-taking incentive ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, vega) with respect to the number of payout periods (n) based on Proposition 1.** Parameter values (example bank: United Bankshares, year: 2006): $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $T = 10$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

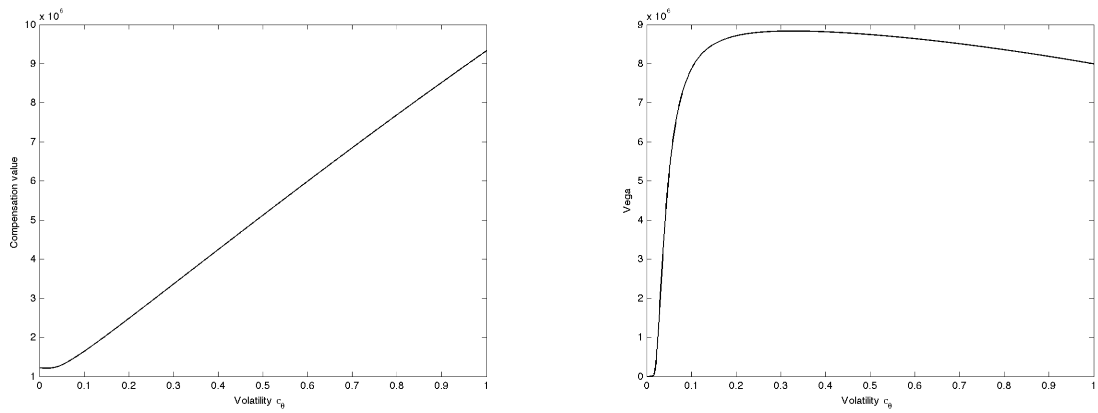

Figure 3: **Compensation value (π_n) and the corresponding risk-taking incentive ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, vega) with respect to the earnings volatility (σ_θ) based on Proposition 1.** Parameter values (example bank: United Bankshares, year: 2006): $A(0) = 634,092,000$, $r = 5.3250\%$, $T = 10$, $n = 10$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

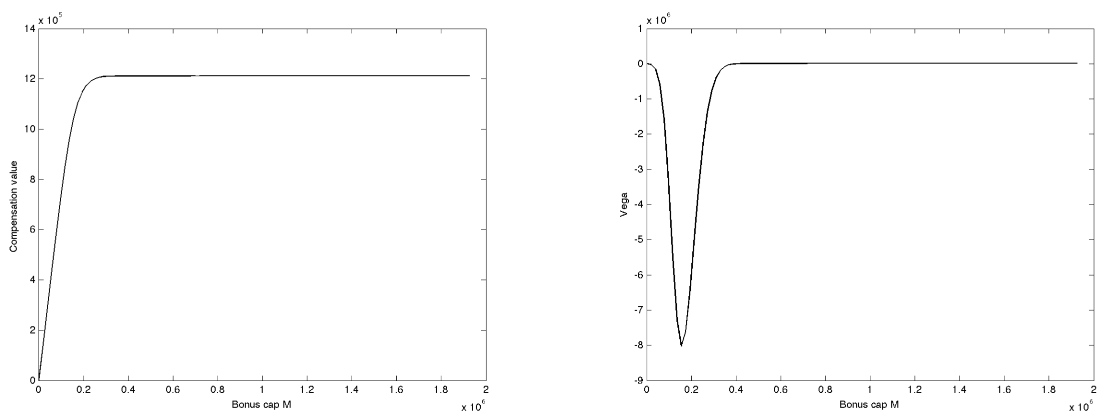

Figure 4: **Compensation value ($\tilde{\pi}_{n,M}$) and the corresponding risk-taking incentive ($\frac{\partial \tilde{\pi}_{n,M}}{\partial \sigma_\theta}$, vega) with respect to the bonus cap (M) based on Corollary 3.** Parameter values (example bank: United Bankshares, year: 2006): $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $T = 10$, $n = 10$, and $k = 0.0037$. The bonus cap M considered in the figures is between zero and three times the CEO's annual salary in 2006, and the risk-free rate r is the mean of monthly 1-year interest rate swaps in 2006. The compensation value and vega without bonus caps are $1,211,144.0620$ and $8,211.1140$, respectively. The compensation value and vega when the bonus cap becomes large enough converge to the situation without bonus caps.

Appendix C Tables of the main results

Table 1: **Summary statistics of cash bonus per net income** (k) **and the earnings volatility** (σ_θ)**.** In Panel A, k 2004 is the cash bonus per net income in 2004 (similarly for k 2005 and k 2006), and average k is the average cash bonus per net income during the period 2004–2006. In Panel B, σ_θ 2006 is the estimated earnings volatility using the quarterly data from 2000Q1 to 2006Q4, and σ_θ 2008 is the estimated earnings volatility using the quarterly data from 2000Q1 to 2008Q4, which is used as a robustness check.

Variable	Obs.	Median	Mean	Std. dev.	Min	Max
Panel A						
k 2004	82	0.0024	0.0045	0.0070	0.0000	0.0522
k 2005	91	0.0032	0.0044	0.0055	0.0000	0.0302
k 2006	94	0.0000	0.0012	0.0025	0.0000	0.0101
average k	94	0.0023	0.0034	0.0040	0.0000	0.0274
Panel B						
σ_θ 2006	92	0.0134	0.0181	0.0142	0.0034	0.0740
σ_θ 2008	92	0.0301	0.0513	0.0482	0.0035	0.2273

Table 2: **Cost function parameters.** The earnings volatility is estimated using quarterly data from 2000Q1 to 2006Q4. The bank-level cost parameters are calculated from (11) and by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$. The smallest cost parameters that satisfy the optimality condition (11) are reported in this table.

