# *Bonus Caps, Deferrals and Banks' Risk-Taking* *

Esa Jokivuolle
Bank of Finland
and Aalto University
esa.jokivuolle@bof.fi

Jussi Keppo
NUS Business School
and Risk Management Institute
National University of Singapore
keppo@nus.edu.sg

Xuchuan Yuan
Risk Management Institute
National University of Singapore
rmiyuanx@nus.edu.sg

January 15, 2015

**Abstract**

We model future bonuses as a series of sequential call options on profits and show that if the cost of risk-taking is ignored bonuses provide the higher risk-taking incentive the shorter is the time between the bonus determination time points and the higher are the bonuses relative to the fixed pay. This motivates regulators to use bonus caps and bonus deferrals to influence banks' risk-taking. In the model bankers' optimal risk-taking depends on the bonus induced risk-taking incentive under the bonus restrictions and on the cost of risk-taking. We calibrate our model to a sample of US banks and their CEOs' bonuses and show that increasing the effective bonus payment interval to two years from the standard one year has no material effect on risk-taking. However, the relationship is nonlinear in a way that lengthening the bonus payment interval would start to have an effect on risk-taking if the original interval were less than a year as is the case in some nonbanks. Further, capping the bonus to be no larger than fixed salary - an equivalent of the new EU regulation - significantly reduces bankers' risk-taking. The bank-specific effect varies widely, and we find some evidence that the bonus cap is most effective in larger banks.

**EFM classification codes**: 190, 510/520, 110, 450

*An earlier draft of this paper was circulated under the title "Bankers' Compensation: Sprint Swimming in Short Bonus Pools?". We thank Jonna Elonen-Kulmala, Dias Lonappan, and Sami Oinonen for research assistance and Mikko Niemenmaa for help with the data. We have benefited from comments at Aalto University, Bank of Finland, Chinese University of Hong Kong, INSEAD, National University of Singapore, INFORMS Annual Meeting, RMI Risk Management Conference, and more specifically from Sumit Agarwal, Rene Caldentey, Josef Korte, Antti Lehtoranta, Pauli Murto, Lin Peng, David M. Reeb, Jouko Vilmunen, Matti Viren, and Hanna Westman. All errors are ours.

# 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 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.[1]

Our contribution in this paper is two-fold. First, we develop a theoretical model for the value of future bonuses and bonus-induced risk-taking incentives, which depend on the size of bonuses, possibly restricted by a regulatory cap and the bonus payment frequency. Second, using data on US banks we calibrate the theoretical model and simulate the effect of a bonus cap and a bonus deferral on the banks' risk-taking. We find that the effect of bonus deferral on the bankers' risk-taking is immaterial unless bonuses are originally paid more frequently than once a year, but we do find that a cap on bonuses can substantially reduce the risk-taking.

More specifically, we evaluate bankers' risk-taking changes due to 1) a bonus cap and 2) a longer bonus determination interval (i.e., a bonus deferral), which some jurisdictions, notably the US and the EU are already in the process of implementing in some form. Using a standard continuous-time asset pricing framework we first derive the theoretical value of a banker's expected future bonus stream, assuming no bonus cap or bonus deferral (beyond the standard one-year bonus determination interval). With this baseline model we measure the banker's risk-taking incentive by the derivative of the present value of bonuses with respect to the bank's earnings volatility. As bonuses are only paid out of positive profits, they are like call options and, hence, the present value of future bonuses is a series of sequential call options on the bank's earnings. Further, since the call options are convex with respect to the earnings, the banker would prefer to increase the earnings

[1]For instance, the European Union has limited the bonus per salary ratio to one and is imposing guidelines for bonus deferrals. In the US, the Dodd-Frank Act imposes clawback policies on bonuses. Many banks, such as the UBS and Deutsche Bank, have introduced or are considering clawback policies voluntarily, perhaps in anticipation of the increasing regulatory pressure. Liikanen Report suggested that bankers' compensation should include debt instruments subject to bail-in clauses (Liikanen 2012).

volatility as much as possible by raising leverage or by buying riskier assets if there were no costs to do that. However, in practice markets, regulators, and banks themselves set constraints and costs in risk-taking and we add these to our baseline model in a stylized manner.

