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Bonus caps, deferrals and bankers' risk-taking

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Bonus caps, deferrals and bankers' risk-taking



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

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Abstract

We derive a principal-agent model to analyze the effectiveness of bonus caps and deferrals in regulating banks' risk-taking. We calibrate the model to a sample of large US banks on the eve of the Global Financial Crisis and run counterfactual analyses of the potential effects of the regulations. We find that the risk-reduction effect on the median bank is negligible as banks respond to the regulations by increasing the earnings sensitivity of bonuses. However, on a small number of banks with high bonus to salary ratios prior to 2008, the bonus cap has a sizeable risk-reduction effect. In contrast, bonus deferrals have only negligible effects on all sample banks.

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

JEL codes: G21, G28

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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. In the United States, the Dodd-Frank Act introduces the possibility of clawbacks on bonuses.¹

In this paper, we quantify the potential effects on individual banks' risk-taking of the actual bonus regulations. We build and calibrate a structural model and run counterfactual analyses with bonus caps and deferrals which resemble those implemented in the European Union. Our analysis aims to answer two questions. First, had the bonus regulations been implemented prior to the financial crisis, how much would they have reduced banks' risk, especially that of the riskiest banks? Second, which of the bonus regulations, caps or deferrals, would have been more effective? To our knowledge, our paper is the first one to consider quantitative risk-reduction effects of the actual bonus regulations using counterfactual analysis, motivated by the actual regulations introduced post-crisis. For that purpose, our model aims to be simple yet realistic enough to lend itself to a meaningful calibration.

More specifically, we use the principal-agent framework of Holmstrom (1979) (see the recent survey paper by Edmans et al. (2017)), and develop a model for the value of a banker's (the agent) future cash bonuses and derive her bonus-induced risk-taking incentives, subject to an adjustment cost facing the banker from changing the risk position of the bank. Bank equity owners (the principal) set the fraction of book equity value change paid out periodically as a cash bonus to maximize bank equity value. This frac-

¹In terms of ultimate bonus payoffs to the banker, bonus clawbacks and deferrals may work in a similar manner. However, while the idea with deferrals is to postpone bonus payment until the result of risk-taking is more fully materialized, clawbacks are typically designed against wrong-doing such as fraud. Hence, their legal structure and implementation can be quite different.

tion determines the earnings sensitivity of the bonus. The equity owners are risk-neutral and do not observe the bank risk level chosen by the banker, who is risk averse. Therefore, the owners provide the banker with the bonus contract to increase her risk-taking incentive.

When bonus regulations are imposed, bank owners optimally adjust the earnings fraction paid as a bonus and the banker optimally adjusts the risk level of the bank. As we focus on the type of bonus caps and deferrals used in actual regulations, we do not derive the optimal regulatory policy. However, the role of regulation can be motivated by the fact that in our model the risk-neutral bank equity owners may prefer a higher level of bank risk than is socially optimal, and this is intensified by the government’s explicit and implicit safety nets (see e.g. Haldane (2009)).

We calibrate the model using a sample of large US banks and their CEO compensation from the end of 2006, the eve of the Global Financial Crisis when there were arguably no expectations of such bonus regulations.² The key parameter to calibrate for each sample bank is the marginal cost of changing the bank risk. With the calibrated cost for each bank, we solve the principal-agent model and then study the effect of bonus regulation on the banks’ risk levels.

We find that the potential effect of either compensation regulation on the median bank is negligible as banks may “nullify” the effect of the regulation by increasing the earnings sensitivity of bonuses they promise to the banker. Interestingly, bonus deferrals never appear effective in reducing risk, having only negligible effects on all sample banks. In contrast, on a small number of banks with high ratios of cash bonus to fixed salary for the CEOs prior to 2008, the bonus cap has a sizeable risk-reduction effect. Further analysis reveals that although these banks partly “fight back” the compensation regulation by increasing the earnings sensitivity of bonuses, it is not enough to maintain, or they prefer not to incite a similar level of the banker’s risk-taking as prevailed in the absence of the bonus cap. Broadly speaking, these results are not inconsistent with the empirical evidence by Kleymenova and Tuna (2017) who find negative bank stock price reactions to the introduction of a bonus cap.

²It is possible, though, that some banks were applying internal caps and/or deferrals as part of their compensation contracts.

All previous findings stay qualitative the same in a number of extensions of the model which we do as robustness analyses. For instance, in one of the extensions, we allow the bank to adjust the fixed salary of the banker so that the expected value of the banker's compensation stays unchanged when bonus regulations are introduced. The robustness of our main results in this central extension follows from the fact that in our model the banker's risk-taking incentive does not depend on the level of her fixed compensation. Overall, despite the potential shown by the bonus cap in a number of extreme cases, neither type of bonus regulation is well-designed according to our analysis to reduce bank risk-taking at least in their current form.

There are many recent papers studying the issues concerning bonus caps and deferrals, e.g., Thanassoulis (2012, 2014) and Hoffmann et al. (2016). A review of the literature is provided in Section 2. However, as already mentioned above, we are not aware of a prior attempt to quantitatively assess the effectiveness of the actual bonus regulations implemented in the EU using counterfactual analysis.

The paper is organized as follows. After a literature review in Section 2, the basic model dynamics without the principal-agent framework 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 subsection 3.2. Section 4 introduces the principal-agent framework, including costs of changing risk, in which the optimal bonus contract and the level of risk-taking is determined. Section 5 presents the counterfactual analyses of bonus regulations by using the calibrated models. Section 6 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 "time horizon" 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, and we use one year duration for the case without compensation regulation. 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. 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 Laeven 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 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’ risks, 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 risk-taking incentives.

We use the principal-agent model in Holmstrom (1979) in the analysis of bonus regulations. Our paper is also related to Grossman and Hart (1983), Holmstrom (1982, 1983, 1999), Holmstrom and Milgrom (1991, 1994), Myerson (1982), Rogerson (1985), Sannikov (2008), and Edmans et al. (2012) as well as the accounts provided in Berk and DeMarzo (2014) and Sannikov (2012a,b). Inderst and Mueller (2004) and Mueller and Inderst (2005) provide 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.

Hakanes and Schnabel (2014) and Thanassoulis and Tanaka (2015) analyze various principal-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. As 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 evidence 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

Before we introduce our principal-agent model, we present our baseline model without the principal-agent setup. We use the baseline model to calibrate the risk adjustment costs of our sample banks prior to the Global Financial Crisis.

In the baseline model, there is a risk averse banker who receives bonuses with a certain frequency during her tenure $[0, T]$. The banker’s bonuses are a fixed fraction of the bank’s equity value increase. In the principal-agent model that we will analyze after the baseline model the bonus fraction is determined endogenously.

3.1 The equity dynamics and the bonus payment

The bank holds two types of assets, a risk-free asset and a risky asset. The risky asset is the bank’s main business, i.e., its loan portfolio, and the risk-free asset is a source of leverage. Thus, the risky asset equals the bank’s total assets. The bank debt is risk-free in our model, and its dynamics are given by

$$dB(t) = rB(t)dt,$$

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 bank’s bond holding is negative and its borrowing cost is the risk-free rate.³

³This is approximately correct due to deposit insurance and other government support mechanisms.

Under the risk-neutral probability measure Q (for more on risk-neutral pricing, see, e.g., Duffie (2001)), the risky asset follows

$$dS(t) = S(t)(r + \beta\sigma)dt + S(t)\sigma dW(t), \quad (1)$$

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 . Note that the parameter β measures the impact of volatility on the growth rate of the risky asset, which is aligned with the capital asset pricing model framework (CAPM). 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.

For simplicity, the bank does not pay dividend to its shareholders. The banker selects the investment in the risky loan portfolio, and after that, the bank controls its asset holdings in continuous time in such a way that it keeps the fractions of the risky and risk-free assets constant. This means that the bank invests all its equity and debt into the risky asset which comprises its loan portfolio. Further, under the risk-neutral probability measure Q , the bank's net portfolio value, i.e., its book equity value (we do not model the market value of equity) evolves according to (see, e.g., Merton (1971))

$$dA(t) = A(t)(r + \beta\sigma_\theta)dt + A(t)\sigma_\theta dW(t), \quad (2)$$

where $A(t)$ is the book equity value and $A(0) > 0$, the equity volatility $\sigma_\theta = (1 + \theta)\sigma$, and 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 size of bond holding (negative) at time t . This gives $n_B(t) = -\theta A(t)/B(t)$. As discussed earlier, this means that the bank adjusts its borrowing all the time to keep its bank debt relative to the equity value θ constant as a long-term strategy.⁴ For instance, when the asset value $S(t)$ falls (rises) then the bank borrows

⁴Note that the equity and risky assets are related through $S(t) = A(t) - n_B(t)B(t)$, i.e., $S(t) =$

less (more) to keep θ constant. 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, i.e., the bank cannot default), and this guarantees that the bank is always able to pay to the bond holders in full.

Note that σ_θ rises in θ and σ . Thus, the banker can increase risk by increasing the leverage or the risky asset volatility (or both), but in this paper we do not focus on the mechanism of how the banker changes σ_θ (although clearly, there are these two ways). As we will explain later, the risk level is determined as the bank's long-term strategy.

From (2) we get

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

or

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

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

For calculating the banker's compensation, we fix the length of bonus payout period and denote this period by Δ . Typically, Δ equals one year, but in principle it can differ from that. During the banker's tenure T , there are $n = \lfloor T/\Delta \rfloor$ many bonus payout periods, where $\lfloor x \rfloor$ is the largest integer less than or equal to x . At the end of each payout period, 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 bonus payout period, the bonus payoff is given by

$$\Pi(A(i\Delta), A((i-1)\Delta)) = k \max[A(i\Delta) - KA((i-1)\Delta), 0] \quad (4)$$

for all $i \in \{1, 2, \dots, n\}$, where $k \in (0, 1)$, and it represents the fraction of book equity value increase paid out as compensation to the banker. Thus, at the end of each time period, the bank pays bonus to the banker if the equity value has risen above the target level measured by $K > 0$. Further, we assume that the banker's compensation is so small relative to the change of equity value that we can ignore its effect on the equity

$A(t)(1 + \theta)$, where $n_B(t)$ is the bond holding and it is adjusted continuously so that θ is constant. The equity dynamics (2) has been used in existing studies, e.g., Peura and Keppo (2006).

dynamics (see Table 1 and the statistics for k there). However, in one of our extensions, we relax this assumption (see subsection 5.2).

For example, if $n = 1$, then we have just one payoff, which happens at time Δ :

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

3.2 Present value of the future bonuses

In this section, we model the banker's risk-taking incentives given the equity dynamics (2) and the bonuses (4), allowing also for possibility of including a bonus deferral or a bonus cap.

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

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

where $\Phi(x) = \int_{-\infty}^x \phi(y) dy$ is the standard cumulative normal distribution function, and $\phi(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$ is the standard normal density function,

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

Thus, $C(\Delta, K, \sigma_\theta)$ 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 $C(\Delta, K, \sigma_\theta)$, and the rest of our analysis would follow in a similar manner.

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

package with bonus payout period Δ and bonus deferral period Δ_d is given by

$$\begin{aligned}\pi_{\Delta}(\Delta_d) &= \sum_{i=1}^n \mathbb{E} [\exp(-r(i\Delta + \Delta_d)) \Pi(A(i\Delta), A((i-1)\Delta))] \\ &= \sum_{i=1}^n \mathbb{E} [\exp(-r(i\Delta + \Delta_d)) k \max[A(i\Delta) - K_1 A((i-1)\Delta), 0] \\ &\quad \cdot \mathbf{1}\{A(i\Delta + \Delta_d) - K_2 A(i\Delta) \geq 0\}],\end{aligned}\tag{6}$$

where $\mathbf{1}\{Y\} = 1$ if Y is true and otherwise it is zero, $n = \lfloor T/\Delta \rfloor$ is the number of bonus payout periods, $T > 0$ is the banker's tenure, the length of bonus payout period $\Delta > 0$, the length of deferral period $\Delta_d \geq 0$, K_1 is the minimum equity return during the bonus accrual period required for a positive bonus, and K_2 is the minimum equity return during the bonus deferral period required for a positive bonus (this compensation structure with a bonus deferral is similar to the contract considered in Leisen (2014)). Thus, the compensation package is a series of sequential exotic call option contracts. By (6) and iterated expectation, we get the result below (all the proofs are in Appendix C).

Proposition 1 *The value of the compensation package with n bonuses, bonus payout period $\Delta > 0$, and bonus deferral period $\Delta_d \geq 0$ is given by*

$$\pi_{\Delta}(\Delta_d) = \begin{cases} kA(0) \left(\frac{1-e^{n\beta\sigma_{\theta}\Delta}}{1-e^{\beta\sigma_{\theta}\Delta}} \right) C(K_1, \Delta, \sigma_{\theta}) e^{-r\Delta_d} \Phi(d_2(K_2, \Delta_d, \sigma_{\theta})), & \beta \neq 0, \\ nkA(0) C(K_1, \Delta, \sigma_{\theta}) e^{-r\Delta_d} \Phi(d_2(K_2, \Delta_d, \sigma_{\theta})), & \beta = 0, \end{cases},$$

where $C(K_1, \Delta, \sigma_{\theta})$ is the option pricing formula given by (5), k is the fraction of equity value increase paid out as bonus, and $A(0)$ is the initial equity value in (2).

Thus, the value of the compensation equals the sum of $kA(0) \left(\frac{1-e^{n\beta\sigma_{\theta}\Delta}}{1-e^{\beta\sigma_{\theta}\Delta}} \right)$ (when $\beta \neq 0$) or $nkA(0)$ (when $\beta = 0$) many call options with maturity Δ and strike price K_1 , multiplied by a factor due to the bonus deferrals of length Δ_d .

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

$$\begin{aligned} \tilde{\pi}_{\Delta, M}(\Delta_d) = & kA(0)g(n)e^{-r\Delta_d}\Phi(d_2(K_2, \Delta_d, \sigma_\theta)) \left\{ C(K_1, \Delta, \sigma_\theta) - \frac{1}{n} \sum_{i=1}^n E \left[C \left(K_1 + \frac{M}{kA(0)} \right. \right. \right. \\ & \left. \left. \left. \cdot \exp \left(\left(\frac{1}{2} \sigma_\theta^2 - r - \beta \sigma_\theta \right) (i-1)\Delta + \sqrt{(i-1)\Delta} \sigma_\theta \varepsilon_i \right), \Delta, \sigma_\theta \right) \right] \right\} \end{aligned}$$

where $n = \lfloor T/\Delta \rfloor$, and

$$g(n) = \begin{cases} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right), & \beta \neq 0, \\ n, & \beta = 0. \end{cases}$$

$A(0)$ is the initial equity value in (2), σ_θ is the equity volatility, r is the risk-free rate, k is the fraction of equity value increase paid out as bonus, $\{\varepsilon_i\}$ are independent standard normal random variables, and $C(K_1, \Delta, \sigma_\theta)$ is the call option price in (5).

By Proposition 1 and Corollary 1, the value of compensation falls as bonuses are capped by M .

Bankers' risk-taking incentive can be measured by the first order derivative of the compensation value in Proposition 1 or Corollary 1 with respect to the equity volatility σ_θ , termed as the *bonus vega*. In Appendix A, we analyze the properties of the bonus vega and how bonus deferrals and caps can affect the banker's risk-taking incentive. It turns out that theoretically bonus deferrals and caps can reduce the banker's risk-taking incentive.

4 Optimal risk level and bonus based incentive

4.1 Banker's optimization

In this section, to prepare for the principal-agent setting in subsection 4.2, we solve the banker's optimal level of risk by including the banker's costs of changing the risk level. The costs incurred by the banker of changing risk may arise from several sources. For instance, high risk levels raise the likelihood of bad performance, which can have detrimental consequences to the banker's career. As mentioned before, the choice of

the risk level in our model is a long-term strategy, and changes in the risk level cause substantial organizational costs. In case of risk reduction, if the bank has a strong risk-taking culture then there may be, e.g., reputational costs or organizational inertia for choosing a low risky strategy. In our cost parameter calibration, we allow both positive and negative cost parameter values. Positive values correspond to costs for the banker and negative values to cost savings from the risk level changes due to, e.g., a banking regulation. We do not explicitly model the sources of these costs to the banker; instead, we use a generic cost function, and calibrate the cost parameters to data.

By (2), the banker takes risk with high leverage θ and/or with riskier assets, having higher volatility, σ . Suppose the current risk level of the bank is σ_θ . The costs of changing the risk position are a function of the change of the equity volatility σ_θ . Further, we use a 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:

$$\max_{\Delta\sigma_\theta \geq -\sigma_\theta} \{ \tilde{\pi}_{\Delta, M}(\sigma_\theta + \Delta\sigma_\theta, \Delta_d) - F(\Delta\sigma_\theta) \}, \quad (7)$$

where we write $\tilde{\pi}_{\Delta, M}(\sigma_\theta, \Delta_d)$ explicitly as a function of equity volatility $\sigma_\theta = (1 + \theta)\sigma$ and the bonus deferral period Δ_d , $\Delta\sigma_\theta$ is the change of current σ_θ , and $F(\cdot)$ is the cost of changing the equity volatility.⁵ The optimization constraint in (7) means that the equity volatility cannot be negative.