Cost function	Linear function		Quadratic function	
parameters	c_+	c_-	c_+	c_-
Panel A: T cap 10 yrs.				
Min	0	-51,720,635	0	-996,466,545
Max	239,289,959	0	33,337,906,791,704	0
Mean	18,190,675	-2,954,965	2,556,019,414,629	-66,852,773
Std	48,512,612	9,612,490	7,107,069,306,590	200,256,181
Corr with σ_θ	0.5660	-0.6054	0.5771	-0.6018
Panel B: T cap 15 yrs.				
Min	0	-73,034,493	0	-1,448,922,858
Max	358,934,939	0	50,006,860,187,555	0
Mean	25,825,082	-4,107,036	3,639,013,471,359	-93,983,667
Std	69,011,241	13,075,805	10,105,002,784,931	277,073,478
Corr with σ_θ	0.5540	-0.6086	0.5597	-0.5997

Table 3: **Risk reductions for bonus caps and bonus deferrals — the cost parameters from Table 2.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the cost functions; see Table 2. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Mean	42.70%	42.70%	34.12%	34.12%	48.09%	48.08%	34.12%	34.12%	42.87%	42.75%
Std	49.22%	49.22%	47.69%	47.69%	49.63%	49.63%	47.69%	47.69%	48.78%	48.76%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Mean	47.08%	47.11%	34.12%	34.12%	52.70%	52.74%	34.12%	34.12%	45.42%	45.42%
Std	49.46%	49.47%	47.69%	47.69%	49.53%	49.56%	47.69%	47.69%	48.98%	48.98%

Table 4: **Risk reductions for bonus caps and bonus deferrals — the cost parameter c_- is zero.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the cost functions in Table 2. Instead of the cost c_- in Table 2, we set $c_- = 0$ to calculate the risk reduction. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	32.62%	32.62%	0.00%	0.00%	26.71%	26.78%	0.00%	0.00%	18.42%	18.40%
Std	43.95%	43.95%	0.00%	0.00%	41.09%	41.08%	0.00%	0.00%	35.32%	35.29%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	40.35%	40.38%	0.00%	0.00%	34.77%	34.81%	0.00%	0.00%	21.74%	21.74%
Std	46.00%	46.02%	0.00%	0.00%	44.66%	44.71%	0.00%	0.00%	38.24%	38.24%

Table 5: **Risk reductions for bonus caps and bonus deferrals — the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the cost functions in Table 2. Instead of the cost c_- in Table 2, we set c_- equal to c_+ to calculate the risk reduction. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	14.90%	7.68%	0.00%	0.00%	11.08%	6.32%	0.00%	0.00%	5.93%	3.99%
Std	32.21%	24.32%	0.00%	0.00%	28.18%	22.91%	0.00%	0.00%	20.09%	16.47%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	98.40%	81.10%
Mean	20.06%	11.10%	0.00%	0.00%	14.80%	8.53%	0.00%	0.00%	7.79%	3.99%
Std	36.62%	28.61%	0.00%	0.00%	32.42%	25.38%	0.00%	0.00%	23.38%	15.87%

Table 6: **Risk reduction correlations.** The risk reduction is $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^\star_{T,\infty}}\right)$ under the linear cost function with CEOs' tenure cap of 10 years as the dependent variable; see Table 5 for $c_- = c_+$ and Table 4 for $c_- = 0$. Bank size is defined as the natural logarithm of the total asset in 2006Q4, crisis return is bank-level stock return from 2 July 2007 to 31 December 2008, and systemic risk is defined as the product of bank size and stock crisis return. p-values are reported in parentheses.

Correlation	Risk reduction of earnings volatility $\left(\frac{\sigma^\star_{T,\infty}-\sigma^*_{T,S}}{\sigma^\star_{T,\infty}}\right)$, $c_- = c_+$	Risk reduction of earnings volatility $\left(\frac{\sigma^\star_{T,\infty}-\sigma^*_{T,S}}{\sigma^\star_{T,\infty}}\right)$, $c_- = 0$
Bank size	0.1665 (0.1277)	0.4326 (0.0000)
Average cash bonus per net income over 2004–2006, k	0.2066 (0.0578)	0.2080 (0.0561)
Leverage in 2006Q4, θ	-0.1192 (0.2772)	0.1249 (0.2547)
Asset return volatility in 2000Q1–2006Q4, σ	-0.0541 (0.6231)	0.2948 (0.0062)
Tenure cap of 10 years	0.1071 (0.3291)	0.1269 (0.2472)
Stock crisis return	-0.0446 (0.6907)	-0.1312 (0.2402)
Systemic risk	-0.0590 (0.5987)	-0.2045 (0.0653)
Market-to-book ratio in 2006Q4	-0.0786 (0.4883)	0.0294 (0.7954)

Table 7: **Risk reduction due to the bonus cap for 10 banks with the highest earnings volatility (σ_θ) or leverage (θ).** The risk reduction is $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^\star_{T,\infty}}\right)$ under the linear cost function with CEOs' tenure cap of 10 years as the dependent variable; see Table 5 for $c_- = c_+$ and Table 4 for $c_- = 0$. Bank size is defined as the natural logarithm of the total asset in 2006Q4, crisis return is bank-level stock return from 2 July 2007 to 31 December 2008, and systemic risk is defined as the product of bank size and stock crisis return. Parameter k is the average cash bonus per net income over 2004–2006, θ is the leverage in 2006Q4, and σ and σ_θ are the estimated asset return volatility and earnings volatility using quarterly data from 2000Q1 to 2006Q4 respectively. Base salary refers to the bank CEO's annual base salary in 2006, and average bonus refers to the average of bank CEO's bonus over 2004–2006.