We obtain three key theoretical results. First, we show that the series of bonuses is worth more, the shorter the time interval between bonus determination points. Intuitively, we may compare this result with Merton (1974) who shows that a portfolio of options on individual stocks is worth more than an option on the basket consisting of those stocks. However, in our case this analysis is over the time interval between bonus options, not over stocks in a portfolio. Our theoretical result suggests that bankers (and similarly, e.g., hedge fund and private equity managers) have a strong incentive to negotiate compensation contracts with short payment horizons.[2]

Second, we show that the shorter the bonus determination interval, the higher is the banker's risk-taking incentive in terms of increasing the earnings volatility.[3] Although our model does not generate any predictions about how the terms of a banker's compensation contract are determined, this result is important because it formalizes the common notion that short-term bonus contracts spur risk-taking.[4] An immediate corollary of the result is that imposing a bonus deferral can help contain risk-taking.

Third, we show that a bonus cap decreases the value of future bonuses and the risk-taking incentive by cutting the "upside" of a bonus above the threshold defined by the cap. More precisely, the bonus cap can be modeled as a short call option on profits with an exercise price determined by the bonus cap rule. As a result, our baseline model for the present value of the banker's future bonus stream is augmented by a series of short

[2] In the hedge fund industry, the effect on risk-taking incentives of short payment horizons can be at least partially controlled by the so called high-water marks (see e.g. Panageas and Westerfield (2009)).

[3] The standard time interval between bonuses is one year. Our theoretical result may be suggestive of the incentive effects of other forms of convex compensation such as executive options in which vesting periods are typically longer than one year. In case of executive options the underlying asset is the bank's stock price, not the bank's profit. Therefore, the current model is not directly applicable to option grants but, assuming that earnings and stock prices are highly correlated, the model can be used as an approximation for option grants (for instance, Durre and Giot (2005) find a significant long-run relationship between stock indexes and earnings).

[4] See e.g. Edmans et al. (2012) for a model which derives the optimal level and performance-sensitivity of CEO compensation contract. Short-term bonus contracts and their effects are also commonly discussed in financial press (see e.g. Bloomberg, 19 June 2013, U.K. Banker Bonuses Face Decade Delays in Industry Overhaul).

calls, representing the bonus caps on the future bonus payments.

To do the policy simulations regarding the effect of bonus regulations on bankers' risk-taking we incorporate the cost of risk-taking in the model. The cost of risk-taking stems from several sources, e.g., from complying with current capital and liquidity regulations, market discipline, risk culture of the bank, and the cost of additional effort. Moreover, an obvious cost of too much risk-taking stems from the possibility that the banker gets fired as a result of poor performance or, ultimately, the bankruptcy of the bank. However, we do not consider these cost elements explicitly; instead, since the risk-taking constraints and costs are not fully observed, we model the cost of changing the earnings volatility with both linear and quadratic functions. Then for robustness we analyze the effects of bonus caps and bonus deferrals under both of the cost function cases. By balancing the cost and the banker's risk-taking incentive due to bonuses, the banker determines her optimal level of risk-taking.

We calibrate the parameters of the cost functions empirically in the context of the baseline model, excluding bonus caps and rules concerning bonus deferrals. Thus, we calibrate the cost functions assuming that compensation regulation is not implemented. To do that, we use a sample of 94 US banks and data on their balance sheets and CEO bonuses during 2004-2006 when there were no compensation regulation proposals.[5] Further, we assume that the historically estimated earnings volatility of each bank is at the optimal level for the respective bank CEO. That is, the volatility of each bank maximizes the difference between the bank CEO's bonus value and her cost of risk-taking. By assuming this equilibrium condition at the end of 2006, we get bank-specific cost parameters for both linear and quadratic cost functions.