We use the following piecewise quadratic cost function:

$$F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2,$$

where c_+ and c_- are cost parameters for volatility increase and decrease, and $\mathbf{1}\{\cdot\}$ is an indicator function given in (6). 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

⁵The 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 (17) since when σ_θ is optimal then $\Delta\sigma_\theta$ is zero.

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.

We analyze the changes in a bank’s risk level, i.e., equity volatility under different bonus caps and bonus deferrals. Given the fixed bonus payment frequency, i.e., n is fixed, by Corollary 1, the bank regulators can limit bankers’ risk-taking by introducing a bonus cap (parameter M) and the deferral of bonuses (parameter Δ_d). We keep $n = T$ so that $\Delta = 1$, i.e., the bonus is calculated annually. Besides, $K_1 = K_2 = 1$. More specifically, let $\bar{\sigma}_\theta$ be regulators’ upper bound on the equity volatility σ_θ . Then the regulators face the following problem: find the range of bonus cap M and bonus deferral period Δ_d values such that

$$\bar{\sigma}_\theta \geq \sigma_{1,M}^*(\Delta_d), \quad (8)$$

where the optimal equity volatility chosen by the banker is given by

$$\sigma_{1,M}^*(\Delta_d) = \sigma_\theta + \arg \max_{\Delta\sigma_\theta \in [-\sigma_\theta, \bar{\sigma}_\theta - \sigma_\theta]} \{ \tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, \Delta_d) - F(\Delta\sigma_\theta) \}. \quad (9)$$

We discuss $\bar{\sigma}_\theta$ and how we estimate the parameters of the cost function $F(\cdot)$ in Appendix B.

4.2 Bank’s optimization

In this subsection, we utilize the principal-agent model in Holmstrom (1979) to solve the optimal bonus per net income, k , and the optimal risk level σ_θ . That is, we extend the model in the previous section by analyzing the effect of compensation regulation on the bonus parameter k , and this way both the direct (previous subsection) and indirect (this subsection) effects on risk level σ_θ .

The bank is the principal and the banker is the agent. The banker’s risk-taking affects the profits of the bank. Different from the canonical moral hazard model in Holmstrom (1979), due to labor market constraints, we assume that the bank has no flexibility in choosing the form of the contract. That is, the banker’s compensation structure is again

given by (4), i.e., it is given by bonuses based on the change of book equity value. This is also consistent with our data (and our model extensions in subsection 5.2.2). Thus, the bank observes its profits at the end of each bonus accrual period, but cannot compensate the banker based on her risk-taking efforts and there is moral hazard.

Our principal-agent model is static, where the bank and the banker make their decisions at the beginning of the banker's tenure, which are maintained during the entire tenure. The equity value changes are observed at the end of each bonus accrual period and based on that the banker's pay materializes. In the beginning of the horizon, the banker's choice of risk level is unobservable to the bank. When calibrating the model in Section 5 we however need an estimate of bank risk. For this we use the historical time-series average of a bank's past book equity value changes.

The banker is effectively risk averse due to the piecewise quadratic cost function in (7). To ensure the concavity of the banker's objective function, we use the quadratic cost function. The bank is risk-neutral, and therefore, it wants to increase the risk-taking of the risk averse banker. However, too much risk-taking is not desired from the societal perspective and, therefore, the regulators try to limit the risk-taking by using the compensation regulation. More specifically, as in subsection 3.2, the bank offers a proportion k of the equity value increase as a bonus to the banker to incentivize her to raise the risk level. Meanwhile, regulators introduce bonus deferrals and caps to manage the banker's risk-taking behavior.

More specifically, the bank's objective is to maximize the expected discounted net profit after bonus payouts to the banker under bonus deferral period Δ_d and bonus cap M . As in subsection 4.1, we focus on the case where the bonus is paid annually, i.e., $n = T$ and $\Delta = 1$. Given the risk level σ_θ , the banker maximizes the expected discounted bonuses $\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, \Delta_d)$ minus the cost of risk-taking $F(\Delta\sigma_\theta)$. For expositional simplicity, denote $\hat{\sigma}_\theta = \sigma_\theta + \Delta\sigma_\theta$ as the equity volatility and \hat{k} as the size of the bonus in terms of the equity value change in the principal-agent model. The bank has the

following optimization problem:⁶

$$\begin{aligned}
& \max_{\hat{k} \in [0, \bar{k}], \hat{\sigma}_\theta \in [0, \bar{\sigma}_\theta]} E \left[e^{-rT} (A(T) - A(0)) - \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) \right] & (10) \\
& \text{such that} \quad \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) - F(\hat{\sigma}_\theta - \sigma_\theta) \geq \underline{H}, \\
& \hat{\sigma}_\theta \in \arg \max_{\hat{\sigma}'_\theta \in [0, \bar{\sigma}_\theta]} \{ \tilde{\pi}_{1,M}(\hat{\sigma}'_\theta, \Delta_d) - F(\hat{\sigma}'_\theta - \sigma_\theta) \},
\end{aligned}$$

where \bar{k} and $\bar{\sigma}_\theta$ are the upper bound of the fraction of net profit paid out as bonus and the upper bound of the equity volatility; see (8). In the model calibration, we assume $\bar{k} = 2k^d$ and $\bar{\sigma}_\theta = 2\sigma_\theta^d$, where k^d and σ_θ^d are the bonus size and equity volatility estimated from the data in subsection 5.1. The banker's expected discounted bonus value, $\tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)$, is given by Corollary 1 with the equity volatility $\hat{\sigma}_\theta$ and \underline{H} is the banker's reservation utility from her outside options. The equity value after the banker's tenure, $A(T)$, follows (2) with equity volatility $\hat{\sigma}_\theta$. By (10), under bonus deferral Δ_d and bonus cap M , the bank's optimal bonus payment, denoted as $k_{1,M}^o(\Delta_d)$, and the banker's optimal risk-taking level, denoted as $\sigma_{1,M}^o(\Delta_d)$, are solved simultaneously.

We focus on the case where $K_1 = K_2 = 1$ (see (6)). Given the initial equity value $A(0)$, the equity value $A(T)$ follows a log normal distribution:

$$\ln A(T) \sim N \left(\ln A(0) + \left(r + \beta \hat{\sigma}_\theta - \frac{1}{2} \hat{\sigma}_\theta^2 \right) T, \hat{\sigma}_\theta^2 T \right),$$

where $\hat{\sigma}_\theta$ is the earning volatility. This gives

$$E[A(T)] = A(0) \exp((r + \beta \hat{\sigma}_\theta) T).$$

We assume the anchored risk level is the equity volatility estimated by the data, σ_θ^d , and the value of the banker's outside option \underline{H} in (10) is proportional to the compensation value $\tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d)$. Then the incentive compatibility constraint in (10) can be written as $\tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) - F(\hat{\sigma}_\theta - \sigma_\theta^d) \geq \alpha \tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d)$, where $\alpha \in (0, 1)$.

⁶Note that there could be multiple solutions to this model. We set the search ranges for \hat{k} and $\hat{\sigma}_\theta$ as $\hat{k} \in [0, 2k^d]$, $\hat{\sigma}_\theta \in [0, 2\sigma_\theta^d]$ to ensure the optimal solution of the principal-agent model is near to the values estimated by the data, i.e., k^d and σ_θ^d . In the policy simulation in Section 5, these two constraints are binding for just a few sample banks.

Now we can write the bank's optimization problem (10) as follows:

$$\begin{aligned}
& \max_{\hat{k} \in [0, 2k^d], \hat{\sigma}_\theta \in [0, 2\sigma_\theta^d]} A(0) [e^{\beta \hat{\sigma}_\theta T} - e^{-rT}] - \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) & (11) \\
& \text{such that } \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) - F(\hat{\sigma}_\theta - \sigma_\theta^d) \geq \alpha \tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d), \\
& \hat{\sigma}_\theta \in \arg \max_{\hat{\sigma}'_\theta \in [0, 2\sigma_\theta^d]} \{ \tilde{\pi}_{1,M}(\hat{\sigma}'_\theta, \Delta_d) - F(\hat{\sigma}'_\theta - \sigma_\theta^d) \}.
\end{aligned}$$

To solve $k_{1,M}^o(\Delta_d)$ and $\sigma_{1,M}^o(\Delta_d)$, we write the KKT conditions as below:

$$\begin{aligned}
& \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) - F(\hat{\sigma}_\theta - \sigma_\theta^d) - \alpha \tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d) \geq 0, \\
& \frac{\partial \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial \hat{\sigma}_\theta} - \frac{\partial F(\hat{\sigma}_\theta - \sigma_\theta^d)}{\partial \hat{\sigma}_\theta} = 0, \\
& -\frac{\partial \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial k} + \lambda \left[\frac{\partial \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial k} - \alpha \frac{\partial \tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d)}{\partial k} \right] + \mu \frac{\partial^2 \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial \hat{\sigma}_\theta \partial k} = 0, \\
& A(0)e^{\beta \hat{\sigma}_\theta T} \beta T - \frac{\partial \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial \hat{\sigma}_\theta} + \mu \left(\frac{\partial^2 \tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d)}{\partial \hat{\sigma}_\theta^2} - \frac{\partial^2 F(\hat{\sigma}_\theta - \sigma_\theta^d)}{\partial \hat{\sigma}_\theta^2} \right) = 0, \\
& \lambda [\tilde{\pi}_{1,M}(\hat{\sigma}_\theta, \Delta_d) - F(\hat{\sigma}_\theta - \sigma_\theta^d) - \alpha \tilde{\pi}_{1,M}(\sigma_\theta^d, \Delta_d)] = 0, \\
& \lambda \geq 0, \\
& \mu \geq 0.
\end{aligned}$$

We solve $k_{1,M}^o(\Delta_d)$ and $\sigma_{1,M}^o(\Delta_d)$ numerically from the KKT conditions by using the solver embedded in the optimization toolbox in Matlab. To solve (11), we need to estimate the banker's cost of changing the risk level and her outside option value. We explain the estimation of these parameters in Appendix B.

The estimated $k_{1,\infty}^o(0)$ and $\sigma_{1,\infty}^o(0)$ are the bank's optimal bonus payment and the banker's optimal risk-taking level without bonus regulations. To evaluate the impact of bonus deferral Δ_d and bonus cap M on the banker's risk-taking, the optimal bonus payment $k_{1,M}^o(\Delta_d)$ and the corresponding equity volatility $\sigma_{1,M}^o(\Delta_d)$ are jointly solved from the principal-agent model (11).⁷ Then we calculate the risk reductions and the

⁷In the constrained optimization problem (11), if there exist multiple equilibria, we always select the one which is closest to the calibrated result.

bonus incentive changes as follows:

$$\text{risk reduction} = \frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}, \quad \text{bonus incentive change} = \frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}.$$

These results are reported in subsection 5.2 under various scenarios of bonus regulations and several model extensions for robustness check.

5 Policy simulations

In this section, we first calibrate the banker's risk-taking cost and then use the principal-agent 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 equity volatility σ_θ . The bonus accrual period is always one year, $\Delta = 1$. More specifically, we calculate eight different cases with the quadratic cost function. These cases are as follows. (i) The bonus deferral period is one year without bonus caps; we solve $\sigma_{1,\infty}^o(1)$ by (11). (ii) The bonus deferral period is three years without bonus caps, which gives $\sigma_{1,\infty}^o(3)$. (iii) The bonus cap equals the CEO's base salary at 2006 without bonus deferrals, which gives $\sigma_{1,S}^o(0)$, where S refers to the base salary. (iv) The bonus cap equals three times of the CEO's base salary at 2006 without bonus deferrals, which gives $\sigma_{1,3S}^o(0)$. (v) The bonus deferral period is one year and the bonus cap equals the CEO's base salary at 2006, which gives $\sigma_{1,S}^o(1)$. (vi) The bonus deferral period is three years and the bonus cap equals the CEO's base salary at 2006, which gives $\sigma_{1,S}^o(3)$. (vii) The bonus deferral period is one year and the bonus cap equals three times of the CEO's base salary at 2006, which gives $\sigma_{1,3S}^o(1)$. (viii) The bonus deferral period is three years and the bonus cap equals three times of the CEO's base salary at 2006, which gives $\sigma_{1,3S}^o(3)$. All these cases are motivated by the current EU regulations on bonus policies (see European Union, 2013).

In subsection 5.1, we first describe the data used to calibrate the model parameters, and then in subsection 5.2, we present the results for cases (i) – (viii) above. We also make several important extensions to the baseline model in subsection 5.2.2.⁸

⁸The baseline model refers to the equity dynamics and bonus payment model presented in subsection 3.2, the baseline cost parameters refer to the cost parameters with $c_- = 0$, and the baseline case refers to the calibration of the baseline model with the baseline cost parameters.

5.1 Data

To calibrate the parameters of the cost function introduced in subsection 4.1, 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 equity volatility.

We calculate the parameters for bankers’ cost of changing risks and the realized risk level as follows. Parameter k^d 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 2006.⁹ Equity volatility σ_θ^d is the annualized volatility estimated from the time series of quarterly return on equity from 2000Q1 to 2006Q4.¹⁰ For robustness, we also consider equity volatility 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 proxy for the possibility that banks had a higher, partly forward-looking equity volatility estimate at the end of 2006 than just the historical equity volatility estimate. Table 1 shows that the estimated equity 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.

To estimate the parameter β , for each sample bank i , we use the quarterly total asset data to get the asset volatility σ_i and the mean growth rate m_i . We assume all the banks have the same β parameter value. Thus, β is estimated by the following linear regression model:

$$m_i = r + \beta\sigma_i - \frac{1}{2}\sigma_i^2 + \epsilon_i, \quad \epsilon_i \sim N(0, 1).$$

⁹This 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).

¹⁰Our measure of return on equity is net income over the book value of equity, which is the same as used, for example, by Fahlenbrach and Stulz (2011).

We estimate the parameter β using the asset volatility values calibrated by the data from 2000Q1 to 2006Q4 and 2000Q1 to 2008Q4, respectively. The β values are estimated as 0.8382 and 0.6739, respectively, which are significant at 1%.

The Δ parameter, measuring the bonus frequency, is set at standard 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 age is common for all CEOs in the sample and is proxied by the highest CEO age in the data, which is 77 years. The cap of 10 years on the remaining CEO tenure is motivated by studies on average CEOs' tenures.¹¹ However, as a robustness check, we also calibrate the model by assuming a CEO tenure cap of 15 years.

5.2 Results

5.2.1 Baseline model

Consistent with Lemma 2, 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 (17). Table 3 shows that in this case both bonus caps and bonus deferrals as well as their combinations would lead to risk reductions. However, we mainly base our analysis of the effectiveness of bonus caps and deferrals on the case in which we assume that the banker's cost of reducing risk is assumed to be zero. With this assumption we get the pure effect on bank risk of the banker's risk-taking incentive channel which the bonus regulations modify. Table 4 presents risk reductions by assuming that c_- is set at zero. We focus in Panel A on Cases I and II with a one or three-year bonus deferral, respectively, and Case III with a bonus cap equal to the banker's fixed salary as in the baseline EU regulation.

Regarding deferrals, we see that the effects on bank risk are negligible regardless of the deferral length. Only 22% of the sample banks are affected, having a non-zero risk reduction, and the maximum risk reduction among the sample banks is only 0.08%. These results stay qualitatively similar even when we change the return threshold parameters of the deferral contract in Tables 7 and 8.

¹¹For 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.

Turning to the bonus cap, Case III in Panel A of Table 4 shows that only 16% of sample banks are affected but the maximum effect among sample banks is considerable, almost 37% risk reduction. In Table 6 we have listed the sample banks with risk reductions. Only four banks have large risk reduction, others have only negligible effect. Of those, two were known problem banks during the 2008 crisis. Other well-known problem banks during the crisis have only very small risk reductions in our counterfactual calculations, or are not affected at all (i.e., have zero risk reductions in our sample). One possibility is that some sample banks which were known problem banks but do not experience a significant risk in our counterfactual analysis had a considerable amount of hidden tail risks or hidden leverage which our model parameters estimated from their balance sheet data do not capture.

In general we see from our results that most sample banks find it optimal (and feasible) to increase parameter k , the sensitivity of bonuses, in order to counteract the effect of bonus regulations on banker's reduced risk-taking incentive. This is the mechanism why bonus regulations generally are quite impotent according to our model. However, in the case of the four banks strongly affected by the bonus cap, the explanation is that they are among only a few banks whose CEOs had an extremely high cash bonus to fixed salary ratio (see Figure 6). Hence, the cap cuts into their bonuses so deeply that an unreasonably large increase in k would be needed to nullify its effect.

Interestingly, as Figure 6 shows, there are two banks with very high bonus to salary ratios but nonetheless practically no risk-reducing effect as a result of the bonus cap. In one case (Bear Stearns), the bank has increased k very much and that may have nullified the effect of the bonus cap. However, in the other case (Merrill Lynch), the bank has even decreased k (see Table 6, the right-most column) in response to the bonus cap. These examples indicate that there may be important non-linearities in determining the effect on a banker's risk-taking of the bonus cap.¹²

¹²Note that in Table 6 the change in parameter k is defined such that a negative change indicates an increase in k and vice versa. Note also that for ensuring the concavity of the banker's decision problem, we have restricted the range of k changes so that the maximum change considered is approximately -344%.

5.2.2 Extensions

We run a number of robustness checks with model extensions and find that the above results stay qualitatively the same. Below we explain in more detail how the model extensions were implemented.