Bank name	Total assets ($ million)	Base salary ($ thousand)	Average bonus ($ thousand)	k	θ	σ	Stock crisis return	Systemic risk	Earnings volatility σ_θ	$\left(\frac{\sigma^\star_{T,\infty}-\sigma^\star_{T,S}}{\sigma^\star_{T,\infty}}\right)$ under $c_- = c_+$	$\left(\frac{\sigma^\star_{T,\infty}-\sigma^\star_{T,S}}{\sigma^\star_{T,\infty}}\right)$ under $c_- = 0$
Panel A: Bank characteristics and risk reduction for the 10 banks with the highest earnings volatility σ_θ.											
First Bancorp	17390.26	1000.00	617.40	0.0052	23.7849	0.0024	0.0100	0.0974	0.0591	0.00%	0.00%
Merrill Lynch	841299.00	700.00	10866.67	0.0017	22.3515	0.0022	-0.8606	-11.7411	0.0522	0.00%	75.70%
Countrywide Financial	199946.23	2866.67	12276.88	0.0052	12.9648	0.0037	-0.8817	-10.7620	0.0519	0.00%	89.70%
PNC Financial	101820.00	950.00	1658.75	0.0013	8.3562	0.0052	-0.3301	-3.8069	0.0490	0.00%	100.00%
Morgan Stanley	1120645.00	800.00	9809.58	0.0020	31.6741	0.0015	-0.2802	-3.9027	0.0485	0.00%	74.00%
Wachovia	707121.00	1090.00	4000.00	0.0007	9.0984	0.0041	-0.8941	-12.0422	0.0417	0.00%	75.40%
SVB Financial Group	6081.45	566.32	569.00	0.0071	8.4118	0.0043	-0.5109	-4.4515	0.0406	0.00%	100.00%
U S Bancorp	219232.00	1100.04	3066.67	0.0007	9.8052	0.0037	-0.2465	-3.0309	0.0405	77.40%	100.00%
Irwin Financial	6237.96	650.00	173.40	0.0025	11.0613	0.0034	-0.9137	-7.9839	0.0404	0.00%	0.00%
Bank of New York Mellon	103370.00	1000.00	5476.50	0.0035	7.9166	0.0044	-0.3598	-4.1540	0.0390	0.00%	75.30%
Panel B: Bank characteristics and risk reduction for the 10 banks with the highest leverage θ.											
Morgan Stanley	1120645.00	800.00		0.0020	31.6741	0.0015	-0.2802	-3.9027	0.0485	0.00%	74.00%
Bear Stearns	350432.60	250.00	13291.06	0.0082	28.7423	0.0006	-0.9323	-11.9028	0.0178	0.00%	26.50%
Lehman Brothers	503545.00	750.00	10083.33	0.0034	26.7658	0.0010	-0.9987	-13.1117	0.0287	0.00%	56.60%
Goldman Sachs	838201.00	345.77	6233.33	0.0007	24.4036	0.0012	-0.6150	-8.3876	0.0316	0.00%	63.10%
First Bancorp	17390.26	1000.00	617.40	0.0052	23.7849	0.0024	0.0100	0.0974	0.0591	0.00%	0.00%
Merrill Lynch	841299.00	700.00	10866.67	0.0017	22.3515	0.0022	-0.8606	-11.7411	0.0522	0.00%	75.70%
Astoria Financial	21554.52	1100.00	613.38	0.0027	16.7293	0.0005	-0.3481	-3.4735	0.0095	0.00%	0.00%
Commerce Bancorp	45271.82	1000.00	916.67	0.0032	15.1622	0.0007	0.0195	0.2088	0.0112	43.50%	100.00%
Citigroup	1884318.00	1000.00	11630.00	0.0006	14.8551	0.0016	-0.8701	-12.5716	0.0261	0.00%	54.50%
Northern Trust	60712.20	1037.50	1500.00	0.0027	14.3940	0.0008	-0.1950	-2.1477	0.0123	78.90%	100.00%

Appendix D Robustness checks

Table 8: **Risk reductions for bonus caps and bonus deferrals — bonuses decrease equity value and the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using the quarterly data from 2000Q1 to 2006Q4. k is the cash bonus per net income in Panel A of Table 1. The average k during the period 2004–2006 is used in this table. Panels A and B are the results by simulating the equity process that drops by the bonus payment at each bonus payment time and between the payment times it follows (2). By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the piecewise linear and quadratic cost functions, and then we set c_- equal to c_+ and c_+ is the smallest cost parameter value that satisfy the optimality condition (11) (not reported for brevity).

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-100.00%	0.00%
Max	99.80%	5.20%	0.00%	0.00%	92.00%	3.30%	0.00%	0.00%	90.80%	1.80%
Mean	14.14%	0.37%	0.00%	0.00%	10.12%	0.14%	0.00%	0.00%	2.06%	0.04%
Std	31.06%	1.05%	0.00%	0.00%	26.18%	0.56%	0.00%	0.00%	22.92%	0.26%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	-100.00%	0.00%	-100.00%	0.00%	0.00%	0.00%	-100.00%	0.00%
Max	99.80%	8.10%	0.00%	0.00%	98.20%	4.80%	0.00%	0.00%	99.30%	2.20%
Mean	18.78%	0.71%	-16.47%	0.00%	3.98%	0.32%	0.00%	0.00%	5.06%	0.10%
Std	35.32%	1.78%	37.31%	0.00%	44.74%	0.99%	0.00%	0.00%	27.75%	0.43%