With the calibrated model we then run the counterfactual analysis of a bonus cap and bonus deferral for each bank. Regarding the bonus cap we limit the bonus to be no greater than the CEO's fixed salary. This case is motivated by the recent EU regulation.[6] We find that on average the bonus cap reduces the banks' earnings volatility by about 23.08% (from 0.0158 to 0.0121) relative to the pre-crisis earnings volatility, but the bank-specific effect varies widely. We find evidence that the bonus cap is most effective

[5] The sample is essentially the same as used in Fahlenbrach and Stulz (2011).

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

on bigger banks. As big banks typically impose biggest systemic risk to the financial system, bonus cap may hence contribute to containing systemic risk.

Regarding the bonus deferral we consider the case where the bonus is determined (and paid) every second year, instead of the one-year standard, based on the bank's cumulative profit over the preceding two-year period.[7] By our counterfactual analysis, in this case the bonus deferral has no material effect on the banks' risk-taking. Even if bonuses were paid only once at the end of the CEO's expected tenure, we would not achieve a nowhere near similar risk reduction impact as with the considered bonus cap which has a sizeable effect on risk-taking. Further, we find the effect of the bonus deferral to be nonlinear in such a way that only if bonuses were originally paid more frequently than once a year (e.g., semi-annually, quarterly, or monthly), then lengthening of the bonus payment interval would start to have a material impact on risk-taking.

The paper is organized as follows. After a literature review in Section 2, the model setup is presented in Section 3. The value of the future bonus stream, considering also the effect of the bonus cap, is derived in Section 4. Section 5 introduces the cost of risk-taking and Section 6 presents the bonus regulation analyses with the calibrated model. Section 7 concludes.

## 2 Literature review

In this section we review the literature on compensation based risk-taking incentives. We then discuss a selection of recent papers which are more directly related to our work from two perspectives, the size and the length of payment horizon in compensation contracts.

There are studies which 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 (cf. Beatty and Zajec (1994)) which may, however, depend on the amount and composition

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

of their personal wealth (see Korkeamaki et al. (2013)). Interestingly, Houston and James (1995) did 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 can be more hidden.

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

The link between bankers' risk-taking incentives and the timing of their compensation is analyzed in several papers. The paper which provides most direct evidence that shorter-term compensation contracts increase risk-taking is by Gopalan et al. (2010). 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. However, not all papers agree that compensation duration is crucial for bankers' 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.

Different evidence is obtained by Fahlenbrach and Stulz (2011) who show that "(b)anks 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 are not given only by compensation but also by the cost of risk-taking.[8] Unlike Gopalan et al. (2010), 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

[8]We obtain consistent results with Fahlenbrach and Stulz (2011) using similar data and our model's bonus induced risk-taking measure, see Table 11.

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. Alternatively, this could be additional evidence reported in Leaven and Levine (2009) and Pathan (2009) that bank risk-taking may be determined at the level of a board which strongly represents shareholder interests, and, as discussed in Haldane (2009), bank shareholders have incentive to increase risks due to deposit insurance and other government support mechanisms. Also Murphy (2012) finds only little evidence that the pay structures provided incentives for risk-taking among top-level banking executives.

Recent empirical papers which find that compensation based risk-taking incentives in banks did 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 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 the annual risk-taking incentive measures with the bank's actual risk-taking the following year, measured from the bank's daily stock returns that year. To measure risk-taking incentives, they use a procedure from earlier studies to empirically determine the delta and the vega of the banks' compensation contracts. They find evidence that stronger contractual risk-taking incentives for CEOs led to higher risks. The effects are largest and most persistent in the largest banks. They attribute the increase in contractual risk-taking incentives for CEOs at large U.S. commercial banks to deregulation around 2000, which in effect expanded these banks' growth opportunities. 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 bank risk, Fahlenbrach and Stulz (2011) focus precisely on the crisis time bank stock returns. The advantage with 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 to measure compensation-based CEO risk-taking incentives.