Bonus payments and equity value dynamics

Table 9 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. We see that the maximum risk reduction of bonus cap (Case III) in Table 9 is smaller (about 24%). Qualitatively the results concerning deferrals and bonus caps are similar to the baseline model case in Table 4.

Option grants

So far we have worked with the baseline model which has only considered cash bonuses, but as we have already discussed, option grants also affect bankers' risk-taking incentives. We now augment the baseline model to incorporate them. In the calibrated baseline model, the state variable that determines the amount of bonus paid in each bonus accrual period is interpreted as earnings. We could use the same model and interpret the state variable as bank market 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 equity volatility, we modify the model by using the (equity) price-to-earnings ratio to transform equity 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 10 and 11 report the cost parameters and the risk reductions, respectively, when the option grants are also considered in the banker's objective function. Again, the results are qualitatively in line with the baseline

results. In fact, incorporating option grants further reduces even the maximum impact of bonus caps.¹³

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 12, 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).

Again, we can see in Table 12 that the results are similar to the baseline results in Table 4. 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 very big (maximum in the sample is 100% risk reduction), while for others, smaller than in the baseline case. These results can be explained with Figure 5 (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. 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

¹³We applied deferral only on cash bonuses but extending them to include option grants would not alter the result, given that we have used a mapping between equity volatility and stock volatility to model the option grants’ effect on risk-taking incentives. In the European Union, deferral applies to all variable pay in a given period, including exercised option grants.

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. Moreover, the result that the bonus cap strongly affects only a small number of banks (from among those who have extremely high bonus to fixed salary ratios for the CEOs) also remains.

Passive principal

We also consider the case where the bank sticks to the bonus payment practice irrespective of the bonus regulations. In other words, the principal is passive and not-responding to the bonus regulations. In the principal-agent model (10), the only decision variable is the risk-level and the bonus per net income is fixed at the value which is calibrated by the time series data. We obtain the same qualitative result that bonus caps have stronger effect on the risk reduction than deferrals. However, since in this case the bank does not respond to the compensation regulations, the effect of bonus caps is stronger than in subsection 5.2.1. These results are reported in the online appendix.

6 Conclusions

In this paper we have analyzed the effect of bonus caps and bonus deferrals that regulators can use, in addition to many other regulations, to restrict banks' risk-taking. To do that, we have derived a new principal-agent model, calibrated it to data from large US banks and their CEOs' compensation packages on the eve of the Global Financial Crisis, and run counterfactual analyses for the effects of the bonus regulations. We find that the potential effect on the median bank's risk is negligible as banks respond to the regulations by increasing the sensitivity of bonuses. However, on a small number of banks who had a very high ratio of cash bonus to fixed salary for their CEOs prior to 2008, the bonus cap has a sizeable risk-reduction effect. In contrast, bonus deferrals have only negligible effects on all sample banks. Overall, despite the potential shown by the bonus cap in these extreme cases, neither type of bonus regulations is generally well-designed

according to our analysis to reduce bank risk-taking at least in their current form.

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Appendix A Bonus vega

Due to the presence of bonus deferral, the equity volatility brings two opposite effects to the compensation value. Since the compensation value is a series of sequential exotic call options, the value $C(K_1, \Delta, \sigma_\theta)$ rises in the equity volatility σ_θ such that $\frac{\partial C(K_1, \Delta, \sigma_\theta)}{\partial \sigma_\theta} = \phi(d_1(K, \Delta, \sigma_\theta))\sqrt{\Delta} > 0$, while the probability that the banker can get the bonus after the deferral period, $\Phi(d_2(K_2, \Delta_d, \sigma_\theta))$, decreases in σ_θ especially when $\ln(\frac{1}{K_2}) + r\Delta_d \geq 0$. By Proposition 1 and Black and Scholes (1973), we get the formula for the bonus vega if $\beta \neq 0$:

$$\begin{aligned} \frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta} &= kA(0) \frac{\partial}{\partial \sigma_\theta} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) C(K_1, \Delta, \sigma_\theta) e^{-r\Delta_d} \Phi(d_2(K_2, \Delta_d, \sigma_\theta)) \\ &\quad + kA(0) e^{-r\Delta_d} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) \left(\phi(d_1(K_1, \Delta, \sigma_\theta))\sqrt{\Delta} \Phi(d_2(K_2, \Delta_d, \sigma_\theta)) \right. \\ &\quad \left. - \frac{C(K_1, \Delta, \sigma_\theta)}{\sigma_\theta} \phi(d_2(K_2, \Delta_d, \sigma_\theta)) \left[d_1(K_2, \Delta_d, \sigma_\theta) - \beta\sqrt{\Delta_d} \right] \right), \end{aligned} \quad (12)$$

where

$$\frac{\partial}{\partial \sigma_\theta} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) = \left(\frac{(n-1)\beta\Delta e^{(n+1)\beta\sigma_\theta\Delta} - n\beta\Delta e^{n\beta\sigma_\theta\Delta} + \beta\Delta e^{\beta\sigma_\theta\Delta}}{(1 - e^{\beta\sigma_\theta\Delta})^2} \right),$$

and

$$\frac{\partial}{\partial \sigma_\theta} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) \begin{cases} > 0, & \beta > 0, \\ < 0, & \beta < 0. \end{cases}$$

While if $\beta = 0$, then the bonus vega is given by

$$\begin{aligned} \frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta} &= nkA(0) e^{-r\Delta_d} \left\{ \sqrt{\Delta} \Phi(d_2(K_2, \Delta_d, \sigma_\theta)) \phi(d_1(K_1, \Delta, \sigma_\theta)) \right. \\ &\quad \left. - \frac{1}{\sigma_\theta} C(K_1, \Delta, \sigma_\theta) \phi(d_2(K_2, \Delta_d, \sigma_\theta)) d_1(K_2, \Delta_d, \sigma_\theta) \right\}, \end{aligned} \quad (13)$$

where $\phi(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$ is the standard normal density function. Without bonus

deferral, i.e., $\Delta_d = 0$, it is easy to see that the bonus vega is calculated as

$$\frac{\partial \pi_{\Delta}(0)}{\partial \sigma_{\theta}} = \begin{cases} kA(0) \frac{\partial}{\partial \sigma_{\theta}} \left(\frac{1 - e^{n\beta\sigma_{\theta}\Delta}}{1 - e^{\beta\sigma_{\theta}\Delta}} \right) C(K_1, \Delta, \sigma_{\theta}) \\ + kA(0) \left(\frac{1 - e^{n\beta\sigma_{\theta}\Delta}}{1 - e^{\beta\sigma_{\theta}\Delta}} \right) \phi(d_1(K_1, \Delta, \sigma_{\theta})) \sqrt{\Delta}, & \beta \neq 0, \\ nkA(0) \sqrt{\Delta} \phi(d_1(K_1, \Delta, \sigma_{\theta})), & \beta = 0. \end{cases} \quad (14)$$

The two opposite effects of the equity volatility on the compensation value may indicate that the bonus vega (13) can be negative, i.e., a higher equity volatility may decrease the banker's compensation value. While the longer the bonus deferral, the effect of equity volatility on the probability $\Phi(d_2(K_2, \Delta_d, \sigma_{\theta}))$ may become weaker. In other words, the bonus vega may increase in the length of the deferral period.

For expositional simplicity, we focus on the case with $\beta = 0$. To illustrate the role of σ_{θ} and Δ_d on the magnitude and sign of the bonus vega (13), let us first fix the parameter values with $\Delta = 1$, $K_1 = K_2 = 1$. Further, we assume $r = \frac{1}{2}\sigma_{\theta}^2 = 0.2$. Then, substituting the parameters into (13), the bonus vega is calculated simply as

$$\frac{\partial \pi_1(\Delta_d)}{\partial \sigma_{\theta}} = TkA(0)e^{-r\Delta_d} \frac{1}{\sqrt{2\pi}} \left[\frac{1}{2}e^{-r} - \left(\Phi(\sqrt{2r}) - \frac{1}{2}e^{-r} \right) \sqrt{\Delta_d} \right],$$

where $\Phi(\sqrt{2r}) - \frac{\exp(-r)}{2} > 0$. If $\Delta_d = 1$, then

$$\frac{\partial \pi_1(1)}{\partial \sigma_{\theta}} = TkA(0)e^{-r} \frac{1}{\sqrt{2\pi}} \left[e^{-r} - \Phi(\sqrt{2r}) \right] > 0.$$

If $\Delta_d = 0.5$, then

$$\frac{\partial \pi_1(0.5)}{\partial \sigma_{\theta}} = TkA(0)e^{-\frac{r}{2}} \frac{1}{\sqrt{2\pi}} \left[\left(\frac{1}{2} + \frac{1}{2\sqrt{2}} \right) e^{-r} - \frac{1}{\sqrt{2}} \Phi(\sqrt{2r}) \right] < 0.$$

These two special examples suggest that the bonus vega may be negative if the bonus deferral period is shorter, positive if the deferral becomes longer. As the bonus vega measures the banker's risk-taking incentive, the managerial implication is that a short bonus deferral may reduce a banker's risk-taking incentive, while a long bonus deferral may drive the banker to take more risks.

Since the bonus vega changes the sign from negative to positive as the length of bonus deferral increases, we expect that the bonus vega increases in the length of bonus deferral period. Indeed, for the special case with $\Delta = 1$, $K_1 = K_2 = 1$, $r = \frac{1}{2}\sigma_\theta^2$, we have

$$\frac{\partial^2 \pi_1(\Delta_d)}{\partial \sigma_\theta \partial \Delta_d} = TkA(0)e^{-r\Delta_d} \frac{1}{\sqrt{2\pi}} \left[\left(\Phi(\sigma_\theta) - \frac{1}{2}e^{-r} \right) \frac{1}{\sqrt{\Delta_d}} (r\Delta_d - 1) - \frac{re^{-r}}{2} \right],$$

where if Δ_d becomes large enough such that

$$\left(\Phi(\sigma_\theta) - \frac{1}{2}e^{-r} \right) \frac{1}{\sqrt{\Delta_d}} (r\Delta_d - 1) - \frac{re^{-r}}{2} > 0,$$

then $\frac{\partial^2 \pi_1(\Delta_d)}{\partial \sigma_\theta \partial \Delta_d} > 0$, which implies the bonus vega increases in the length of the bonus deferral period.

To generalise the above result, we focus on the case with $K_1 \geq K_2$, $K_2 = 1$, and $r \geq \frac{1}{2}\sigma_\theta^2$. All our sample banks satisfy $r \geq \frac{1}{2}\sigma_\theta^2$. Let us introduce the following condition

$$C_1 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) < C_2, \quad (15)$$

where

$$\begin{aligned} C_1 &= \sqrt{\Delta} \phi(d_1(K_1, \Delta, \sigma_\theta)) > 0, \\ C_2 &= \frac{1}{\sigma_\theta} C(K_1, \Delta, \sigma_\theta) \left(\frac{r}{\sigma_\theta} + \frac{\sigma_\theta}{2} \right) > 0. \end{aligned}$$

Equation (15) holds with all our sample banks. The bonus vega (13) is simplified as

$$\frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta} = nkA(0)e^{-r\Delta_d} \left\{ C_1 \Phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d} \right] - C_2 \phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d} \right] \sqrt{\Delta_d} \right\}.$$

Denote

$$G(\Delta_d) = C_1 \Phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d} \right] - C_2 \phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d} \right] \sqrt{\Delta_d}. \quad (16)$$

Let variables $\underline{\Delta}_d$ and $\bar{\Delta}_d$ satisfy $G(\underline{\Delta}_d) = G(\bar{\Delta}_d) = 0$ and $0 < \underline{\Delta}_d < \bar{\Delta}_d$. The following

lemma gives the existence of $\underline{\Delta}_d$ and $\bar{\Delta}_d$ (the proof is in Appendix C.3).

Lemma 1 *Assume (15) holds. For the case with $\beta = 0$, there exist $\underline{\Delta}_d$ and $\bar{\Delta}_d$ such that $0 < \underline{\Delta}_d < \bar{\Delta}_d < \infty$ and $G(\underline{\Delta}_d) = G(\bar{\Delta}_d) = 0$, where $G(\Delta_d)$ is given by (16).*

Now we can give the following corollary in terms of the effect of bonus deferral on bonus vega (12), and the proof is in Appendix C.4.

Proposition 2 *Assume (15), $K_1 \geq K_2$, $K_2 = 1$, and $r \geq \frac{1}{2}\sigma_\theta^2$. Then, we have:*

(i) *Without bonus deferral ($\Delta_d = 0$), for the case with $\beta \geq 0$, the bonus vega (14) is always positive.*

(ii) *For the case with $\beta \leq 0$, there exist a non-empty set of deferral lengths such that if Δ_d is in the set, then the bonus vega (12) is negative. Specifically, for $\beta = 0$, the non-empty set is $(\underline{\Delta}_d, \bar{\Delta}_d)$, where $\underline{\Delta}_d$ and $\bar{\Delta}_d$ are given by Lemma 1.*

The first point of Proposition 2 says that without bonus deferral, the bonus vega is always positive for the case with $\beta \geq 0$, i.e., the banker has incentive to increase the risk level. While the second point says that for the case with $\beta \leq 0$, a sufficiently shorter bonus deferral may lead to a negative bonus vega which reduces the banker's risk-taking incentive. By Proposition 2, without bonus deferral, the bonus vega is always positive for the case with $\beta \geq 0$. However, the bonus vega can be negative if there exists a bonus deferral which is in a certain range for the case with $\beta \leq 0$. For the case with $\beta > 0$, there could also exist non-empty set in terms of the bonus deferral period such that the bonus vega is negative. We resort to numerical examples to illustrate this result.

Figure 1 illustrates the compensation value (Proposition 1) and risk-taking incentives (12) with a positive β , that is, bonus vega $\left(\frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta}\right)$ with respect to the length of bonus deferral period Δ_d for an example bank when the cost of changing the risk level is not considered and the bonus accrual length is one year. As can be seen, the compensation value first decreases and then increases with respect to the length of deferral when Δ_d is very short. When Δ_d becomes longer, the compensation value starts to decrease. The vega first decreases and becomes negative when the deferral length is very short. When the deferral length becomes longer, the vega starts to increase and become positive. Thus, by our model and the numerical example of Figure 1, a short enough bonus deferral length, say less than 1 year, may decrease the banker's risk-taking incentives.

However, when the bonus deferral length becomes long, the vega is always positive, i.e., the banker has incentive to take more risks.

Figure 2 illustrates the compensation value and risk-taking incentives with respect to the equity volatility. As can be seen, the compensation value rises in the equity volatility, while the risk-taking incentive is low at very small volatility values but rises rapidly.

Next, we consider the bonus vega of the compensation package with the bonus cap while without bonus deferral, and give the following result:

Corollary 2 *The sensitivity of the compensation value under a bonus cap without bonus deferral with respect to the equity volatility can be negative; that is, $\frac{\partial \tilde{\pi}_{\Delta, M}(0)}{\partial \sigma_\theta} < 0$ for sufficiently low M .*

Proof: We consider a special case with $n = 1$ and $\Delta_d = 0$, i.e., the bonus is paid instantly at the end of the banker's tenure. Then the bonus vega is given by

$$\frac{\partial \tilde{\pi}_{T, M}(0)}{\partial \sigma_\theta} = kA(0) \left[\frac{\partial C(K_1, \Delta, \sigma_\theta)}{\partial \sigma_\theta} - \frac{\partial C\left(K_1 + \frac{M}{kA(0)}, \Delta, \sigma_\theta\right)}{\partial \sigma_\theta} \right] = kA(0) [\phi(d_2(\Delta)) - \phi(d_3(\Delta))],$$

where

$$d_2(\Delta) = \frac{1}{\sigma_\theta \sqrt{\Delta}} \left[\ln \left(\frac{1}{K_1} \right) + \left(r + \beta \sigma_\theta - \frac{1}{2} \sigma_\theta^2 \right) \Delta \right],$$

$$d_3(\Delta) = \frac{1}{\sigma_\theta \sqrt{\Delta}} \left[\ln \left(\frac{1}{K_1 + \frac{M}{kA(0)}} \right) + \left(r + \beta \sigma_\theta - \frac{1}{2} \sigma_\theta^2 \right) \Delta \right].$$

Therefore, if $|d_2(\Delta)| > |d_3(\Delta)|$, i.e.,

$$0 < M < kA(0) \left(\frac{\exp \left(2 \left(r - \frac{1}{2} \sigma_\theta^2 \right) T \right)}{K_1} - K_1 \right),$$

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

This result is important since it indicates that bonus caps alone can create incentive to decrease the risk level.

Appendix B Calibration of cost parameters and outside option value

To jointly solve the banker's optimal risk-taking level and the bank's optimal bonus incentive by (11), we need to know the banker's risk-taking cost and the value of her outside option. To do that, we use a two-step estimation procedure, where we first estimate the bank-level cost parameters, and after that, the value of the outside option. This procedure is as follows.