Table 9: **Cost function parameters — option grants.** The earnings volatility is estimated using quarterly data from 2000Q1 to 2006Q4. The bank-level cost parameters are calculated from $\tilde{\pi}_{T,\infty}(\sigma_\theta + \Delta\sigma_\theta) + N\pi_{BS}(\sigma_S + \Delta\sigma_S) - F(\Delta\sigma_\theta) = 0$, where N is the number of option grants in 2006, π_{BS} is the Black-Scholes value of the option grants, and σ_S is the stock volatility. The bonus value $\tilde{\pi}_{T,\infty}$ is calculated by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). The stock volatility σ_S is estimated by using the daily stock price from 2000Q1 to 2006Q4, and a linear relationship between the earnings volatility σ_θ is estimated as $\sigma_S = a + 0.95 * \sigma_\theta$ to calculate the change of stock volatility $\Delta\sigma_S$ due to the change of the earnings volatility σ_θ (see Vuolteenaho (2002)). Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the piecewise linear and quadratic cost functions, where we select the smallest cost parameter values that satisfy the optimality condition (11).

Cost function	Linear function		Quadratic function	
parameters	c_+	c_-	c_+	c_-
Panel A: T cap 10 yrs.				
Min	7	-109,567,032	1,069,560	-1,222,157,285
Max	234,677,777	-7	2,980,930,256,815	-1,069
Mean	25,281,227	-6,916,738	308,528,444,812	-99,230,871
Std	46,847,220	16,273,853	574,694,368,292	195,202,653
Panel B: T cap 15 yrs.				
Min	8	-51,715,483	1,174,804	-996,267,654
Max	358,934,953	0	5,008,435,539,163	-2
Mean	23,520,104	-3,251,710	323,941,895,933	-77,737,372
Std	64,136,152	9,356,435	920,423,621,677	215,813,232

Table 10: **Risk reductions for bonus caps and bonus deferrals — option grants and the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using the quarterly data from 2000Q1 to 2006Q4. k is the cash bonus per net income in Panel A of Table 1. The average k during the period 2004–2006 is used in this table. The banker's objective is to maximize the net payoff $\tilde{\pi}_{n,M}(\sigma_\theta + \Delta\sigma_\theta) + N\pi_{BS}(\sigma_S + \Delta\sigma_S) - F(\Delta\sigma_\theta)$, where N is the number of option grants in 2006, π_{BS} is the Black-Scholes value of the option grants, and σ_S is the stock volatility. The bonus value $\tilde{\pi}_{T,\infty}$ is calculated by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). The stock volatility σ_S is estimated by using the daily stock price from 2000Q1 to 2006Q4, and a linear relationship between the earnings volatility σ_θ is estimated as $\sigma_S = a + 0.95 * \sigma_\theta$ to calculate the change of stock volatility $\Delta\sigma_S$ due to the change of the earnings volatility σ_θ (see Vuolteenaho (2002)). The parameters of the piecewise linear and quadratic cost functions are reported in Table 9. To calculate the risk reduction, we set c_- equal to c_+ in the cost functions. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	82.80%	0.80%	0.00%	0.00%	63.40%	0.30%	0.00%	0.00%	0.00%	0.10%
Mean	9.69%	0.05%	0.00%	0.00%	1.73%	0.02%	0.00%	0.00%	0.00%	0.01%
Std	23.89%	0.14%	0.00%	0.00%	9.52%	0.07%	0.00%	0.00%	0.00%	0.03%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	91.20%	75.70%
Mean	27.65%	17.88%	0.00%	0.00%	19.55%	13.19%	0.00%	0.00%	9.49%	6.82%
Std	39.38%	33.48%	0.00%	0.00%	34.70%	28.09%	0.00%	0.00%	23.34%	17.56%

Table 11: **Cost function parameters — internal bonus cap.** The earnings volatility is estimated using quarterly data from 2000Q1 to 2006Q4. Different from the optimality condition (11), to calculate the bank-level cost parameters, we assume that the internal bonus cap is five times the annual salary in 2006 if the bonus is no more than five times the annual salary in 2006, whereas if the bonus is more than five times the annual salary in 2006, we assume that the internal bonus cap is infinite in 2006. Besides, we assume that the bonus is paid every year. The optimality condition is similar to (11) but with the internal bonus cap. The bank-level cost parameters are calculated using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$. We select the smallest cost parameter values that satisfy the above optimality condition.

Cost function	Linear function		Quadratic function	
parameters	c_+	c_-	c_+	c_-
Panel A: T cap 10 yrs.				
Min	-63,535,115	-48,684,793	-1,309,339,014	-933,524,489
Max	239,289,959	7,167,380,914	3,338,956,682,603	2,404,864,434,231
Mean	10,111,538	167,941,696	161,262,343,043	86,137,536,890
Std	38,465,334	905,393,764	539,244,064,791	368,876,418,781
Panel B: T cap 15 yrs.				
Min	-83,428,477	-73,027,190	-1,719,303,709	-1,400,286,734
Max	358,934,939	8,492,198,084	5,008,435,023,895	3,275,347,310,215
Mean	13,930,819	206,184,177	229,112,646,293	136,935,206,853
Std	56,775,157	1,085,803,710	785,145,102,131	548,334,727,710