More generally, our paper is also related to principal-agent models (see e.g. Grossman and Hart (1983), Holmstrom (1979, 1982, 1983, 1999), Holmstrom and Milgrom (1991, 1994), Myerson (1982), Rogerson (1985), and Sannikov (2008)).[9] In the present paper, we do not use principal-agent modeling but take the bankers' compensation contract and the cost of risk-taking as given. We then focus on counterfactual analysis of changes in risk-taking due to changes in compensation based risk-taking incentives induced by regulatory changes. Further, because our model makes the assumption that the benefits and costs of risk-taking are in balance, our approach implies that one cannot necessarily 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.

# 3 Model

We consider a risk-neutral banker who receives bonuses with certain frequency during her tenure $[0, T]$. The banker's bonuses are calculated from the bank's earnings and the earnings depend on the change of the bank's asset values.

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

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

where $r$ is the risk-free rate and $r > 0$. When the bank borrows money from the market, it sells the bonds, i.e., the holding is negative and its borrowing cost is the risk-free rate.[10]

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

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

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

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

$$dS(t) = S(t)rdt + S(t)\sigma dW(t),$$

where $S(0) > 0$, $\sigma$ is the volatility and it satisfies $\sigma > 0$, and $W(t)$ is a standard Wiener process under $Q$. We denote by $\{F_t\}$ the information filtration generated by the Wiener process. Thus, $F_t$ is the information at time $t$.

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

$$dA(t) = A(t)rdt + A(t)\sigma_\theta dW(t), \tag{1}$$

where $A(t)$ is the equity value and $A(0) > 0$, levered volatility $\sigma_\theta = (1+\theta)\sigma$, and $\theta$ is the bank debt relative to the equity value. Thus,

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

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

We analyze how the levered volatility $\sigma_\theta$ affects the compensation value. Note again that $\sigma_\theta$ rises in $\theta$ and $\sigma$, i.e., the banker can increase risk by increasing the leverage and/or the risky asset volatility, and here we do not focus on the mechanism how the banker changes $\sigma_\theta$ (but clearly there are two ways).

From (1) we get

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

or

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

where $t_2 > t_1$.

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

$$\Pi(A(i\Delta), A((i-1)\Delta)) = k\max[A(i\Delta) - A((i-1)\Delta), 0] \tag{3}$$

for all $i \in \{1, 2, ..., n\}$, where $k \in (0, 1)$ and it represents the fraction of profits paid out as compensation to the banker, $\Delta$ is the time interval between the time points and $n\Delta = T$. Thus, at the end of each time interval the bank pays bonus to the banker if the net asset value has risen.

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

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

# 4 Value of the compensation

In this section we first analyze how the bonus frequency affects the compensation value and the banker's risk-taking incentives. More specifically, we model the incentives given the asset dynamics (1) and the bonuses (3), and do not consider explicitly the banker's effort in Section 4.1. After that we extend the model to include a bonus cap in Section 4.2.

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

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

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

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

Thus, $C(\Delta, K)$ is $\Delta$-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. Kou (2002)), and then this would change the pricing of $C(\Delta, K)$ and the rest of our analysis would be the same.

## 4.1 Compensation value without bonus cap

By the risk-neutral pricing and (3), the present value of the banker's compensation package is given by

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

Thus, the compensation package is a sequence of call option contracts. The number of contracts in the sequence depends on $\Delta$. For instance, if $\Delta = T$ then $\pi_1$ equals one call option with maturity date $T$. By (5) and iterated expectation, we get the following result.