B.1 Calibration of cost parameters

The cost function parameters for each bank are calculated by 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 the equity volatility $\sigma_\theta = \sigma_\theta^d$, where σ_θ^d is the equity volatility at the end of 2006, which is estimated from the time series of quarterly return on equity from 2000Q1 to 2006Q4. To be consistent with (10) and (11), the regulator's upper bound on the equity volatility in subsection 4.1 is $\bar{\sigma}_\theta = 2\sigma_\theta$ (see (8)). Thus, the cost function parameters are such that the equity volatility in 2006 of each bank equals the optimal level chosen by the banker $\sigma_{1,\infty}^*(0)$ in (9), i.e.,

$$\arg \max_{\Delta\sigma_\theta \in [-\sigma_\theta, \sigma_\theta]} \{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - F(\Delta\sigma_\theta)\} = 0. \quad (17)$$

This condition gives a range of cost function parameter values. 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 (17), 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 (17); and (iii) c_- equals zero: c_+ is as in (ii) but c_- is set to zero. The cost parameters and their impact on the banker's risk-taking by assuming the bonus incentive is fixed are summarized in Appendix E.

We have the following result:

Lemma 2 *If there are no bounds on the cost parameters and if initially there are no bonus caps or bonus deferrals, then the smallest cost parameter c_- that satisfies the optimality condition (17) is negative.*

Proof: By the optimality condition (17), for the quadratic cost function we have,

$$c_- \geq \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{(\Delta\sigma_\theta)^2},$$

and by Corollary 2, $\Delta_d = 0$, $\frac{\partial \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{\partial \sigma_\theta} > 0$, we have

$$\max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{(\Delta\sigma_\theta)^2} < 0.$$

This implies that the smallest value of $c_- < 0$ that satisfies (17) is negative. \square

Thus, if c_- is not bounded to be positive, and if there is no bonus cap initially, then $c_- < 0$. However, a more conservative assumption is that 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 conservative 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 and can hence be interpreted as a switching cost. Given the cost function parameters, in Section 5, we study the effect of bonus caps and deferrals on the bank CEO's optimized σ_θ using the principal-agent framework, where the amount of bonus measured by the bonus per net income k is simultaneously optimized by the bank.¹⁴ 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 equity

¹⁴In the model in the online appendix, we assume the bonus per net income k is fixed and stays unchanged, i.e., the banker selects the optimal equity volatility given the bonus incentive.

volatility. Let σ_θ be the initial optimal equity volatility in (17), which gives the parameter values in the cost function $F(\cdot)$. Then regulators introduce a bonus cap and/or a bonus deferral, and the banker reacts by solving a new equity volatility $\sigma_{T,M}^*(\Delta_d)$, where M is the positive bonus cap and Δ is the bonus deferral period and it satisfies $\Delta_d \geq 0$. Thus, we use the cost function parameters from (17), and then, we solve the new optimal risk level $\sigma_{T,M}^*(\Delta_d)$ from (9) under the calibrated cost parameters, where Δ_d is the regulatory bonus payment deferral during the banker's tenure T and M is the bonus cap.

By Corollary 2, if regulators introduce a bonus cap, we have the following result and the proof is in Appendix C.5.

Proposition 3 *Even if $c_- \in (0, \bar{c}_-)$ and $\Delta_d = 0$, there is bonus cap $M > 0$ such that $\sigma_{1,M}^*(0) < \sigma_\theta$, where T is the initial bonus frequency, σ_θ is the initial equity volatility in (17), and $\bar{c}_- = \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\bar{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \bar{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} > 0$. If $c_- \leq 0$, bonus caps decrease the equity volatility, i.e., $\sigma_{1,M}^*(0) < \sigma_\theta$ for all bounded bonus caps.*

The above result indicates that given the bonus per net income, 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. Without bonus caps, due to the deferral effect, it is also possible that the presence of bonus deferral can decrease the risk level, even if there exists cost of doing so. In particular, by Corollary 2, we have the following result in terms of the effect of bonus deferral on risk reduction even if there are no bonus caps and positive costs of reducing risks, and the proof is in Appendix C.6.

Proposition 4 *With bonus deferrals and without bonus caps, i.e., $\Delta_d > 0$ and $M = \infty$, even if $c_- \geq 0$, there exists bonus deferral period $\Delta_d \in (\underline{\Delta}_d, \bar{\Delta}_d)$ which decreases the equity volatility, i.e., $\sigma_{1,\infty}^*(\Delta_d) < \sigma_\theta$. For two deferral periods $\Delta_d^1 < \Delta_d^2$ and $\Delta_d^i \in (\underline{\Delta}_d^c, \bar{\Delta}_d)$, $i = 1, 2$, we have $\sigma_{1,\infty}^*(\Delta_d^1) < \sigma_{1,\infty}^*(\Delta_d^2)$. The parameters $\underline{\Delta}_d < \Delta_d^c < \bar{\Delta}_d$ are defined in Corollary 2.*

The above result indicates that given the bonus per net income, the bonus deferral alone can decrease the risk as well, especially for a shorter bonus deferral period. The effect of a short bonus deferral on risk reduction is due to the negative bonus vega, which reduces the banker's risk-taking incentive.

B.2 Calibration of outside option value

To estimate the value of the banker's outside option, we first estimate $k_{1,\infty}^o(0)$ and $\sigma_{1,\infty}^o(0)$ under $\Delta_d = 0$ and $M = \infty$, where the parameter α needs to be calibrated (see (11)). We use the following procedure to find parameter α . Given α , we denote the optimal bonus per net income and the equity volatility in the principal-agent model (11) as $k_{1,\infty}^\alpha(0)$ and $\sigma_{1,\infty}^\alpha(0)$, respectively. To find α , we take the following steps:

- For each $\alpha \in \{5\%, 10\%, \dots, 95\%\}$ the model optimized $k_{1,\infty}^\alpha(0)$ and $\sigma_{1,\infty}^\alpha(0)$ are solved for each bank;
- The mean squared error between $k_{1,\infty}^\alpha(0)$ and k^d , and the mean squared error between $\sigma_{1,\infty}^\alpha(0)$ and σ_θ^d , are calculated, i.e.,

$$\frac{1}{N} \sum_{i=1}^N (k_{1,\infty}^\alpha(0) - k^d)^2, \quad \frac{1}{N} \sum_{i=1}^N (\sigma_{1,\infty}^\alpha(0) - \sigma_\theta^d)^2,$$

where N is the number of banks in our sample, parameters k^d and σ_θ^d are estimated from the data in subsection 5.1;

- For each bank, we select and use α corresponding to the smallest sum of the mean squared errors, denoted as α^o , in all the cases with different bonus regulations (different Δ_d and M values).
- The optimal risk level and the bonus per net income with Δ_d and M solved by (11) using the parameter α^o in the banker's incentive compatibility constraint are denoted as $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$, respectively.

By the above procedure, an appropriate value for the parameter α is calibrated for each bank. We test the goodness of fit of the volatility values estimated using the data in subsection 5.1, i.e., σ_θ^d , with respect to the optimal $\sigma_{1,\infty}^o(0)$ under the selected α^o by using a linear regression. By this regression, σ_θ^d fit well the optimal $\sigma_{1,\infty}^o(0)$ solved from the principal-agent model, the R^2 of this regression is almost 100%.

Appendix C Proofs

C.1 Proof of Proposition 1

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

$$\begin{aligned}
\pi_\Delta(\Delta_d) &= \sum_{i=1}^n \mathbb{E} \left[e^{-ri\Delta} k A((i-1)\Delta) \max \left[\frac{A(i\Delta)}{A((i-1)\Delta)} - K_1, 0 \right] \right. \\
&\quad \left. \cdot e^{-r\Delta_d} \mathbf{1} \left\{ \frac{A(i\Delta + \Delta_d)}{A(i\Delta)} \geq K_2 \right\} \right] \\
&= \sum_{i=1}^n \mathbb{E} \left[e^{-ri\Delta} k A((i-1)\Delta) \max \left[\frac{A(i\Delta)}{A((i-1)\Delta)} - K_1, 0 \right] \right. \\
&\quad \left. \cdot e^{-r\Delta_d} \mathbb{E} \left(\mathbf{1} \left\{ \frac{A(i\Delta + \Delta_d)}{A(i\Delta)} \geq K_2 \right\} \middle| F_{i\Delta} \right) \right] \\
&= \sum_{i=1}^n \mathbb{E} \left[e^{-r(i-1)\Delta} k A((i-1)\Delta) \mathbb{E} \left(e^{-r\Delta} \max \left[\frac{A(i\Delta)}{A((i-1)\Delta)} - K_1, 0 \right] \middle| F_{(i-1)\Delta} \right) \right] \\
&\quad \cdot e^{-r\Delta_d} \Phi(d_2(K_2, \Delta_d, \sigma_\theta)) \\
&= \sum_{i=1}^n A(0) e^{\beta\sigma_\theta(i-1)\Delta} k C(K_1, \Delta, \sigma_\theta) e^{-r\Delta_d} \Phi(d_2(K_2, \Delta_d, \sigma_\theta)).
\end{aligned}$$

Therefore, $\pi_\Delta(\Delta_d)$ is given by the proposition. Note that $\pi_\Delta(\Delta_d)$ is continuous at $\beta = 0$ as

$$\lim_{\beta \rightarrow 0} \frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} = \lim_{\beta \rightarrow 0} \frac{-n\sigma_\theta\Delta e^{n\beta\sigma_\theta\Delta}}{-\sigma_\theta e^{\beta\sigma_\theta\Delta} \Delta} = n.$$

□

C.2 Proof of Corollary 1

Proof: Let us consider i 'th Δ -period. By (4) and the definition of the bonus cap, if $k[A(i\Delta) - K_1 A((i-1)\Delta)] \geq M$, then the bonus is capped at M . Therefore, we have

the following bonus payoff:

$$\begin{aligned} & \tilde{\Pi}(A(i\Delta), A((i-1)\Delta)) \\ &= \{k \max[A(i\Delta) - K_1 A((i-1)\Delta), 0] \\ & \quad - k \max[A(i\Delta) - K_1(\chi + A((i-1)\Delta)), 0]\} \mathbf{1}\{A(i\Delta + \Delta_d) - K_2 A(i\Delta) \geq 0\}, \end{aligned}$$

where $\chi = M/(kK_1)$ and M is the maximum bonus during the Δ -period.¹⁵ By Proposition 1, the compensation value is the sum of expected discounted payoffs:

$$\begin{aligned} \tilde{\pi}_{\Delta, M}(\Delta_d) &= \sum_{i=1}^n E \left[\exp(-ri\Delta) \tilde{\Pi}(A(i\Delta), A((i-1)\Delta)) \right] \\ &= \pi_{\Delta}(\Delta_d) - k \sum_{i=1}^n E \left[\exp(-ri\Delta) A((i-1)\Delta) \max \left[\frac{A(i\Delta)}{A((i-1)\Delta)} - K_1 \frac{\chi + A((i-1)\Delta)}{A((i-1)\Delta)}, 0 \right] \right] \\ & \quad \times \mathbf{1}\{A(i\Delta + \Delta_d) - K_2 A(i\Delta) \geq 0\} \end{aligned}$$

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

C.3 Proof of Lemma 1

Proof: For the case with $\beta = 0$, the bonus vega (13) is calculated as

$$\begin{aligned} \frac{\partial \pi_{\Delta}(\Delta_d)}{\partial \sigma_{\theta}} &= nkA(0)e^{-r\Delta_d} \left\{ C_1 \Phi \left[\left(\frac{r}{\sigma_{\theta}} - \frac{\sigma_{\theta}}{2} \right) \sqrt{\Delta_d} \right] - C_2 \phi \left[\left(\frac{r}{\sigma_{\theta}} - \frac{\sigma_{\theta}}{2} \right) \sqrt{\Delta_d} \right] \sqrt{\Delta_d} \right\} \\ &= nkA(0)e^{-r\Delta_d} \left\{ C_1 \Phi \left[\left(\frac{r}{\sigma_{\theta}} - \frac{\sigma_{\theta}}{2} \right) \sqrt{\Delta_d} \right] - C_2 \frac{1}{\sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{r}{\sigma_{\theta}} - \frac{\sigma_{\theta}}{2} \right)^2 \Delta_d \right] \sqrt{\Delta_d} \right\}. \end{aligned}$$

¹⁵Thus, when earnings $A(i\Delta) - A((i-1)\Delta) < \chi$, then the bonus equals

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

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

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

Denote $G(\Delta_d) = C_1 \Phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d} \right] - C_2 \frac{1}{\sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^2 \Delta_d \right] \sqrt{\Delta_d}$. Then, we have

$$\frac{\partial G(\Delta_d)}{\partial \Delta_d} = \frac{1}{2\sqrt{2\pi}\Delta_d} \exp \left[-\frac{1}{2} \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^2 \Delta_d \right] \left\{ C_1 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) + C_2 \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^2 \Delta_d - 1 \right] \right\},$$

where under the condition $C_1 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) - C_2 < 0$,

$$\lim_{\Delta_d \rightarrow 0^+} \frac{\partial G(\Delta_d)}{\partial \Delta_d} \rightarrow -\infty, \text{ and } \frac{\partial G(\Delta_d)}{\partial \Delta_d} > 0, \text{ if } \Delta_d > C_2 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-2} - C_1 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-1} > 0.$$

We also have $G(0) = \frac{1}{2}C_1 > 0$, $\lim_{\Delta_d \rightarrow \infty} G(\Delta_d) = C_1 > 0$. Denote $G^c = \min_{\Delta_d \geq 0} G(\Delta_d)$, where we have

$$G^c = \min_{\Delta_d \geq 0} G(\Delta_d) = C_1 \Phi \left[\left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) \sqrt{\Delta_d^c} \right] - C_2 \frac{1}{\sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^2 \Delta_d^c \right] \sqrt{\Delta_d^c},$$

where

$$\Delta_d^c = \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-2} - \frac{C_1}{C_2} \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-1} > 0.$$

For a special case, if $\Delta_d = \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-2} > \Delta_d^c$, then

$$G(\Delta_d) = C_1 \Phi(-1) - C_2 \frac{1}{\sqrt{2\pi}} \exp \left(-\frac{1}{2} \right) \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right)^{-1} < 0,$$

since

$$\frac{\frac{1}{\sqrt{2\pi}} \exp \left(-\frac{1}{2} \right)}{\Phi(-1)} > 1, \quad C_1 \left(\frac{r}{\sigma_\theta} - \frac{\sigma_\theta}{2} \right) - C_2 < 0.$$

Therefore, $G^c < 0$, which implies there exist $0 < \underline{\Delta}_d < \bar{\Delta}_d$, where $G(\underline{\Delta}_d) = G(\bar{\Delta}_d) = 0$, such that if $\Delta_d \in (\underline{\Delta}_d, \bar{\Delta}_d)$, $G(\Delta_d) < 0$ due to the continuity of $G(\Delta)$ with respect to Δ . \square

C.4 Proof of Proposition 2

Proof: If $\Delta_d = 0$, then for the case with $\beta \geq 0$, the bonus vega (13) is always positive as for $\beta > 0$, $\frac{\partial}{\partial \sigma_\theta} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) > 0$, see (14). If $\Delta_d > 0$, then for the case with $\beta = 0$, by Lemma 1, there exist $0 < \underline{\Delta}_d < \bar{\Delta}_d$ such that if $\Delta_d \in (\underline{\Delta}_d, \bar{\Delta}_d)$, then $G(\Delta_d) < 0$, i.e., $\frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta} = nkA(0)e^{-r\Delta_d}G(\Delta_d) < 0$. For the case with $\beta < 0$, by (12), since $\frac{\partial}{\partial \sigma_\theta} \left(\frac{1 - e^{n\beta\sigma_\theta\Delta}}{1 - e^{\beta\sigma_\theta\Delta}} \right) < 0$, there must exist a non-empty set in terms of the bonus deferral length such that if Δ_d is in the set, $\frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta} < 0$. \square

C.5 Proof of Proposition 3

Proof: Since c_+ and c_- satisfy (17), for the quadratic cost case, we have

$$\begin{aligned} c_+ &\geq \max_{\Delta\sigma_\theta > 0} \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{(\Delta\sigma_\theta)^2}, \\ c_- &\geq \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{(\Delta\sigma_\theta)^2}. \end{aligned}$$

We first argue that $\sigma_{1,M}^* \leq \sigma_\theta$. By Corollary 2, $\frac{\partial \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\partial \sigma_\theta} \leq \frac{\partial \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{\partial \sigma_\theta}$ and, thus for $\Delta\sigma_\theta > 0$ we have

$$\frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} \leq \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} \leq c_+,$$

which implies that $\Delta\sigma_\theta > 0$ cannot be optimal if there exists a bonus cap, that is, $\sigma_{1,M}^* \leq \sigma_\theta$. For all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, we have

$$\frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} \geq \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,\infty}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2},$$

and by Corollary 2, for a certain range of M values,

$$\frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} > 0,$$

which implies if

$$c_- < \max_{\Delta\sigma_\theta \in [-\sigma_\theta, 0)} \frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2}.$$

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, $\sigma_{1,M}^* < \sigma_\theta$. If $c_- \leq 0$, since c_- satisfies the optimality condition (17), and $M > 0$ is bounded, then by Corollary 2, either for all $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$,

$$\frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} > c_-,$$

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

$$\frac{\tilde{\pi}_{1,M}(\sigma_\theta + \Delta\sigma_\theta, 0) - \tilde{\pi}_{1,M}(\sigma_\theta, 0)}{\Delta\sigma_\theta^2} > c_-,$$

which implies $\sigma_{1,M}^* < \sigma_\theta$. The linear cost function case can be proved in the same way, which is omitted here. \square

C.6 Proof of Proposition 4

Proof: Consider the piecewise linear cost function. By Corollary 2, if $\Delta_d \in (\underline{\Delta}_d, \bar{\Delta}_d)$, then $\frac{\partial \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d)}{\partial \sigma_\theta} < 0$, and for $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$, we have

$$\frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta, \Delta_d) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d)}{\Delta\sigma_\theta} < 0,$$

which indicates if there exists some $\Delta\sigma_\theta^* \in [-\sigma_\theta, 0)$, such that

$$\frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d)}{\Delta\sigma_\theta} < -c_-,$$

then

$$\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d) + c_- \Delta\sigma_\theta^* > \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d),$$

i.e., the optimal risk level is $\sigma_{1,\infty}^*(\Delta_d) = \sigma_\theta + \Delta\sigma_\theta^* < \sigma_\theta$.