Table 12: **Risk reductions for bonus caps and bonus deferrals — internal bonus cap and the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. By $\sigma^*_{T,\infty}$, (11), and the internal bonus cap, we get the parameters of the cost functions in Table 11. To calculate the risk reduction, we set c_- equal to c_+ in the cost functions. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$. $\sigma^*_{T/2,2I}$ and $\sigma^*_{T/5,5I}$ refer to the optimal earnings volatilities under bonus deferrals of two years or five years with a scaled internal bonus cap.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & internal bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2I}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & internal bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5I}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%	-100.00%	-100.00%	0.00%	-1.70%
Max	100.00%	100.00%	0.00%	8.80%	100.00%	100.00%	0.00%	6.20%	100.00%	100.00%
Mean	21.27%	15.28%	-4.71%	-3.28%	15.95%	12.78%	-3.53%	-3.31%	9.46%	8.75%
Std	36.76%	31.58%	21.30%	18.65%	32.84%	29.56%	18.56%	18.63%	26.56%	24.65%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%	-100.00%	-100.00%	0.00%	-1.70%
Max	100.00%	100.00%	0.00%	8.30%	100.00%	100.00%	0.00%	8.30%	100.00%	100.00%
Mean	28.13%	21.06%	-5.88%	-4.44%	21.00%	17.02%	-4.71%	-4.45%	13.62%	11.97%
Std	40.62%	36.28%	23.67%	21.40%	37.12%	33.56%	21.30%	21.40%	30.95%	27.64%

Table 13: **Risk reductions for bonus caps and bonus deferrals — augmented fixed salary and the cost parameters are equal.** The CEO's annual base salary has been augmented as follows: we first calculate the total expected discounted value of the bonuses that are paid every year without the bonus cap and the annual base salary during the CEO's tenure cap of 10 or 15 years, denoted as K_{10} or K_{15}, for example, $K_{10} = \sum_{i=1}^{T\ cap\ 10} \exp(-(i-1)r)\tilde{\pi}_{T,\infty} + S$, where S is the actual base salary in 2006; then we consider the total value of the bonuses and the augmented base salary during the CEO's tenure, which is K'_{10} or K'_{15} under the tenure cap of 10 or 15 years, where bonuses are paid every year and capped at this augmented base salary, for example, $K'_{10} = \sum_{i=1}^{T\ cap\ 10} \exp(-(i-1)r)\tilde{\pi}_{T,S'} + S'$, where S' is the augmented base salary such that $K_{10} = K'_{10}$. The bank-level bonus cap is the CEO's annual augmented base salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual augmented base salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual augmented base salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the cost functions (not reported for brevity). To calculate the risk reduction, we set c_- equal to c_+ in the cost functions. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	81.40%	79.60%
Mean	19.72%	12.01%	0.00%	0.00%	12.81%	9.91%	0.00%	0.00%	5.89%	5.33%
Std	33.91%	27.75%	0.00%	0.00%	29.25%	25.60%	0.00%	0.00%	18.53%	15.96%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	25.14%	17.08%	0.00%	0.00%	16.75%	12.83%	0.00%	0.00%	10.52%	8.20%
Std	37.48%	32.46%	0.00%	0.00%	33.15%	28.43%	0.00%	0.00%	26.73%	21.35%

Table 14: **Jump size parameters for the jump-diffusion process.** σ_θ 2006 is the earnings volatility estimated using quarterly data from 2000Q1 to 2006Q4. The equity dynamics follow the jump-diffusion process $\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t)$, where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. In the above jump-diffusion process, the expected growth rate of the jump-diffusion process is r, the same as the drift in (2). We also match the instantaneous volatility of the jump-diffusion process with the Wiener process in (2) as $\sigma_\theta^2 = \sigma^2 + \lambda u^2$. We fix $\lambda = 0.1$. Further, we assume that at the end of 2006, $\sigma = 0$, to solve the equilibrium jump size u in 2006 as $u = -\frac{\sigma_\theta}{\sqrt{\lambda}}$.

Jump size	u, 2006
Min	-0.2339
Max	-0.0106
Mean	-0.0522
Std	0.0430

Table 15: **Cost function parameters under the jump-diffusion process.** The earnings volatility is estimated using quarterly data from 2000Q1 to 2006Q4. The bank-level cost parameters are calculated from (11) and by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). Piecewise linear cost function: $F(\Delta u) = c_+ I\{\Delta u\} \geq 0\}\Delta u - c_- I\{\Delta u < 0\}\Delta u$, piecewise quadratic cost function: $F(\Delta u) = c_+ I\{\Delta u \geq 0\}(\Delta u)^2 + c_- I\{\Delta u < 0\}(\Delta u)^2$. The equity dynamics follow the jump-diffusion process $\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t)$, where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. In the above jump-diffusion process, the expected growth rate of the jump-diffusion process is r, the same as the drift in (2). We also match the instantaneous volatility of the jump diffusion process with the Wiener process in (2) as $\sigma_\theta^2 = \sigma^2 + \lambda u^2$. To calibrate the parameters in the cost functions, we assume that at the end of 2006, $\sigma = 0$ and $u = -\frac{\sigma_\theta}{\sqrt{\lambda}}$. Since u does not decrease, $c_- = 0$ for both the linear cost function and the quadratic cost function.