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

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

*where $C(T/n, 1)$ is the call option price (4), $k$ is the fraction of profits paid out as compensation, and $A(0)$ is the initial net asset value.*

**Proof:** By (5) and iterated expectation, we get

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

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

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

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

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

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

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

Corollary 1 is a sufficient condition for $C(\Delta, 1)$ being increasing and concave for all $\Delta \in \left[0, \frac{T}{n}\right]$ and this guarantees $\pi_{n+1} \geq \pi_n$. Even though it is possible to find parameter values, where $C(\Delta, 1)$ is locally convex in $\Delta$,[11] we have not found a case, where the result ($\pi_{n+1} \geq \pi_n$) does not hold since this would require convexity for a wide range of $\Delta$ values.

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

$$\frac{\partial \pi_n}{\partial \sigma_\theta} = nkA(0)\frac{\partial C(T/n, 1)}{\partial \sigma_\theta} = nkA(0)\exp(-rT/n)\sqrt{T/n}\phi(d_2(T/n)), \tag{6}$$

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

**Corollary 2** *The sensitivity of the compensation value with respect to levered volatility $\sigma_\theta$ rises in the number of periods $n$:*

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

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

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

This gives

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

□

By Corollary 2, the shorter the time period $\Delta = T/n$ is, the stronger the effect of the levered volatility. This implies that bankers with short term compensation packages have a high incentive to increase leverage and/or their business risk. This is consistent with Gopalan et al. (2010; see prediction 2), according to which the pay duration is shorter for firms with more volatile cash flows.

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

Figure 1 illustrates the compensation value (Corollary 1) and risk-taking incentives (6) for the median bank in our sample, i.e., bonus vega ($\frac{\partial \pi_n}{\partial \sigma_\theta}$) with respect to the number of compensation time periods. Note that the higher the number, the shorter the compensation time interval $\Delta$. As can be seen, both the compensation value and the vega are positive and increasing in the number of periods. Thus, by our model and the numerical example of Figure 1, the higher the bonus payment frequency is, the higher the compensation value and the risk-taking incentives. However, vega is substantial only if the payment interval is shorter than one year; i.e., for $n$ larger than 10. The higher the levered volatility $\sigma_\theta$, the lower the critical bonus frequency under which vega starts to become substantial. For instance, if $\sigma_\theta$ is doubled then the critical frequency is less than every second year.

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

## 4.2 Compensation value with bonus cap

We next extend the model to include bonus cap. Let $M$ be the bonus cap for each $\Delta$-period, i.e., $M$ is the maximum bonus during the $\Delta$ periods. Then from Proposition 1 we get the following result.

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

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

*where $\Delta = T/n$, $A(0)$ is initial net asset value, $\sigma_\theta$ is the levered volatility, $r$ is the risk-free rate, $k$ is the fraction of profits paid out as compensation, $\{\varepsilon_i\}$ are independent standard normal variables, and $C(\Delta, K)$ is the call option price in* (4).

**Proof:** Let us consider $i$'th $\Delta$-period. By (3) and the definition of bonus cap, if $k\,[A(i\Delta) - A((i-1)\Delta)] \geq M$ then the bonus is capped at $M$. Therefore, we have the following bonus payoff:

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

where $\chi = M/k$ and $M$ is the maximum bonus during the $\Delta$ period.[12] By Proposition 1, the compensation value is the sum of expected discounted payoffs:

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

which with iterated expectations, (2), and (4) gives the result. □

# 5 Optimal risk level

In this section we solve the banker's optimal risk level by assuming that there is an increasing cost to risk-taking. The cost of risk-taking may arise from several sources such as market discipline, regulation, and the banker's own career concerns as a result of poor performance or, ultimately, bankruptcy. To understand the total effect of a policy change, both the cost of risk-taking and incentives to risk-taking need to be considered. That is, so far in this paper we have focused on the incentives and in order to do counterfactual analysis with changes in bonus regulation, we need to include the cost of risk-taking. In the current paper, we do not explicitly model the sources of the costs of risk-taking but by using generic cost functions.