Given two bonus deferral periods, $0 < \Delta_d^1 < \Delta_d^2$ in the set $(\Delta_d^c, \bar{\Delta}_d)$, since $\frac{\partial^2 \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d)}{\partial \sigma_\theta \partial \Delta_d} > 0$, we have

$$\frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d^1) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d^1)}{\Delta\sigma_\theta} < \frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d^2) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d^2)}{\Delta\sigma_\theta},$$

together with $\frac{\partial \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d)}{\partial \sigma_\theta} < 0$, imply there may exist some $\Delta\sigma_\theta^* \in [-\sigma_\theta, 0)$, such that

$$\frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d^1) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d^1)}{\Delta\sigma_\theta} < -c_-,$$

while for any $\Delta\sigma_\theta \in [-\sigma_\theta, 0)$,

$$\frac{\tilde{\pi}_{1,\infty}(\sigma_\theta + \Delta\sigma_\theta^*, \Delta_d^2) - \tilde{\pi}_{1,\infty}(\sigma_\theta, \Delta_d^2)}{\Delta\sigma_\theta} > -c_-.$$

Under such conditions, the bonus deferral of length Δ_d^1 decreases the risk level, while the bonus deferral of length Δ_d^2 cannot decrease the risk level. \square

Appendix D Figures

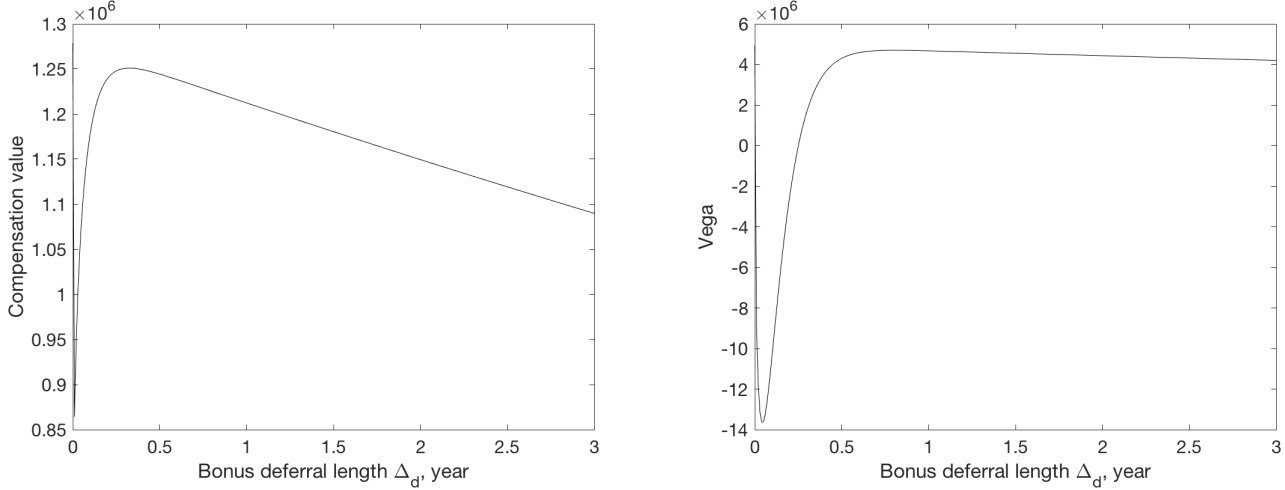


Figure 1: **Compensation value** ($\pi_\Delta(\Delta_d)$) **and the corresponding risk-taking incentive** ($\frac{\partial \pi_\Delta(\Delta_d)}{\partial \sigma_\theta}$, vega) **with respect to the length of bonus deferral period** Δ_d **based on Proposition 1.** Parameter values (example bank: United Bankshares, year: 2006): $K_1 = K_2 = 1$, $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $\beta = 0.8382$, $\Delta = 1$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

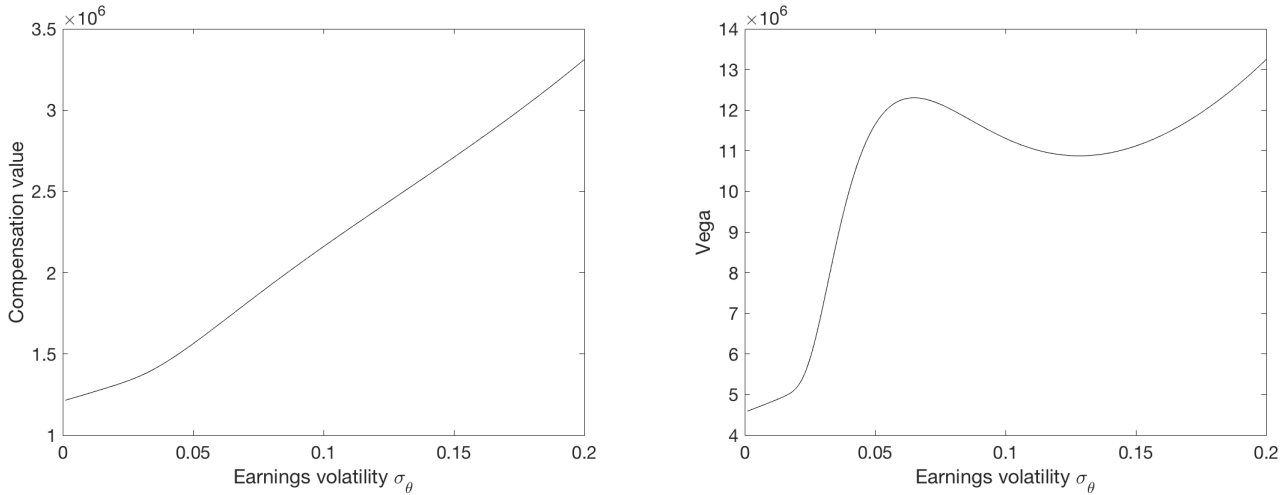


Figure 2: **Compensation value** (π_n) **and the corresponding risk-taking incentive** ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, vega) **with respect to the equity volatility** (σ_θ) **based on Proposition 1.** Parameter values (example bank: United Bankshares, year: 2006): $K_1 = K_2 = 1$, $A(0) = 634,092,000$, $r = 5.3250\%$, $\beta = 0.8382$, $\Delta = 1$, $\Delta_d = 0$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

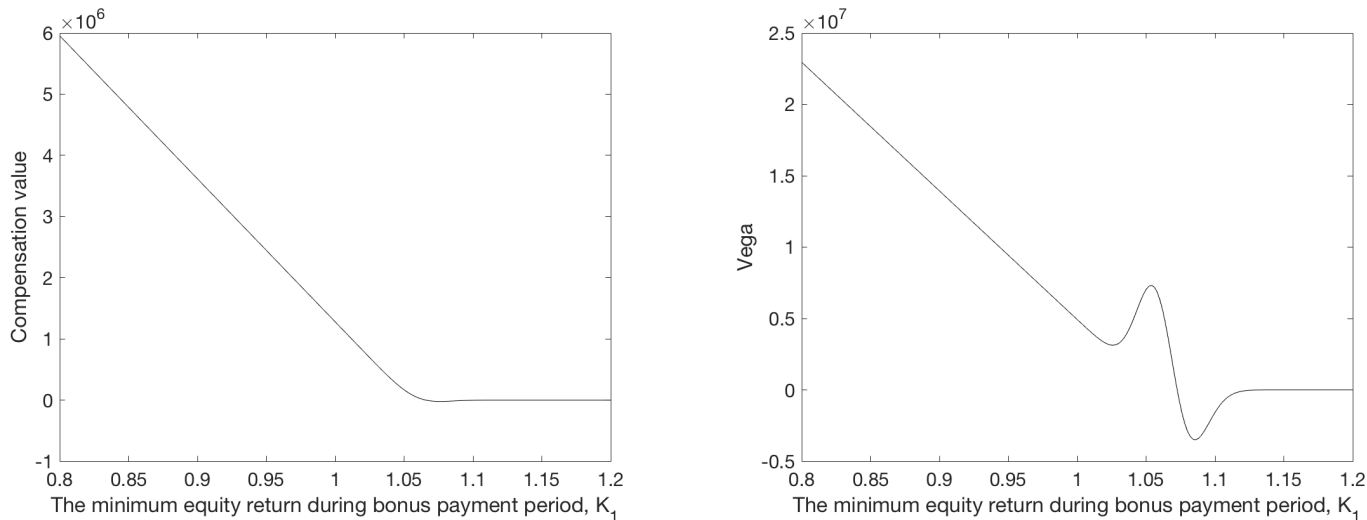


Figure 3: **Compensation value** (π_n) and the corresponding risk-taking incentive ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, vega) with respect to K_1 based on Proposition 1. Parameter values (example bank: United Bankshares, year: 2006): $K_2 = 1$, $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $\beta = 0.8382$, $\Delta = 1$, $\Delta_d = 0$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

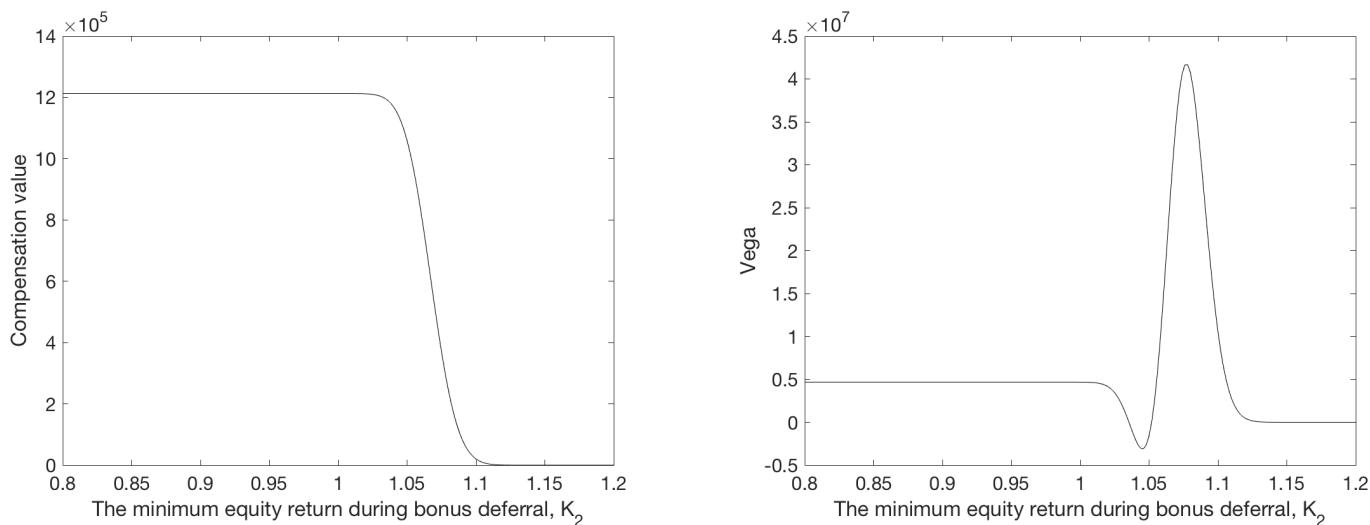


Figure 4: **Compensation value** (π_n) and the corresponding risk-taking incentive ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, vega) with respect to K_2 based on Proposition 1. Parameter values (example bank: United Bankshares, year: 2006): $K_1 = 1$, $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $\beta = 0.8382$, $\Delta = 1$, $\Delta_d = 1$, and $k = 0.0037$. The risk-free rate r is the mean of monthly one-year interest rate swaps in 2006.

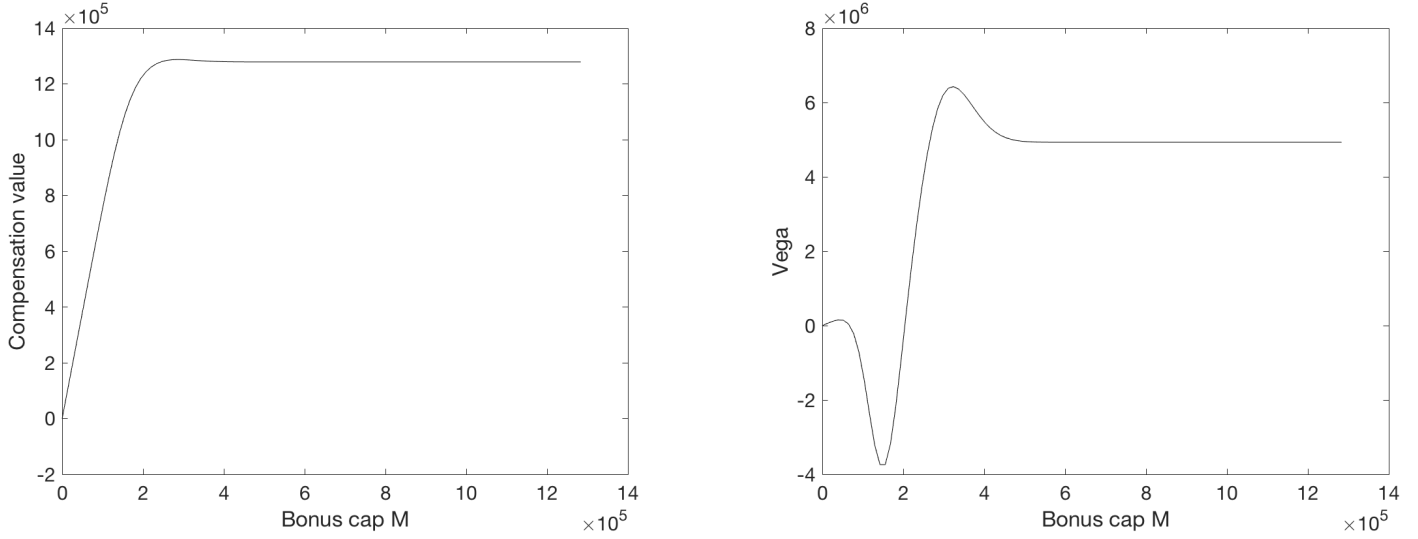


Figure 5: **Compensation value** ($\tilde{\pi}_{\Delta, M}(\Delta_d)$) **and the corresponding risk-taking incentive** ($\frac{\partial \tilde{\pi}_{\Delta, M}(\Delta_d)}{\partial \sigma_\theta}$, **vega**) **with respect to the bonus cap** (M) **based on Corollary 1**. Parameter values (example bank: United Bankshares, year: 2006): $K_1 = K_2 = 1$, $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.3250\%$, $\beta = 0.8382$, $T = 10$, $n = 10$, $\Delta_d = 0$, 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 or bonus deferrals (i.e., $M = \infty$ and $\Delta_d = 0$) are 1,278,641.54 and 4,929,397.24, respectively. The compensation value and vega when the bonus cap becomes large enough converge to the situation without bonus caps.

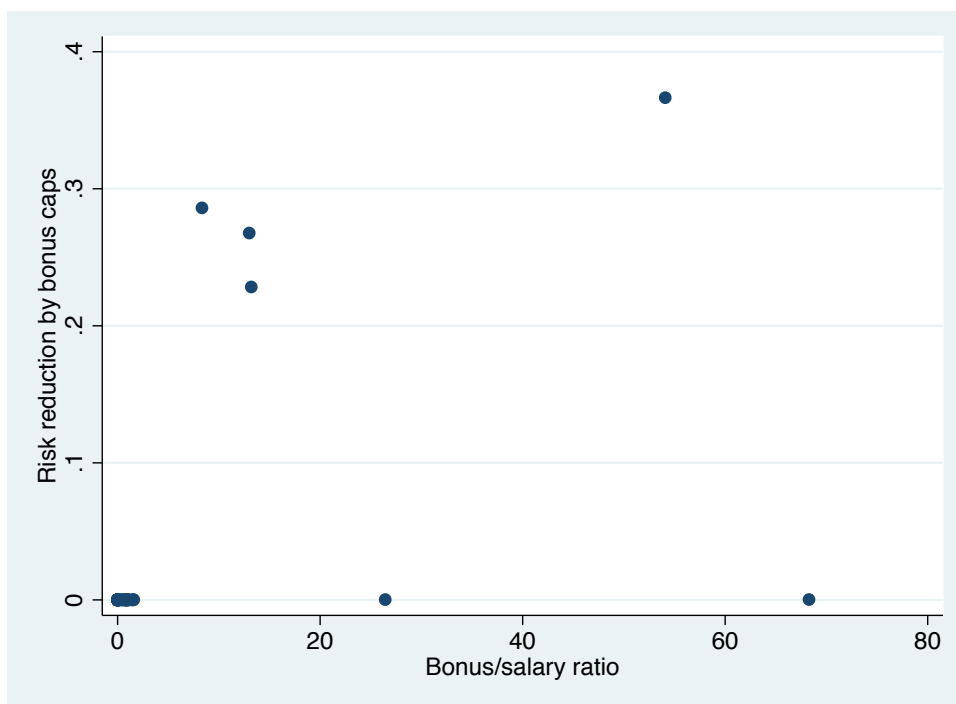


Figure 6: **Scatter plot of the risk reduction by bonus caps with respect to the bonus salary ratio in 2006.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(0)}{\sigma_{1,\infty}^o(0)}$; see Case III in Panel A of Table 4. The bonus and the salary are the cash bonus and the salary paid in 2006. There are 85 sample banks.