Cost function	Linear function		Quadratic function	
parameters	c_+	c_-	c_+	c_-
Panel A: T cap 10 yrs.				
Min	0	0	0	0
Max	3,596,137,000	0	3,596,137,000	0
Mean	197,686,307	0	194,837,652	0
Std	452,253,715	0	451,681,893	0
Panel B: T cap 15 yrs.				
Min	0	0	0	0
Max	5,394,205,500	0	5,394,205,500	0
Mean	294,727,890	0	290,454,906	0
Std	676,470,025	0	675,598,327	0

Table 16: **Jump size increments for bonus caps and bonus deferrals.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using the quarterly data from 2000Q1 to 2006Q4. k is the cash bonus per net income in Panel A of Table 1. The average k during the period 2004–2006 is used in this table. The equity dynamics follow the jump-diffusion process $\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t)$, where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. In the above jump-diffusion process, the expected growth rate of the jump-diffusion process is r, the same as the drift in (2). We also match the instantaneous volatility of the jump-diffusion process with the Wiener process in (2) as $\sigma^2_\theta = \sigma^2 + \lambda u^2$. Similar to the optimality condition in (11), the banker's objective is to maximize $\tilde{\pi}_{n,M}(u^*_{T,\infty} + \Delta u) - F(\Delta u)$, where $u^*_{T,\infty}$ is the equilibrium jump size; see Table 14, and the optimal jump size is denoted as $u^*_{n,M}$. The parameters of the piecewise linear and quadratic cost functions in terms of change of jump size u are in Table 15.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{u^*_{T,\infty} - u^*_{T,S}}{u^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{u^*_{T,\infty} - u^*_{T/2,\infty}}{u^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{u^*_{T,\infty} - u^*_{T/2,2S}}{u^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{u^*_{T,\infty} - u^*_{T/5,\infty}}{u^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{u^*_{T,\infty} - u^*_{T/5,5S}}{u^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.00%	3.90%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mean	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.44%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.00%	3.90%	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%	0.10%
Mean	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.44%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%

Table 17: **Cost function parameters for the risk averse banker.** The banker is assumed to be risk averse and her objective is to maximize the net expected utility defined as $U_{n,M}(\sigma_\theta + \Delta\sigma_\theta) = E\left[\frac{W_{n,M}^{1-\gamma}(\sigma_\theta+\Delta\sigma_\theta)}{1-\gamma}\right] - F(\Delta\sigma_\theta)$, where $W_{n,M}(\sigma_\theta) = \sum_i^n \min[k\max[A(i\Delta)-A((i-1)\Delta),0],M]$, we set $\gamma = 0.5$, and $A(t)$ is the equity process in (3).[30] Instead of (11), the bank-level cost parameters are calculated by the optimality condition $\arg\max_{\Delta\sigma_\theta \geq -\sigma_\theta} U_{T,\infty}(\sigma^*_{T,\infty} + \Delta\sigma_\theta) = 0$, where $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4, and by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). The smallest cost parameters that satisfy the above optimality condition are reported in this table. Piecewise linear cost function: $F(\Delta u) = c_+ I\{\Delta u\} \geq 0\}\Delta u - c_- I\{\Delta u < 0\}\Delta u$, piecewise quadratic cost function: $F(\Delta u) = c_+ I\{\Delta u \geq 0\}(\Delta u)^2 + c_- I\{\Delta u < 0\}(\Delta u)^2$.

Cost function parameters	Linear function c_+	Linear function c_-	Quadratic function c_+	Quadratic function c_-
Panel A: T cap 10 yrs.				
Min	-1,225	-5,353	-122,299	-102,656
Max	25,665	3,128	396,625,603	174,372,442
Mean	2,718	61	36,448,116	28,109,437
Std	6,311	1,264	88,548,050	28,118,139
Panel B: T cap 15 yrs.				
Min	-1,225	-7,475	-92,126	-143,349
Max	32,014	3,128	508,104,661	174,372,442
Mean	3,474	-151	47,369,055	21,607,904
Std	7,649	1,539	111,058,726	25,846,107

[30] Bankers' risk aversion is captured by $\gamma > 0$, $\gamma \neq 1$. Parameter $\gamma = 2$ is used, e.g., in Mehra and Prescott (1985) and Keppo and Petajisto (2014). We use $\gamma = 0.5$ instead in order to have a relatively large utility value to avoid the potential numerical errors in the risk reduction simulation. Note that under $\gamma = 0.5$, the utility function is concave and, thus, the banker is risk averse.

Table 18: **Risk reductions for bonus caps and bonus deferrals — risk averse banker and c_- is nonnegative.** The banker is assumed to be risk averse and her objective is to maximize the net expected utility defined as $U_{n,M}(\sigma_\theta + \Delta\sigma_\theta) = E\left[\frac{W_{n,M}^{1-\gamma}(\sigma_\theta+\Delta\sigma_\theta)}{1-\gamma}\right] - F(\Delta\sigma_\theta)$, where $W_{n,M}(\sigma_\theta) = \sum_i^n \min[k\max[A(i\Delta) - A((i-1)\Delta), 0], M]$, we set $\gamma = 0.5$, and $A(t)$ is the equity process in (3). The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. To calculate the risk reduction, we set $c_- = \max(c^s_-, 0)$ and $c_+ = c^s_+$ in the cost functions, where c^s_+ and c^s_- are the cost parameters in Table 17. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	93.70%	93.70%	100.00%	100.00%	92.40%	92.40%	100.00%	100.00%
Mean	25.37%	14.03%	18.48%	17.37%	27.27%	18.56%	18.72%	17.75%	19.90%	16.06%
Std	40.20%	33.14%	35.13%	33.65%	40.04%	35.79%	34.54%	33.36%	36.70%	34.33%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	93.80%	93.80%	100.00%	100.00%	98.70%	98.70%	100.00%	100.00%
Mean	34.95%	16.37%	20.53%	19.85%	34.74%	20.56%	23.74%	22.61%	27.39%	18.67%
Std	43.35%	35.32%	37.49%	36.67%	43.07%	38.09%	40.78%	39.61%	41.14%	37.30%