By (1), the banker takes risk with high leverage $\theta$ and/or with low asset quality, i.e., with high risky asset volatility $\sigma$. We assume that the risk-taking cost is a function of

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

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

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

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

the levered volatility $\sigma_\theta$ which is the measure of risk-taking in our model. Further, we assume 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 the net value, i.e., the value of the compensation minus the cost:

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

where we wrote $\hat{\pi}_{n,M}$ explicitly as a function of levered volatility $\sigma_\theta = (1+\theta)\sigma$, $\Delta\sigma_\theta$ is the change of current $\sigma_\theta$, and $F(\cdot)$ is the cost of changing the levered volatility. The optimization constraint in (7) means that the levered volatility cannot be negative.

We use two alternative cost functions:

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

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

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

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

By our model, the total risk-taking incentive depends on the CEO's compensation and the cost of risk-taking. Therefore, the model implies that 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 banks' CEO bonuses and fixed salary at the end of 2006 did not predict the banks' stock price performance during the crisis of 2007-2008. Using the same data, we also do a similar test using the CEO's risk-taking incentive (vega) derived from Proposition 1, i.e., from the model without the risk-taking cost. Table 11 in Appendix B shows that the vega did not predict the banks' stock price returns during the crisis. Hence, this and the results in Fahlenbrach and Stulz (2011) are consistent with our model with the cost of risk-taking.

By (7), regulators have three ways to affect bankers' risk-taking: (*i*) limit compensation and in this way decrease bankers' incentive for risk taking (lower $M$ and/or decrease $n$), (*ii*) increase the cost of risk-taking (increase $c_+$), and (*iii*) increase the rewards of decreasing risk-taking (decrease $c_-$). Example of (*i*) is bankers' bonus cap in EU (European Union, 2013). Trading book's market risk requirement within the Basel capital adequacy framework is an example of (*ii*) since the more a bank trades or, more specifically, the higher its trading book's value-at-risk is, the more it should finance itself with equity capital. Basel II's risk-weights represent an example of (*iii*) since lowering the risk-weights of certain asset classes rewards banks to hold more those assets.

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

$$\hat{\sigma} \geq \sigma^*_{n,M}, \tag{8}$$

where the model optimal levered volatility is given by

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

Since we do not know $\hat{\sigma}$ and the parameters of the cost function $F$, we analyze (8) as follows. We use a sample of US banks' CEO bonus and accounting data from 2004 to 2006. The data is introduced in Section 6.1. We calculate the cost function parameters for each bank using one of the alternative cost functions and by assuming that at the end of 2006 the bank's risk level is in equilibrium in the sense that the bank does not want to change its levered volatility $\sigma_\theta$. That is, the cost function parameters are such that the levered volatility in 2006 of each bank equals the model's $\sigma^*_{T,\infty}$ in (8), i.e.,

$$\arg \max_{\Delta\sigma_\theta \geq -\sigma_\theta} \{ \tilde{\pi}_{n,M}(\sigma_\theta + \Delta\sigma_\theta) - F(\Delta\sigma_\theta) \} = 0,$$

where $\sigma_\theta$ is the levered volatility at the end of 2006. This condition gives as the range of cost function parameters and for both the cost functions above we select the smallest $c_+$ and the highest $c_-$, so that the above equilibrium condition holds. This means that we use the smallest penalty for risk increase and the smallest reward for risk decrease in our analyses. Given the cost function parameters, in the next section we study the effect of bonus regulation on the bank CEO's optimized $\sigma_\theta$.

# 6 Policy simulations

We use the calibrated model for studying the effect of a bonus cap and bonus deferral, applied separately or jointly, on the CEO's optimized risk level in terms of levered asset volatility $\sigma_\theta$. More specifically, we calculate five different cases with the alternative cost functions. The first three cases are (*i*) bonus cap equals CEO's base salary at 2006, i.e., we solve $\sigma^*_{T,S}$ in (8), where $S$ is the annual base salary; (*ii*) bonuses paid every second year, which gives $\sigma^*_{T/2,\infty}$; and (*iii*) bonuses paid every second year and bonus cap equals CEO's base salary during two years, i.e., $\sigma^*_{T/2,2S}$. All these cases are motivated by the current EU regulation regarding bonus policy (see European Union, 2013). Cases (*iv*) and (*v*) simply repeat cases (*ii*) and (*iii*) by considering bonuses that are paid every fifth year. Note that regarding the implementation of the bonus deferral policy we assume that the bonus cap is calculated based on the cumulative base salary over the bonus payment interval; one, two or five years. Further, note that for simplicity we ignore salary rises.