Appendix E Tables of the main results

Table 1: **Summary statistics of cash bonus per net income (k^d) and the equity volatility (σ_θ^d).** 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 equity volatility using the quarterly data from 2000Q1 to 2006Q4, and σ_θ 2008 is the estimated equity volatility using the quarterly data from 2000Q1 to 2008Q4, which is used as a robustness check.

Variable	Obs.	Median	Mean	Std. dev.	Min	Max
<i>Panel A</i>						
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
<i>Panel B</i>						
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 equity volatility σ_θ^d is estimated using quarterly data from 2000Q1 to 2006Q4. The bank-level cost parameters are calculated from (17) and by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+\mathbf{1}\{\Delta\sigma_\theta \geq 0\}(\Delta\sigma_\theta)^2 + c_-\mathbf{1}\{\Delta\sigma_\theta < 0\}(\Delta\sigma_\theta)^2$. The smallest cost parameters that satisfy the optimality condition (17) are reported in this table.

Cost function parameters	c_+	c_-
<i>Panel A: T cap 10 yrs.</i>		
Min	2,151,603,646	-10,371,807,873
Max	12,393,579,050,515	-342,472
Mean	1,659,171,965,225	-1,478,941,274
Std	2,148,553,276,751	1,876,789,691
<i>Panel B: T cap 15 yrs.</i>		
Min	2,151,603,646	-25,064,504,658
Max	30,068,031,987,979	-342,472
Mean	3,697,527,374,760	-3,287,255,404
Std	5,049,803,618,456	4,412,465,844

Table 3: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — the cost parameters are from Table 2.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^{\circ}(0) - \sigma_{1,M}^{\circ}(\Delta_d)}{\sigma_{1,\infty}^{\circ}(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^{\circ}(0) - k_{1,M}^{\circ}(\Delta_d)}{k_{1,\infty}^{\circ}(0)}$, where $\sigma_{1,M}^{\circ}(\Delta_d)$ and $k_{1,M}^{\circ}(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility σ_{θ}^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters; see Table 2. Piecewise quadratic cost function: $F(\Delta\sigma_{\theta}) = c_+ \mathbf{1}\{\Delta\sigma_{\theta} \geq 0\} (\Delta\sigma_{\theta})^2 + c_- \mathbf{1}\{\Delta\sigma_{\theta} < 0\} (\Delta\sigma_{\theta})^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^{\circ}(0) - \sigma_{1,M}^{\circ}(\Delta_d)}{\sigma_{1,\infty}^{\circ}(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.08%	0.01%	23.50%	24.27%	22.22%	20.96%	21.38%	20.98%
Mean	0.00%	0.00%	2.27%	0.46%	2.29%	1.95%	0.25%	0.40%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.01%	0.00%	6.79%	3.07%	6.72%	5.84%	2.30%	2.65%
% of positive change	22.09%	2.33%	25.58%	10.47%	34.88%	31.40%	23.26%	13.95%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^{\circ}(0) - k_{1,M}^{\circ}(\Delta_d)}{k_{1,\infty}^{\circ}(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	77.50%	0.00%	87.73%	66.86%	88.42%	88.42%	77.50%	66.86%
Mean	0.90%	0.00%	-25.26%	-9.86%	-22.16%	-25.33%	-9.11%	-10.02%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.36%	0.00%	98.64%	66.35%	99.46%	98.84%	67.32%	66.66%
% of positive change	1.16%	0.00%	19.77%	9.30%	22.09%	19.77%	10.47%	9.30%
% of negative change	0.00%	0.00%	31.40%	13.95%	30.23%	31.40%	13.95%	13.95%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^{\circ}(0) - \sigma_{1,M}^{\circ}(\Delta_d)}{\sigma_{1,\infty}^{\circ}(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.02%	0.01%	26.23%	28.88%	22.36%	22.87%	22.52%	25.25%
Mean	0.00%	0.00%	2.46%	0.61%	2.30%	2.11%	0.78%	0.53%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	7.24%	3.98%	6.76%	6.20%	4.12%	3.45%
% of positive change	16.28%	2.33%	30.23%	13.95%	37.21%	36.05%	19.77%	16.28%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^{\circ}(0) - k_{1,M}^{\circ}(\Delta_d)}{k_{1,\infty}^{\circ}(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.46%	-344.45%	-344.45%
Max	0.00%	0.00%	90.04%	71.47%	90.04%	90.04%	71.47%	71.47%
Mean	0.00%	0.00%	-21.69%	-9.45%	-21.52%	-21.56%	-9.38%	-9.40%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	99.53%	67.11%	99.52%	99.54%	67.02%	67.00%
% of positive change	0.00%	0.00%	29.07%	12.79%	29.07%	29.07%	12.79%	12.79%
% of negative change	0.00%	0.00%	36.05%	12.79%	36.05%	36.05%	12.79%	12.79%

Table 4: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — the cost parameter c_- is zero.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters; see Table 2. Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.08%	0.01%	36.64%	37.73%	38.32%	36.64%	38.04%	37.73%
Mean	0.00%	0.00%	1.34%	0.85%	1.44%	1.34%	0.90%	0.85%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.01%	0.00%	6.18%	5.34%	6.62%	6.18%	5.48%	5.34%
% of positive change	22.09%	2.33%	16.28%	9.30%	24.42%	22.09%	22.09%	12.79%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	77.50%	0.00%	88.42%	66.86%	88.42%	88.42%	77.50%	66.86%
Mean	0.90%	0.00%	-25.18%	-9.86%	-22.13%	-25.31%	-9.10%	-10.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.36%	0.00%	98.86%	66.44%	99.60%	98.99%	67.32%	66.67%
% of positive change	2.33%	0.00%	19.77%	9.30%	23.26%	19.77%	11.63%	9.30%
% of negative change	0.00%	0.00%	29.07%	13.95%	27.91%	29.07%	13.95%	13.95%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.02%	0.01%	23.63%	23.22%	27.70%	23.63%	24.81%	23.22%
Mean	0.00%	0.00%	0.66%	0.52%	0.89%	0.66%	0.61%	0.52%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	3.26%	3.19%	4.22%	3.26%	3.60%	3.19%
% of positive change	16.28%	2.33%	19.77%	11.63%	27.91%	25.58%	17.44%	13.95%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.46%	-344.45%	-344.46%	-344.46%	-344.45%	-344.45%
Max	0.02%	0.00%	90.04%	71.47%	90.04%	90.04%	71.47%	71.47%
Mean	0.00%	0.00%	-21.51%	-9.35%	-21.46%	-21.43%	-9.29%	-9.30%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	99.68%	67.12%	99.67%	99.56%	67.03%	67.03%
% of positive change	1.16%	0.00%	29.07%	12.79%	30.23%	29.07%	13.95%	12.79%
% of negative change	0.00%	0.00%	34.88%	12.79%	34.88%	34.88%	12.79%	12.79%

Table 5: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — the cost parameters are equal.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters; see Table 2. Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.10%	0.01%	0.01%	0.02%	0.10%	0.01%	0.10%	0.02%
Mean	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
% of positive change	2.33%	2.33%	3.49%	2.33%	5.81%	5.81%	4.65%	4.65%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%
Max	97.50%	0.00%	88.08%	65.83%	97.50%	88.08%	97.50%	65.83%
Mean	1.13%	0.00%	-311.08%	-132.77%	-313.06%	-311.09%	-134.64%	-132.79%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	10.51%	0.00%	1074.32%	720.51%	1074.59%	1074.29%	720.82%	720.52%
% of positive change	1.16%	0.00%	22.09%	9.30%	22.09%	20.93%	10.47%	9.30%
% of negative change	0.00%	0.00%	27.91%	13.95%	27.91%	27.91%	13.95%	13.95%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.01%	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%
Mean	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% of positive change	2.33%	2.33%	0.00%	1.16%	2.33%	1.16%	4.65%	3.49%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%
Max	0.01%	0.00%	90.13%	71.54%	90.13%	90.13%	71.54%	71.54%
Mean	0.00%	0.00%	-309.53%	-132.08%	-312.61%	-310.00%	-135.02%	-132.56%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	1074.80%	720.68%	1074.68%	1074.65%	720.68%	720.62%
% of positive change	1.16%	0.00%	29.07%	11.63%	27.91%	29.07%	12.79%	11.63%
% of negative change	0.00%	0.00%	34.88%	13.95%	36.05%	34.88%	13.95%	13.95%

Table 6: **Banks with the most risk reduction by bonus caps with $c_- = 0$.** The risk reduction is $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ with CEOs' tenure cap of 10 or 15 years as the dependent variable; see 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_θ^d is the equity volatility using quarterly data from 2000Q1 to 2006Q4 respectively.

Bank name	Total		θ	Stock crisis return	Systemic risk	Earnings volatility σ_θ^d	$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$		$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	
	assets (\$ million)	k					under Case I	under Case III	under Case I	under Case III
<i>Panel A: Bank characteristics and risk reduction under Tenure cap 10 years.</i>										
GOLDMAN SACHS GROUP INC	838201.00	0.0007	24.4036	-0.6150	-8.3876	0.0316	0.0055%	36.6433%	-0.0007%	-344.4519%
LEHMAN BROTHERS HOLDINGS INC	503545.00	0.0034	26.7658	-0.9987	-13.1117	0.0287	0.0047%	28.6041%	-0.0005%	-344.4508%
JPMORGAN CHASE & CO	1351520.00	0.0012	10.6722	-0.3585	-5.0608	0.0287	0.0047%	26.7680%	-0.0005%	-344.4508%
CITIGROUP INC	1884318.00	0.0006	14.8551	-0.8701	-12.5716	0.0261	0.0038%	22.8324%	-0.0003%	-344.4500%
BEAR STEARNS COMPANIES INC	350432.60	0.0082	28.7423	-0.9323	-11.9028	0.0178	0.0017%	0.0225%	0.0000%	-343.3349%
WACHOVIA CORP	707121.00	0.0007	9.0984	-0.8941	-12.0422	0.0417	0.0068%	0.0225%	-0.0013%	-122.2281%
FLAGSTAR BANCORP INC	15497.21	0.0086	18.0797	-0.9424	-9.0928	0.0740	0.0062%	0.0225%	-0.0025%	-110.2498%
WELLS FARGO & CO	481996.00	0.0007	9.5009	-0.1698	-2.2221	0.0169	0.0013%	0.0213%	0.0000%	-344.4475%
MERRILL LYNCH & CO INC	841299.00	0.0017	22.3515	-0.8606	-11.7411	0.0522	0.0068%	0.0199%	-0.0018%	88.4171%
MORGAN STANLEY	1120645.00	0.0020	31.6741	-0.2802	-3.9027	0.0485	0.0069%	0.0197%	-0.0016%	87.7337%
BANK OF AMERICA CORP	1459737.00	0.0002	10.0019	-0.7145	-10.1417	0.0112	0.0012%	0.0179%	0.0000%	-344.4466%
BANK OF NEW YORK MELLON CORP	103370.00	0.0035	7.9166	-0.3598	-4.1540	0.0390	0.0066%	0.0152%	-0.0011%	71.5727%
COUNTRYWIDE FINANCIAL CORP	199946.23	0.0052	12.9648	-0.8817	-10.7620	0.0519	0.0072%	0.0127%	-0.0017%	61.1055%
PNC FINANCIAL SVCS GROUP INC	101820.00	0.0013	8.3562	-0.3301	-3.8069	0.0490	0.0069%	0.0065%	-0.0016%	38.2392%
REGIONS FINANCIAL CORP	143369.02	0.0008	5.9256	-0.7651	-9.0844	0.0044	0.0012%	0.0043%	0.0000%	19.1917%
<i>Panel B: Bank characteristics and risk reduction under Tenure cap 15 years.</i>										
GOLDMAN SACHS GROUP INC	838201.00	0.0007	24.4036	-0.6150	-8.3876	0.0316	0.0041%	23.6302%	-0.0007%	-344.4556%
LEHMAN BROTHERS HOLDINGS INC	503545.00	0.0034	26.7658	-0.9987	-13.1117	0.0287	0.0035%	13.9909%	-0.0005%	-344.4541%
JPMORGAN CHASE & CO	1351520.00	0.0012	10.6722	-0.3585	-5.0608	0.0287	0.0035%	11.7961%	-0.0005%	-344.4541%
CITIGROUP INC	1884318.00	0.0006	14.8551	-0.8701	-12.5716	0.0261	0.0029%	7.0014%	-0.0004%	-344.4530%
BEAR STEARNS COMPANIES INC	350432.60	0.0082	28.7423	-0.9323	-11.9028	0.0178	0.0017%	0.0225%	0.0000%	-343.3349%
FLAGSTAR BANCORP INC	15497.21	0.0086	18.0797	-0.9424	-9.0928	0.0740	0.0054%	0.0225%	-0.0028%	-122.0800%
MERRILL LYNCH & CO INC	841299.00	0.0017	22.3515	-0.8606	-11.7411	0.0522	0.0054%	0.0208%	-0.0020%	90.0430%
MORGAN STANLEY	1120645.00	0.0020	31.6741	-0.2802	-3.9027	0.0485	0.0054%	0.0207%	-0.0018%	89.4551%
WELLS FARGO & CO	481996.00	0.0007	9.5009	-0.1698	-2.2221	0.0169	0.0013%	0.0195%	-0.0001%	-344.4492%
WACHOVIA CORP	707121.00	0.0007	9.0984	-0.8941	-12.0422	0.0417	0.0052%	0.0186%	-0.0014%	78.4084%
BANK OF NEW YORK MELLON CORP	103370.00	0.0035	7.9166	-0.3598	-4.1540	0.0390	0.0050%	0.0179%	-0.0012%	75.5387%
BANK OF AMERICA CORP	1459737.00	0.0002	10.0019	-0.7145	-10.1417	0.0112	0.0012%	0.0168%	0.0000%	-344.4478%
COUNTRYWIDE FINANCIAL CORP	199946.23	0.0052	12.9648	-0.8817	-10.7620	0.0519	0.0072%	0.0127%	-0.0017%	61.1055%
PNC FINANCIAL SVCS GROUP INC	101820.00	0.0013	8.3562	-0.3301	-3.8069	0.0490	0.0054%	0.0121%	-0.0018%	46.5576%
U S BANCORP	219232.00	0.0007	9.8052	-0.2465	-3.0309	0.0405	0.0052%	0.0087%	-0.0013%	35.4388%

Table 7: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — the cost parameter c_- is zero.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters; see Table 2. We set the minimum equity return during the deferral period $K_2 = 0.8$; see (6). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.01%	0.01%	36.64%	37.73%	36.64%	36.64%	37.73%	37.73%
Mean	0.00%	0.00%	1.34%	0.85%	1.34%	1.34%	0.85%	0.85%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	6.18%	5.34%	6.18%	6.18%	5.34%	5.34%
% of positive change	2.33%	2.33%	16.28%	9.30%	18.60%	22.09%	12.79%	12.79%
% of negative change	0.00%	0.00%	1.16%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	0.00%	0.00%	88.42%	66.86%	88.42%	88.42%	66.86%	66.86%
Mean	0.00%	0.00%	-25.18%	-9.86%	-25.16%	-25.31%	-9.85%	-10.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	98.86%	66.44%	98.85%	98.99%	66.43%	66.67%
% of positive change	0.00%	0.00%	19.77%	9.30%	19.77%	19.77%	9.30%	9.30%
% of negative change	0.00%	0.00%	29.07%	13.95%	29.07%	29.07%	13.95%	13.95%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.02%	0.00%	-0.01%	0.00%	0.00%	0.00%
Max	0.01%	0.01%	23.63%	23.22%	23.63%	23.63%	23.22%	23.22%
Mean	0.00%	0.00%	0.66%	0.52%	0.66%	0.66%	0.52%	0.52%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	3.26%	3.19%	3.26%	3.26%	3.19%	3.19%
% of positive change	2.33%	2.33%	19.77%	11.63%	23.26%	25.58%	13.95%	13.95%
% of negative change	0.00%	0.00%	1.16%	0.00%	1.16%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.46%	-344.45%	-344.46%	-344.46%	-344.45%	-344.45%
Max	0.00%	0.00%	90.04%	71.47%	90.04%	90.04%	71.47%	71.47%
Mean	0.00%	0.00%	-21.51%	-9.35%	-21.46%	-21.47%	-9.31%	-9.31%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	99.68%	67.12%	99.64%	99.64%	67.04%	67.05%
% of positive change	0.00%	0.00%	29.07%	12.79%	29.07%	29.07%	12.79%	12.79%
% of negative change	0.00%	0.00%	34.88%	12.79%	34.88%	34.88%	12.79%	12.79%