Table 19: **Risk reductions for bonus caps and bonus deferrals — risk averse banker and the cost parameters are equal.** The banker is assumed to be risk averse and her objective is to maximize the net expected utility defined as $U_{n,M}(\sigma_\theta+\Delta\sigma_\theta) = E\left[\frac{W_{n,M}^{1-\gamma}(\sigma_\theta+\Delta\sigma_\theta)}{1-\gamma}\right] - F(\Delta\sigma_\theta)$, where $W_{n,M}(\sigma_\theta) = \sum_i^n \min[k\max[A(i\Delta)-A((i-1)\Delta),0], M]$, we set $\gamma = 0.5$, and $A(t)$ is the equity process in (3). The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2006Q4. To calculate the risk reduction, we set $c_- = c_+ = \max(c^s_+, c^s_-)$ in the cost functions, where c^s_+ and c^s_- are the cost parameters in Table 17. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	99.10%	0.00%	0.00%	0.00%	91.80%	0.00%	0.00%	0.00%	91.30%	0.00%
Mean	17.26%	0.00%	0.00%	0.00%	12.12%	0.00%	0.00%	0.00%	4.52%	0.00%
Std	33.21%	0.00%	0.00%	0.00%	28.19%	0.00%	0.00%	0.00%	17.00%	0.00%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	99.70%	0.00%	0.00%	0.00%	99.40%	0.00%	0.00%	0.00%	98.50%	0.00%
Mean	22.05%	0.00%	0.00%	0.00%	16.25%	0.00%	0.00%	0.00%	8.31%	0.00%
Std	37.16%	0.00%	0.00%	0.00%	32.27%	0.00%	0.00%	0.00%	22.96%	0.00%

Appendix E Further robustness checks

Table 20: **Risk reductions for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008 — the smallest cost parameters.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2008Q4. By $\sigma^*_{T,\infty}$ and (11), we get the smallest parameters of the cost functions (not reported for brevity). Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Mean	63.52%	63.52%	70.59%	70.59%	74.06%	74.04%	70.59%	70.59%	73.81%	73.76%
Std	48.42%	48.41%	45.83%	45.83%	44.03%	44.02%	45.83%	45.83%	43.97%	43.97%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Mean	67.97%	68.00%	70.59%	70.59%	75.29%	75.29%	70.59%	70.59%	74.87%	74.87%
Std	46.71%	46.72%	45.83%	45.83%	45.83%	45.83%	45.83%	45.83%	43.23%	43.23%

Table 21: **Risk reductions for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008 — the cost parameter c_- is zero.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2008Q4. By $\sigma^*_{T,\infty}$ and (11), we get the smallest parameters of the cost functions (not reported for brevity). Instead of the smallest cost c_-, we set $c_- = 0$ to calculate the risk reduction. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	36.09%	36.09%	0.00%	0.00%	35.95%	35.94%	0.00%	0.00%	35.66%	35.60%
Std	46.17%	46.17%	0.00%	0.00%	45.62%	45.60%	0.00%	0.00%	44.74%	44.69%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	0.00%	100.00%	100.00%
Mean	45.10%	45.73%	0.00%	0.00%	43.04%	43.04%	0.00%	0.00%	42.06%	42.06%
Std	47.71%	47.73%	0.00%	0.00%	47.31%	47.31%	0.00%	0.00%	46.02%	46.02%

Table 22: **Risk reductions for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008 — the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2008Q4. By $\sigma^*_{T,\infty}$ and (11), we get the smallest parameters of the cost functions (not reported for brevity). Instead of the smallest cost c_-, we set c_- equal to c_+ to calculate the risk reduction. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	98.90%	0.00%	0.00%	100.00%	95.20%	0.00%	0.00%	83.00%	82.60%
Mean	8.79%	2.43%	0.00%	0.00%	3.68%	2.24%	0.00%	0.00%	1.67%	1.66%
Std	24.07%	15.06%	0.00%	0.00%	16.59%	14.22%	0.00%	0.00%	10.96%	10.90%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	100.00%	98.10%	0.00%	0.00%	98.40%	81.40%
Mean	10.18%	3.33%	0.00%	0.00%	4.96%	2.33%	0.00%	0.00%	3.08%	1.99%
Std	26.53%	16.73%	0.00%	0.00%	19.12%	14.40%	0.00%	0.00%	16.24%	12.40%

Table 23: **Risk reductions for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008 — internal bonus cap and the cost parameters are equal.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2008Q4. By $\sigma^*_{T,\infty}$, (11), and the internal bonus cap, we get the parameters of the cost functions (not reported for brevity). To calculate the risk reduction, we set c_- equal to c_+ in the cost functions. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\left(\Delta\sigma_\theta\right)^2 + c_- I\{\Delta\sigma_\theta < 0\}\left(\Delta\sigma_\theta\right)^2$. $\sigma^*_{T/2,2I}$ and $\sigma^*_{T/5,5I}$ refer to the optimal earnings volatilities under bonus deferrals of two years or five years with a scaled internal bonus cap.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & internal bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2I}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & internal bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5I}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	8.50%	100.00%	100.00%	0.00%	6.00%	100.00%	100.00%
Mean	13.86%	6.67%	-7.06%	-3.40%	8.32%	5.90%	-4.71%	-3.43%	5.54%	4.94%
Std	30.40%	23.25%	25.77%	18.61%	25.05%	22.20%	21.30%	18.59%	20.73%	19.69%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%	-100.00%	-100.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	8.00%	100.00%	100.00%	0.00%	8.00%	100.00%	100.00%
Mean	17.55%	9.56%	-8.24%	-4.58%	12.48%	8.08%	-5.88%	-4.58%	7.96%	7.00%
Std	34.28%	27.32%	27.65%	21.35%	29.04%	25.09%	23.67%	21.35%	25.42%	23.33%