In Section 6.1, we first discuss the data used to calibrate the model parameters, and then in Section 6.2 the results concerning cases $(i) - (v)$ above and some further robustness checks are given.

## 6.1 Data

For calibrating the parameters of the cost functions introduced in Section 5 we use US bank data from the following sources. The CEO cash bonus data come from the Execucomp database. Variables needed in calculating bank risk-taking incentive measures (the vegas henceforth) are measured as follows. Parameter $k$ is the average of CEO cash bonus divided by net income in years 2004-2006. We use the average because a large part of the sample banks paid zero bonus in 2006 and this way we end up with 78 banks with non-zero average bonus payment. Asset return volatility $\sigma$ is the standard deviation of quarterly net income divided by the book value of assets from 2000Q1 to 2006Q4[13] and $\theta$ is debt over equity in book values at 2006Q4. For robustness, we also consider $\sigma$-estimate based on data from 2000Q1 to 2008Q4, i.e., we include the crisis of 2007-2008 to our sample. This can be viewed as a crude way to account for a possible forward-looking tail risk element in the banks earnings volatility projections at the end of 2006. By equation (1), $\sigma$ and $\theta$ give the levered earnings volatility $\sigma_\theta$. Table 1 shows that the estimated levered earnings volatility for an average bank almost triples when we use data until 2008Q4 instead of 2006Q4, so including the crisis period constitutes an important robustness check.

In the parameter estimation the $\Delta$ parameter, measuring the payment interval of bonuses, is set at one year. Parameter $T$, the remaining tenure of the CEO is estimated by taking the minimum of 10 years and the difference between the CEO's retirement age and current age. The retirement age is assumed to be common for all CEOs in the sample and is proxied by the highest CEO age in the data, which is 77 years. Admittedly, this is a crude proxy with which we settled in the absence of more detailed information of individual CEO contracts. The cap of 10 years on the remaining CEO tenure is motivated by studies on average CEO tenures.[14] However, as a robustness check, we also calibrate the model by assuming a CEO tenure cap of 15 years. All equity market information and bank balance sheet data come from Compustat and BankScope, and they form a balanced sample of 78 banks out of the 94 original sample banks.

## 6.2 Results

Tables 2 and 3 present the calibration results for the two alternative cost functions, the two alternative estimation periods of the levered earnings volatility, $\sigma_\theta$, and the two alternative assumptions concerning the CEO's maximum remaining tenure. The

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

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

parameters are calculated by assuming that the historical estimate of $\sigma_\theta$ is at optimal level for each bank. We note from Tables 2 and 3 that variation in the bank-specific cost parameters is very large in all cases considered. Further, we find that the cost parameters correlate positively with bank size; see Tables 2 and 3. This indicates that large banks find it more difficult to change their risk level. However, explaining the bank level risk-taking costs is beyond the scope of the present paper; instead, we focus on the effects of bonus deferrals and bonus caps on risk-taking incentives by taking the calibrated cost parameters as given.