Table 8: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — the cost parameter c_- is zero.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters; see Table 2. We set the minimum equity return during the deferral period $K_2 = 1.2$; see (6). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	-0.06%	-5.60%	-0.01%	0.00%	-0.03%	-5.61%	-0.07%	-5.60%
Max	0.10%	0.00%	36.64%	37.73%	0.10%	18.77%	0.10%	0.02%
Mean	0.02%	-0.70%	1.34%	0.85%	0.02%	-0.40%	0.02%	-0.69%
Median	0.02%	-0.14%	0.00%	0.00%	0.02%	-0.13%	0.02%	-0.14%
Std	0.02%	1.02%	6.18%	5.34%	0.01%	2.31%	0.02%	1.02%
% of positive change	84.88%	0.00%	16.28%	9.30%	93.02%	13.95%	90.70%	8.14%
% of negative change	10.47%	86.05%	1.16%	0.00%	2.33%	79.07%	6.98%	81.40%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-344.46%	-344.45%	-344.45%	-344.45%	-344.46%	-344.46%	-344.46%	-344.45%
Max	0.30%	0.54%	88.42%	66.86%	0.30%	88.42%	0.30%	66.86%
Mean	-189.95%	-126.69%	-25.18%	-9.86%	-189.11%	-141.70%	-190.61%	-132.49%
Median	-122.22%	0.00%	0.00%	0.00%	-122.22%	-0.78%	-122.22%	-0.02%
Std	107.17%	165.52%	98.86%	66.44%	103.75%	171.95%	106.19%	169.62%
% of positive change	2.33%	34.88%	19.77%	9.30%	1.16%	36.05%	1.16%	41.86%
% of negative change	96.51%	38.37%	29.07%	13.95%	97.67%	59.30%	97.67%	50.00%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	-0.06%	-5.60%	-0.02%	0.00%	0.00%	-5.61%	-0.03%	-5.60%
Max	0.10%	0.00%	23.63%	23.22%	0.10%	6.97%	0.10%	0.02%
Mean	0.02%	-0.45%	0.66%	0.52%	0.02%	-0.31%	0.02%	-0.44%
Median	0.02%	-0.09%	0.00%	0.00%	0.02%	-0.08%	0.02%	-0.09%
Std	0.02%	0.82%	3.26%	3.19%	0.01%	1.12%	0.02%	0.82%
% of positive change	88.37%	0.00%	19.77%	11.63%	96.51%	15.12%	91.86%	10.47%
% of negative change	4.65%	79.07%	1.16%	0.00%	0.00%	75.58%	3.49%	77.91%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-344.47%	-344.45%	-344.46%	-344.45%	-344.47%	-344.46%	-344.47%	-344.45%
Max	0.28%	0.79%	90.04%	71.47%	0.28%	90.04%	0.28%	100.00%
Mean	-186.76%	-104.09%	-21.51%	-9.35%	-191.33%	-119.02%	-189.89%	-111.96%
Median	-122.22%	0.00%	0.00%	0.00%	-122.22%	-0.03%	-122.22%	0.01%
Std	107.77%	159.15%	99.68%	67.12%	107.83%	169.75%	104.69%	166.06%
% of positive change	3.49%	43.02%	29.07%	12.79%	1.16%	43.02%	1.16%	51.16%
% of negative change	95.35%	30.23%	34.88%	12.79%	97.67%	52.33%	97.67%	39.53%

Appendix F Robustness checks

Table 9: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — bonuses decrease equity value and $c_- = 0$.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . The equity drops when the bonus is paid out at each payment time and between the payment times it follows (2). By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters. We set $c_- = 0$ and c_+ is the smallest cost parameter values that satisfy the optimality condition (17) (not reported for brevity).

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	-0.02%	0.00%	-0.02%	0.00%	-0.02%	-0.02%	-0.02%	0.00%
Max	0.01%	0.02%	23.72%	0.00%	45.92%	40.51%	0.01%	0.01%
Mean	0.00%	0.00%	0.28%	0.00%	0.54%	0.48%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	2.57%	0.00%	4.98%	4.39%	0.00%	0.00%
% of positive change	1.16%	2.33%	1.18%	0.00%	2.35%	2.35%	1.18%	1.18%
% of negative change	1.16%	0.00%	2.35%	0.00%	2.35%	2.35%	1.18%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-36165.00%	-36165.01%	-3901.10%	0.00%	-36165.00%	-36165.01%	-36165.00%	-36165.01%
Max	99.45%	99.72%	99.55%	90.33%	99.45%	99.72%	99.45%	99.72%
Mean	-820.05%	-812.26%	-100.58%	8.09%	-944.16%	-913.35%	-821.61%	-815.78%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	5338.41%	5339.56%	609.32%	21.91%	5392.50%	5383.95%	5370.65%	5371.47%
% of positive change	3.49%	9.30%	42.35%	22.35%	43.53%	44.71%	25.88%	29.41%
% of negative change	3.49%	2.33%	5.88%	0.00%	8.24%	7.06%	3.53%	2.35%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%
Max	0.02%	0.01%	31.56%	0.00%	43.50%	0.01%	0.02%	0.01%
Mean	0.00%	0.00%	0.37%	0.00%	0.51%	0.00%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	3.42%	0.00%	4.72%	0.00%	0.00%	0.00%
% of positive change	3.49%	1.16%	1.18%	0.00%	2.35%	1.18%	2.35%	1.18%
% of negative change	1.16%	1.16%	1.18%	1.18%	1.18%	2.35%	1.18%	2.35%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-41426.41%	-41534.50%	-1060921.70%	-25384.27%	-1063580.91%	-1063567.61%	-41426.41%	-41534.50%
Max	99.77%	99.74%	99.75%	99.68%	99.77%	99.74%	99.77%	99.74%
Mean	-1080.76%	-2141.81%	-13861.38%	-406.68%	-13827.40%	-14013.40%	-888.75%	-1964.68%
Median	0.00%	0.00%	0.04%	0.00%	0.10%	0.10%	0.00%	0.00%
Std	5902.60%	8445.86%	115110.08%	2938.98%	115400.55%	115388.25%	5332.63%	8109.17%
% of positive change	11.63%	9.30%	54.12%	22.35%	57.65%	58.82%	31.76%	28.24%
% of negative change	9.30%	8.14%	9.41%	3.53%	11.76%	10.59%	9.41%	9.41%

Table 10: **Cost function parameters — option grants.** The equity volatility σ_θ^d is estimated using quarterly data from 2000Q1 to 2006Q4. The bank-level cost parameters are calculated from $\tilde{\pi}_{1,\infty}(\sigma_\theta^d + \Delta\sigma_\theta, 0) + N\pi_{BS}(\sigma_S^d + \Delta\sigma_S) - F(\Delta\sigma_\theta) = 0$, 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 $\tilde{\pi}_{1,\infty}$ is calculated by using the average cash bonus per net income during the period 2004–2006 (average k in Panel A of Table 1) with $\Delta = 1$, $\Delta_d = 0$ and $M = \infty$. The stock volatility σ_S^d is estimated by using the daily stock price from 2000Q1 to 2006Q4, and a linear relationship between the equity volatility σ_θ^d is estimated as $\sigma_S^d = a + 0.95 * \sigma_\theta^d$ to calculate the change of stock volatility $\Delta\sigma_S$ due to the change of the equity volatility σ_θ^d (see Vuolteenaho (2002)). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$. By the estimated equity volatility using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters, where we select the smallest cost parameter values that satisfy the optimality condition (17).

Cost function parameters	c_+	c_-
<i>Panel A: T cap 10 yrs.</i>		
Min	54,159,680,390	-10,371,808,215
Max	12,393,579,395,958	-50,795,456
Mean	1,928,995,736,301	-1,756,735,246
Std	2,409,491,258,578	2,165,569,558
<i>Panel B: T cap 15 yrs.</i>		
Min	133,100,002,637	-25,064,505,000
Max	30,068,032,333,422	-121,939,366
Mean	4,370,107,499,795	-3,982,408,013
Std	5,663,438,179,311	5,097,305,589

Table 11: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals only — option grants and $c_- = 0$.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . The banker's objective is to maximise the net payoff $\tilde{\pi}_{1,\infty}(\hat{\sigma}_\theta + \Delta\sigma_\theta, \Delta_d) + N\pi_{BS}(\hat{\sigma}_S + \Delta\sigma_S) - F(\Delta\sigma_\theta)$, 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 stock volatility $\hat{\sigma}_S$ and the equity volatility $\hat{\sigma}_\theta$ are related as $\hat{\sigma}_S = a + 0.95 * \hat{\sigma}_\theta$ which is used to calculate the change of stock volatility $\Delta\sigma_S$ due to the change of the equity volatility σ_θ (see Vuolteenaho (2002)). The parameters of the piecewise quadratic cost function are reported in Table 10. To calculate the risk reduction, we set $c_- = 0$ in the cost functions. Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.02%	0.01%	26.77%	37.73%	29.35%	26.77%	38.04%	37.73%
Mean	0.00%	0.00%	0.97%	1.38%	1.07%	0.98%	1.41%	1.38%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	4.88%	6.90%	5.34%	4.88%	7.06%	6.90%
% of positive change	23.08%	1.92%	13.73%	3.92%	21.57%	21.57%	17.65%	7.84%
% of negative change	0.00%	0.00%	1.96%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	0.00%	0.00%	61.11%	33.53%	74.90%	61.11%	33.53%	33.53%
Mean	0.00%	0.00%	-24.96%	-12.73%	-21.10%	-24.96%	-12.73%	-12.73%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	96.49%	67.87%	96.46%	96.49%	67.87%	67.87%
% of positive change	0.00%	0.00%	23.53%	5.88%	25.49%	23.53%	5.88%	5.88%
% of negative change	0.00%	0.00%	35.29%	19.61%	33.33%	35.29%	19.61%	19.61%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.01%	0.01%	11.80%	23.22%	17.49%	11.80%	24.81%	23.22%
Mean	0.00%	0.00%	0.37%	0.82%	0.58%	0.37%	0.92%	0.82%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	1.90%	4.11%	2.95%	1.90%	4.62%	4.11%
% of positive change	17.31%	1.92%	19.61%	5.88%	29.41%	27.45%	11.76%	7.84%
% of negative change	0.00%	0.00%	1.96%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	0.00%	0.00%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	0.00%	0.00%	78.41%	42.36%	78.41%	78.41%	42.36%	42.36%
Mean	0.00%	0.00%	-18.88%	-12.29%	-18.88%	-18.88%	-12.29%	-12.29%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	97.39%	68.06%	97.39%	97.39%	68.06%	68.06%
% of positive change	0.00%	0.00%	35.29%	11.76%	35.29%	35.29%	11.76%	11.76%
% of negative change	0.00%	0.00%	37.25%	17.65%	37.25%	37.25%	17.65%	17.65%

Table 12: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals — augmented fixed salary and $c_- = 0$.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . 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} , e.g., $K_{10} = \sum_{i=1}^{T \text{ cap } 10} \exp(-(i-1)r)\tilde{\pi}_{1,\infty} + S$, 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, e.g., $K'_{10} = \sum_{i=1}^{T \text{ cap } 10} \exp(-(i-1)r)\tilde{\pi}_{1,S'} + S'$, where S' is the augmented base salary such that $K_{10} = K'_{10}$. By the estimated equity volatility σ_θ^d using quarterly data from 2000Q1 to 2006Q4, and (17), we get the bank-level cost parameters (not reported for brevity). To calculate the risk reduction, we set $c_- = 0$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S'$	$\Delta_d = 0$ $M = 3S'$	$\Delta_d = 1$ $M = S'$	$\Delta_d = 3$ $M = S'$	$\Delta_d = 1$ $M = 3S'$	$\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.08%	0.01%	100.00%	0.00%	38.25%	100.00%	0.08%	0.01%
Mean	0.00%	0.00%	3.68%	0.00%	0.80%	3.69%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.01%	0.00%	16.46%	0.00%	4.73%	16.48%	0.01%	0.00%
% of positive change	21.18%	2.35%	14.12%	0.00%	22.35%	18.82%	12.94%	2.35%
% of negative change	0.00%	0.00%	1.18%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S'$	$\Delta_d = 0$ $M = 3S'$	$\Delta_d = 1$ $M = S'$	$\Delta_d = 3$ $M = S'$	$\Delta_d = 1$ $M = 3S'$	$\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-344.45%	-2.77%	-344.45%	-344.45%	-2.77%	-2.77%
Max	77.50%	0.00%	97.78%	3.27%	77.50%	97.78%	77.50%	3.27%
Mean	0.92%	0.00%	-5.63%	-0.12%	-5.73%	-5.00%	0.80%	-0.12%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.46%	0.00%	68.55%	0.73%	67.45%	68.67%	8.50%	0.73%
% of positive change	2.38%	0.00%	25.30%	2.38%	27.38%	25.00%	4.76%	2.38%
% of negative change	0.00%	0.00%	21.69%	16.67%	22.62%	22.62%	17.86%	17.86%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S'$	$\Delta_d = 0$ $M = 3S'$	$\Delta_d = 1$ $M = S'$	$\Delta_d = 3$ $M = S'$	$\Delta_d = 1$ $M = 3S'$	$\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.02%	0.01%	99.92%	0.00%	18.37%	100.00%	0.02%	0.01%
Mean	0.00%	0.00%	3.72%	0.00%	0.22%	2.54%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	18.48%	0.00%	1.99%	15.16%	0.00%	0.00%
% of positive change	15.29%	2.35%	14.12%	0.00%	21.18%	22.35%	5.88%	2.35%
% of negative change	0.00%	0.00%	1.18%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S'$	$\Delta_d = 0$ $M = 3S'$	$\Delta_d = 1$ $M = S'$	$\Delta_d = 3$ $M = S'$	$\Delta_d = 1$ $M = 3S'$	$\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-344.45%	-2.76%	-344.45%	-344.45%	-2.76%	-2.76%
Max	0.01%	0.00%	97.78%	7.66%	50.18%	97.78%	7.66%	7.66%
Mean	0.00%	0.00%	5.24%	0.22%	3.38%	4.34%	0.22%	0.22%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	44.35%	1.36%	41.14%	42.66%	1.36%	1.36%
% of positive change	1.19%	0.00%	34.94%	9.52%	36.90%	35.71%	10.71%	9.52%
% of negative change	0.00%	0.00%	27.71%	13.10%	27.38%	27.38%	13.10%	13.10%

Internet Appendix to “Bonus Caps, Deferrals, and Bankers’ Risk-Taking”

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Abstract

Tables 13–18 replicate the baseline case and the extension in the main text 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.

Table 13: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008**

— **the smallest cost parameters.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$

and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, and (12), we get the bank-level cost parameters (not reported for brevity).