Table 24: **Risk reductions for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008 — augmented fixed salary and the cost parameters are equal.** The CEO's annual base salary has been augmented as follows: we first calculate the total expected discounted value of the bonuses that are paid every year without the bonus cap and the annual base salary during the CEO's tenure cap of 10 or 15 years, denoted as K_{10} or K_{15}, for example, $K_{10} = \sum_{i=1}^{T\ cap\ 10} \exp(-(i-1)r)\tilde{\pi}_{T,\infty} + S$, where S is the actual base salary in 2006; then we consider the total value of the bonuses and the augmented base salary during the CEO's tenure, which is K'_{10} or K'_{15} under the tenure cap of 10 or 15 years, where bonuses are paid every year and capped at this augmented base salary, for example, $K'_{10} = \sum_{i=1}^{T\ cap\ 10} \exp(-(i-1)r)\tilde{\pi}_{T,S'} + S'$, where S' is the augmented base salary such that $K_{10} = K'_{10}$. The bank-level bonus cap is the CEO's annual augmented base salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual augmented base salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual augmented base salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using quarterly data from 2000Q1 to 2008Q4. By $\sigma^*_{T,\infty}$ and (11), we get the parameters of the cost functions (not reported for brevity). To calculate the risk reduction, we set c_- equal to c_+ in the cost functions. Piecewise linear cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}\Delta\sigma_\theta - c_- I\{\Delta\sigma_\theta < 0\}\Delta\sigma_\theta$, piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ I\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_- I\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	97.50%	0.00%	0.00%	100.00%	98.20%	0.00%	0.00%	56.10%	55.80%
Mean	8.26%	3.35%	0.00%	0.00%	4.68%	2.74%	0.00%	0.00%	1.49%	1.49%
Std	23.15%	15.50%	0.00%	0.00%	18.15%	14.56%	0.00%	0.00%	8.17%	7.91%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	100.00%	100.00%	0.00%	0.00%	98.50%	88.70%	0.00%	0.00%	100.00%	100.00%
Mean	11.81%	5.12%	0.00%	0.00%	5.72%	3.56%	0.00%	0.00%	3.00%	2.93%
Std	27.48%	19.17%	0.00%	0.00%	19.23%	15.04%	0.00%	0.00%	16.04%	14.21%

Table 25: **Jump size parameters for the jump-diffusion process with earnings volatility estimates including years 2007 and 2008.** σ_θ 2008 is the earnings volatility estimated using quarterly data from 2000Q1 to 2008Q4. The equity dynamics follow the jump-diffusion process $\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t)$, where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. In the above jump-diffusion process, the expected growth rate of the jump-diffusion process is r, the same as the drift in (2). We also match the instantaneous volatility of the jump-diffusion process with the Wiener process in (2) as $\sigma_\theta^2 = \sigma^2 + \lambda u^2$. We fix $\lambda = 0.1$. Further, we assume that at the end of 2006, $\sigma = 0$, to solve the equilibrium jump size u in 2006 as $u = -\frac{\sigma_\theta}{\sqrt{\lambda}}$.

Jump size	u, 2008
Min	-0.5529
Max	-0.0112
Mean	-0.1533
Std	0.1471

Table 26: **Jump size increments for bonus caps and bonus deferrals with earnings volatility estimates including years 2007 and 2008.** The bank-level bonus cap is the CEO's annual salary in 2006 if the bonus interval is one year, the bonus cap is twice the CEO's annual salary in 2006 if the bonus interval is two years, and the bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated earnings volatility using the quarterly data from 2000Q1 to 2008Q4. k is the cash bonus per net income in Panel A of Table 1. The average k during 2004-2006 is used in this table. The equity dynamics follow the jump-diffusion process $\frac{dA(t)}{A(t)} = (r - \lambda u)dt + \sigma dW(t) + udN(t)$, where $u \in [-1, 0]$ is the jump size and λ is the intensity of the Poisson process $N(t)$. In the above jump-diffusion process, the expected growth rate of the jump-diffusion process is r, the same as the drift in (2). We also match the instantaneous volatility of the jump-diffusion process with the Wiener process in (2) as $\sigma^2_\theta = \sigma^2 + \lambda u^2$. Similar to the optimality condition in (11), the banker's objective is to maximize $\tilde{\pi}_{n,M}(u^*_{T,\infty} + \Delta u) - F(\Delta u)$, where $u^*_{T,\infty}$ is the equilibrium jump size; see Table 25. The optimal jump size is denoted as $u^*_{n,M}$.

	Case I: Bonus interval of 1 year & bonus cap $\left(\frac{u^*_{T,\infty}-u^*_{T,S}}{u^*_{T,\infty}}\right)$		Case II: Bonus interval of 2 years & no bonus cap $\left(\frac{u^*_{T,\infty}-u^*_{T/2,\infty}}{u^*_{T,\infty}}\right)$		Case III: Bonus interval of 2 years & bonus cap $\left(\frac{u^*_{T,\infty}-u^*_{T/2,2S}}{u^*_{T,\infty}}\right)$		Case IV: Bonus interval of 5 years & no bonus cap $\left(\frac{u^*_{T,\infty}-u^*_{T/5,\infty}}{u^*_{T,\infty}}\right)$		Case V: Bonus interval of 5 years & bonus cap $\left(\frac{u^*_{T,\infty}-u^*_{T/5,5S}}{u^*_{T,\infty}}\right)$	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Panel A: T cap 10 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%	0.10%
Max	0.00%	4.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mean	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.49%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%
Panel B: T cap 15 yrs.										
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%	0.10%
Max	0.00%	4.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mean	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.49%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.02%