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.09%	0.02%	23.63%	25.74%	21.81%	20.42%	19.58%	25.80%
Mean	0.01%	0.00%	0.67%	0.62%	0.51%	0.57%	0.69%	0.89%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
Std	0.01%	0.00%	3.65%	3.78%	3.19%	3.13%	3.46%	4.29%
% of positive change	61.63%	27.91%	37.21%	16.28%	63.95%	45.35%	60.47%	30.23%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-0.01%	-0.01%	-344.45%	-344.44%	-344.45%	-344.45%	-344.44%	-344.45%
Max	77.50%	0.14%	96.30%	89.01%	95.96%	95.96%	89.01%	88.94%
Mean	0.90%	0.00%	2.13%	0.03%	5.03%	2.37%	2.93%	0.01%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.36%	0.02%	81.99%	57.43%	74.47%	82.17%	46.20%	57.43%
% of positive change	2.33%	1.16%	48.84%	25.58%	48.84%	48.84%	25.58%	25.58%
% of negative change	3.49%	1.16%	18.60%	23.26%	18.60%	18.60%	23.26%	23.26%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.08%	0.02%	23.55%	23.67%	22.24%	20.15%	22.14%	20.29%
Mean	0.01%	0.00%	0.58%	0.32%	0.57%	0.51%	0.75%	0.32%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.00%
Std	0.01%	0.00%	3.51%	2.57%	3.33%	2.99%	3.79%	2.24%
% of positive change	58.14%	20.93%	44.19%	19.77%	63.95%	51.16%	60.47%	34.88%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-0.01%	-0.01%	-344.45%	-343.34%	-344.45%	-344.45%	-343.34%	-344.45%
Max	77.50%	0.00%	97.78%	93.80%	97.78%	97.78%	93.80%	93.80%
Mean	1.80%	0.00%	5.68%	2.47%	7.06%	5.65%	3.97%	2.43%
Median	0.00%	0.00%	4.44%	0.00%	4.44%	4.44%	0.00%	0.00%
Std	11.75%	0.00%	83.10%	58.52%	77.73%	83.21%	51.15%	58.89%
% of positive change	2.33%	0.00%	56.98%	37.21%	56.98%	56.98%	37.21%	37.21%
% of negative change	9.30%	2.33%	17.44%	15.12%	17.44%	17.44%	15.12%	15.12%

Table 14: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008**

— **the cost parameter c_- is zero.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$

and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, and (12), we get the bank-level cost parameters (not reported for brevity). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.09%	0.02%	37.92%	100.00%	38.86%	37.92%	50.57%	99.75%
Mean	0.01%	0.00%	1.23%	1.59%	1.72%	1.23%	1.58%	1.59%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
Std	0.01%	0.00%	6.48%	11.43%	7.79%	6.48%	8.39%	11.40%
% of positive change	61.63%	27.91%	34.88%	15.12%	62.79%	43.02%	60.47%	27.91%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	-0.01%	-0.01%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	77.50%	0.14%	96.30%	89.01%	100.00%	96.30%	89.01%	89.01%
Mean	0.90%	0.00%	2.40%	0.43%	6.26%	2.44%	5.00%	1.15%
Median	0.00%	0.00%	0.00%	0.00%	0.30%	0.00%	0.00%	0.00%
Std	8.36%	0.02%	82.30%	57.52%	75.32%	82.29%	47.91%	58.22%
% of positive change	3.49%	1.16%	48.84%	26.74%	51.16%	48.84%	29.07%	26.74%
% of negative change	3.49%	1.16%	18.60%	22.09%	17.44%	18.60%	20.93%	22.09%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.08%	0.02%	27.70%	26.45%	29.08%	27.70%	28.90%	26.45%
Mean	0.01%	0.00%	0.88%	0.31%	0.95%	0.88%	0.35%	0.32%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
Std	0.01%	0.00%	4.64%	2.85%	5.00%	4.64%	3.12%	2.85%
% of positive change	58.14%	20.93%	41.86%	18.60%	61.63%	48.84%	59.30%	33.72%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	-0.01%	-0.01%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	77.50%	0.00%	97.78%	93.80%	100.00%	97.78%	93.80%	93.80%
Mean	1.80%	0.00%	5.68%	2.47%	7.43%	5.67%	4.02%	2.45%
Median	0.00%	0.00%	4.44%	0.00%	4.44%	4.44%	0.00%	0.00%
Std	11.75%	0.00%	83.15%	58.61%	78.25%	83.35%	51.24%	58.89%
% of positive change	3.49%	0.00%	56.98%	37.21%	58.14%	56.98%	38.37%	37.21%
% of negative change	9.30%	2.33%	17.44%	15.12%	17.44%	17.44%	15.12%	15.12%

Table 15: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008**

— **the cost parameters are equal.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$

and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, and (12), we get the bank-level cost parameters (not reported for brevity). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.10%	0.02%	0.08%	0.04%	0.09%	0.09%	0.10%	0.06%
Mean	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.01%	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%
% of positive change	3.49%	3.49%	5.81%	2.33%	6.98%	5.81%	4.65%	4.65%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-3900.01%	-3900.00%	-3900.00%	-3900.00%	-3900.00%	-3900.00%
Max	97.50%	2.22%	96.55%	89.94%	96.55%	96.55%	97.48%	89.94%
Mean	1.16%	0.03%	-141.02%	-61.57%	-140.09%	-162.86%	-59.39%	-82.62%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	10.51%	0.24%	750.94%	470.78%	750.20%	830.43%	469.68%	592.42%
% of positive change	4.65%	3.49%	48.84%	23.26%	48.84%	48.84%	25.58%	25.58%
% of negative change	0.00%	0.00%	18.60%	25.58%	18.60%	18.60%	24.42%	24.42%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.10%	0.02%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Mean	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.02%	0.00%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
% of positive change	5.81%	5.81%	6.98%	4.65%	8.14%	8.14%	6.98%	6.98%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$ $M = \infty$	$\Delta_d = 3$ $M = \infty$	$\Delta_d = 0$ $M = S$	$\Delta_d = 0$ $M = 3S$	$\Delta_d = 1$ $M = S$	$\Delta_d = 3$ $M = S$	$\Delta_d = 1$ $M = 3S$	$\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%	-3900.01%
Max	97.50%	0.00%	99.34%	98.01%	99.77%	99.46%	99.35%	98.38%
Mean	2.27%	0.00%	-150.55%	-71.78%	-158.89%	-159.11%	-79.48%	-80.01%
Median	0.00%	0.00%	4.09%	0.00%	4.09%	4.09%	0.00%	0.00%
Std	14.78%	0.00%	795.21%	539.87%	830.85%	831.32%	592.37%	592.97%
% of positive change	2.33%	0.00%	56.98%	36.05%	56.98%	56.98%	37.21%	37.21%
% of negative change	0.00%	0.00%	17.44%	16.28%	17.44%	17.44%	15.12%	15.12%

Table 16: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008** — **internal bonus cap and $c_- = 0$** . The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$

and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, (12), and the internal bonus cap, we get the bank-level cost parameters (not reported for brevity). To calculate the risk reduction, we set $c_- = 0$ in the cost function. Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	0.44%	0.33%	54.16%	99.97%	100.00%	54.16%	50.57%	97.98%
Mean	0.01%	0.01%	2.25%	1.62%	2.93%	2.31%	1.62%	1.69%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
Std	0.05%	0.04%	9.20%	11.49%	13.22%	9.41%	8.43%	11.30%
% of positive change	60.00%	25.88%	34.12%	15.29%	61.18%	42.35%	58.82%	27.06%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-43.24%	-32.94%	-344.53%	-490.23%	-344.45%	-344.53%	-344.45%	-344.45%
Max	77.50%	77.50%	96.92%	91.12%	100.00%	96.92%	91.67%	91.60%
Mean	1.32%	0.53%	1.13%	-0.93%	3.19%	1.12%	5.58%	3.93%
Median	0.00%	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%
Std	12.79%	9.17%	82.35%	69.78%	80.99%	82.36%	47.98%	47.53%
% of positive change	4.71%	2.35%	48.24%	25.88%	50.59%	48.24%	28.24%	25.88%
% of negative change	10.59%	2.35%	18.82%	22.35%	17.65%	18.82%	21.18%	22.35%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	9.20%	4.68%	99.99%	26.45%	100.00%	100.00%	28.90%	26.45%
Mean	0.14%	0.08%	2.15%	0.65%	2.23%	2.16%	0.69%	0.66%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%
Std	1.02%	0.53%	11.72%	3.70%	11.86%	11.72%	3.96%	3.72%
% of positive change	58.82%	28.24%	41.18%	20.00%	61.18%	48.24%	58.82%	34.12%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-0.01%	-0.01%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%	-344.45%
Max	77.50%	0.00%	98.31%	94.92%	100.00%	98.32%	95.22%	95.20%
Mean	1.82%	0.00%	9.21%	8.37%	9.87%	9.26%	8.84%	8.45%
Median	0.00%	0.00%	4.03%	0.00%	4.03%	4.03%	0.00%	0.00%
Std	11.82%	0.00%	74.52%	47.26%	75.09%	74.54%	47.93%	47.36%
% of positive change	3.53%	0.00%	56.47%	37.65%	57.65%	56.47%	38.82%	37.65%
% of negative change	12.94%	5.88%	16.47%	14.12%	16.47%	16.47%	14.12%	14.12%

Table 17: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008 — augmented fixed salary and $c_- = 0$.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . 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} , e.g., $K_{10} = \sum_{i=1}^{T \text{ cap } 10} \exp(-(i-1)r)\tilde{\pi}_{1,\infty} + S$, 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, e.g., $K'_{10} = \sum_{i=1}^{T \text{ cap } 10} \exp(-(i-1)r)\tilde{\pi}_{1,S'} + S'$, where S' is the augmented base salary such that $K_{10} = K'_{10}$. By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, and (12), we get the bank-level cost parameters (not reported for brevity). To calculate the risk reduction, we set $c_- = 0$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S'$	Case IV $\Delta_d = 0$ $M = 3S'$	Case V $\Delta_d = 1$ $M = S'$	Case VI $\Delta_d = 3$ $M = S'$	Case VII $\Delta_d = 1$ $M = 3S'$	Case VIII $\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-0.08%	-0.08%	0.00%	-0.07%	0.00%	-0.05%
Max	0.10%	0.09%	99.99%	0.11%	39.08%	98.85%	0.12%	0.12%
Mean	0.01%	0.01%	1.64%	0.00%	0.47%	1.63%	0.01%	0.01%
Median	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.02%	0.01%	11.58%	0.02%	4.24%	11.46%	0.02%	0.02%
% of positive change	60.00%	22.35%	28.24%	9.41%	49.41%	38.82%	42.35%	12.94%
% of negative change	0.00%	0.00%	2.35%	4.71%	0.00%	1.18%	0.00%	1.18%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-0.01%	0.00%	-344.45%	-271.85%	-344.45%	-344.45%	-3.48%	-232.25%
Max	77.50%	77.50%	89.74%	81.41%	89.74%	89.74%	81.41%	81.41%
Mean	3.67%	0.92%	9.56%	2.78%	12.50%	9.69%	6.40%	3.33%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	16.52%	8.46%	56.78%	36.20%	47.86%	56.36%	20.56%	32.79%
% of positive change	5.95%	1.19%	44.58%	19.05%	46.43%	45.24%	21.43%	19.05%
% of negative change	5.95%	0.00%	24.10%	29.76%	23.81%	23.81%	28.57%	29.76%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S'$	Case IV $\Delta_d = 0$ $M = 3S'$	Case V $\Delta_d = 1$ $M = S'$	Case VI $\Delta_d = 3$ $M = S'$	Case VII $\Delta_d = 1$ $M = 3S'$	Case VIII $\Delta_d = 3$ $M = 3S'$
Min	0.00%	0.00%	-0.04%	-0.01%	0.00%	-0.03%	0.00%	0.00%
Max	0.04%	0.03%	99.99%	0.11%	0.15%	98.85%	0.13%	0.13%
Mean	0.01%	0.01%	2.36%	0.01%	0.02%	2.34%	0.01%	0.01%
Median	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
Std	0.01%	0.01%	15.18%	0.03%	0.04%	15.04%	0.03%	0.03%
% of positive change	52.94%	24.71%	40.00%	12.94%	51.76%	47.06%	38.82%	22.35%
% of negative change	0.00%	0.00%	1.18%	2.35%	0.00%	1.18%	0.00%	0.00%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-0.01%	-0.01%	-129.95%	-5.26%	-1.82%	-128.89%	-1.77%	-1.77%
Max	0.02%	0.00%	97.78%	78.03%	89.31%	97.78%	80.29%	78.82%
Mean	0.00%	0.00%	19.65%	7.29%	20.30%	19.59%	7.96%	7.57%
Median	0.00%	0.00%	4.50%	0.00%	5.29%	5.29%	0.00%	0.00%
Std	0.00%	0.00%	33.69%	19.59%	27.76%	33.60%	21.03%	20.08%
% of positive change	1.19%	0.00%	56.63%	33.33%	58.33%	57.14%	34.52%	33.33%
% of negative change	7.14%	4.76%	20.48%	19.05%	20.24%	20.24%	19.05%	19.05%

Table 18: **Risk reductions and bonus incentive changes for bonus caps and bonus deferrals with equity volatility estimates including years 2007 and 2008 — bonuses decrease equity value and $c_- = 0$.** The risk reduction is calculated as $\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$ and the bonus incentive change is calculated as $\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$, where $\sigma_{1,M}^o(\Delta_d)$ and $k_{1,M}^o(\Delta_d)$ are jointly solved by (11) with the bonus deferral Δ_d and the bonus cap M . In the simulation, the equity drops when the bonus is paid out at each payment time and between the payment times it follows (2). By the estimated equity volatility using quarterly data from 2000Q1 to 2008Q4, and (12), we get the bank-level cost parameters. We set $c_- = 0$ and c_+ is the smallest cost parameter values that satisfy the optimality condition (12) (not reported for brevity).

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	-0.01%	-0.01%	0.00%	0.00%	0.00%	-0.01%	-0.01%	-0.01%
Max	0.03%	0.02%	50.21%	0.00%	65.18%	50.50%	0.03%	0.02%
Mean	0.00%	0.00%	0.59%	0.00%	0.77%	0.60%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	5.45%	0.00%	7.07%	5.48%	0.00%	0.00%
% of positive change	3.49%	8.14%	2.35%	0.00%	3.53%	4.71%	2.35%	4.71%
% of negative change	1.16%	1.16%	0.00%	0.00%	0.00%	1.18%	1.18%	1.18%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-296.32%	-296.32%	-3877.32%	0.00%	-3891.47%	-3877.32%	-296.32%	-296.32%
Max	99.55%	99.57%	100.00%	96.27%	99.49%	100.00%	99.55%	99.57%
Mean	1.04%	2.86%	-66.22%	13.76%	-50.66%	-53.44%	13.79%	13.51%
Median	0.00%	0.00%	4.26%	0.00%	6.91%	9.32%	0.01%	0.00%
Std	38.35%	40.07%	521.17%	25.97%	480.35%	525.29%	45.53%	45.02%
% of positive change	4.65%	6.98%	63.53%	47.06%	65.88%	65.88%	50.59%	49.41%
% of negative change	1.16%	1.16%	4.71%	0.00%	3.53%	3.53%	1.18%	1.18%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_{1,\infty}^o(0) - \sigma_{1,M}^o(\Delta_d)}{\sigma_{1,\infty}^o(0)}$	Case I $\Delta_d = 1$ $M = \infty$	Case II $\Delta_d = 3$ $M = \infty$	Case III $\Delta_d = 0$ $M = S$	Case IV $\Delta_d = 0$ $M = 3S$	Case V $\Delta_d = 1$ $M = S$	Case VI $\Delta_d = 3$ $M = S$	Case VII $\Delta_d = 1$ $M = 3S$	Case VIII $\Delta_d = 3$ $M = 3S$
Min	-0.02%	0.00%	0.00%	-0.02%	0.00%	0.00%	-0.02%	-0.02%
Max	0.03%	0.02%	46.46%	0.03%	64.29%	51.47%	0.05%	0.04%
Mean	0.00%	0.00%	0.55%	0.00%	0.76%	0.61%	0.00%	0.00%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	0.00%	0.00%	5.04%	0.00%	6.97%	5.58%	0.01%	0.01%
% of positive change	2.33%	2.33%	2.35%	1.18%	3.53%	3.53%	2.35%	3.53%
% of negative change	1.16%	0.00%	0.00%	1.18%	0.00%	0.00%	1.18%	1.18%
$\frac{k_{1,\infty}^o(0) - k_{1,M}^o(\Delta_d)}{k_{1,\infty}^o(0)}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
Min	-20463.87%	-20463.91%	-24948.18%	-490.92%	-31529.81%	-31477.44%	-20463.87%	-20463.91%
Max	99.64%	99.63%	100.00%	97.96%	99.64%	100.00%	99.64%	97.96%
Mean	-243.66%	-235.64%	-546.02%	11.39%	-624.23%	-623.80%	-226.93%	-228.46%
Median	0.00%	0.00%	13.63%	0.02%	15.61%	13.63%	0.10%	0.09%
Std	2207.37%	2206.98%	3493.78%	61.78%	4066.86%	4062.05%	2222.03%	2221.84%
% of positive change	2.33%	3.49%	70.59%	51.76%	71.76%	70.59%	54.12%	52.94%
% of negative change	2.33%	1.16%	3.53%	1.18%	4.71%	3.53%	2.35%	2.35%

Table 19: **Risk reductions for bonus caps and bonus deferrals with fixed bonus incentive — the cost parameter c_- is zero.** The risk reduction is calculated as $\frac{\sigma_\theta - \sigma_{1,M}^o(\Delta_d)}{\sigma_\theta}$ where $\sigma_{1,M}^o(\Delta_d)$ is solved by (9) with the bonus deferral Δ_d and the bonus cap M . σ_θ the estimated equity volatility using quarterly data from 2000Q1 to 2006Q4. By (12), we get the bank-level cost parameters (not reported for brevity). Piecewise quadratic cost function: $F(\Delta\sigma_\theta) = c_+ \mathbf{1}\{\Delta\sigma_\theta \geq 0\} (\Delta\sigma_\theta)^2 + c_- \mathbf{1}\{\Delta\sigma_\theta < 0\} (\Delta\sigma_\theta)^2$.

<i>Panel A: Tenure cap 10 years</i>								
$\frac{\sigma_\theta - \sigma_{1,M}^o(\Delta_d)}{\sigma_\theta}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	76.30%	0.00%	92.70%	91.20%	92.70%	92.70%	91.20%	91.20%
Mean	0.89%	0.00%	13.02%	6.99%	14.00%	13.02%	8.31%	6.99%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.23%	0.00%	26.06%	21.99%	26.99%	26.06%	23.39%	21.99%
% of positive change	1.16%	0.00%	23.53%	10.59%	24.71%	23.53%	12.94%	10.59%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
<i>Panel B: Tenure cap 15 years</i>								
$\frac{\sigma_\theta - \sigma_{1,M}^o(\Delta_d)}{\sigma_\theta}$	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII
	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 0$	$\Delta_d = 0$	$\Delta_d = 1$	$\Delta_d = 3$	$\Delta_d = 1$	$\Delta_d = 3$
	$M = \infty$	$M = \infty$	$M = S$	$M = 3S$	$M = S$	$M = S$	$M = 3S$	$M = 3S$
Min	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Max	76.30%	0.00%	88.20%	85.90%	88.20%	88.20%	85.90%	85.90%
Mean	0.89%	0.00%	9.73%	6.06%	10.86%	9.73%	7.40%	6.06%
Median	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Std	8.23%	0.00%	22.56%	19.36%	23.85%	22.56%	21.03%	19.36%
% of positive change	1.16%	0.00%	21.18%	10.59%	22.35%	21.18%	12.94%	10.59%
% of negative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

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