Table 4 presents the policy simulation results concerning the adjustment in banks' optimal risk level in response either to the bonus cap, bonus deferral, or both. Table 5 presents the corresponding set of results but with the levered earnings volatility estimation period including the crisis years 2007-2008. By Table 4, the bonus cap reduces the average bank's risk level ($\sigma_\theta$) by 16.32% for the linear cost function and by 24.65% for the quadratic cost function, while the longer bonus payment frequency, even the five year case, has no visible effect. The bank-specific variation in the adjustment is very large, ranging from zero effect to roughly 99% reduction in risk level. When the bonus cap and the longer payment interval are considered jointly, Table 4 shows that in this case the risk level is in actuality reduced somewhat less than in the case in which the bonus cap is the only restriction. This difference results from the fact that multiplying the bonus cap when moving to the every second (or every fifth) year bonus payment constitutes a somewhat milder bonus restriction than the one-year bonus cap. In Table 5 we obtain qualitatively the same but somewhat more pronounced results which are due to the higher bank-specific earnings volatility estimates. In this case the bonus cap reduces the average bank's risk level ($\sigma_\theta$) by ca. 21.84% for the linear cost function and by 27.85% for the quadratic cost function, while the longer payment frequency still has no visible effect. Note that, by Tables 4 and 5, these findings are also robust with respect to the tenure cap.

To further illustrate the economic significance of the risk reduction achieved by the bonus cap that equals base salary, suppose a representative bank reduces its risk level by 20% which is roughly supported by our results. Suppose further that the bank does that solely by reducing its leverage. Assume the bank's earnings volatility is 0.0012 and its original debt to equity ratio is 96 to 4 so that its equity is at 4%. This would imply that the bank would increase its equity to 5%. This is not an insignificant change, but hardly alone accounting for the magnitude that regulators are currently targeting. Therefore, a bonus cap should be seen as a complementary tool to control banks' riskiness but not the only one (as is indeed the case in the regulatory reform package). Of course, our results suggest that for some banks the effect of the bonus cap is much stronger in terms of leverage decrease.

Next we take a closer look at the bank-specific risk reductions achieved by the bonus cap. Table 10 depicts in the last column the risk reduction for each individual bank in our sample, where the risk reduction is taken as the average per bank over 24 different cases in Tables 4 and 5.[15] Table 10 also depicts in the first column the total assets as a measure of bank size. Because bank size has a relatively high correlation with the cost of risk-taking (see Tables 2 and 3), it is interesting to see whether bank risk reduction is also related to bank size. We study this in Tables 6 and 7. The results show that bank size, when measured as the logarithm of total assets, is positively related to risk reduction, and the result is statistically significant especially when risk reduction is calculated by using the quadratic cost function. This may result from larger banks having higher risk-taking incentives, at least partly, due to the higher risk-taking costs, so that the bonus cap has the largest effect on them. Or it could be that large banks impose a high risk-taking incentive on their CEO because their equity holders prefer higher risk due to too-big-to-fail status and the resulting implicit government subsidy to their debt. These explanations are consistent with the relatively high positive correlation between the cost parameters and the vega (see Tables 2 and 3). Because the largest banks are typically the most crucial for financial stability (see Laeven et al. 2014), it is an important finding that the bonus cap would seem to have the biggest bite on their risk-taking.[16]

It is an important and also unexpected finding that bonus deferrals have so small

[15]The 24 cases are obtained by forming the following combinations: [$\sigma_\theta$ estimated until 2006 or $\sigma_\theta$ estimated until 2008] and [case I or III or V] and [case T cap 10 or T cap 15] and [linear cost function or quadratic cost function].

[16]We also tested whether risk reduction is related to bank stock performance during the crisis, or its product with bank size, which establishes a crude measure of a bank's systemic risk. However, these variables do not add robust explanatory power over and above bank size, although some of these measures are significant especially when we include the crisis period in the levered volatility estimation; see Tables 6 – 9.

effect on risk reduction according to our model. This can be seen from Figures 1 and 3; for the median bank bonus cap changes vega substantially but the bonus frequency has only effect if bonuses are paid more frequently than annually, i.e., more frequently than currently without the bonus regulation. That is, the current annual bonus frequency does not raise typical banks' risk-taking incentives. However, since some non-banks receive performance fee quarterly or even monthly, the bonus frequency might raise their risk-taking.

# 7 Conclusions

In this paper we have modeled future bonuses as a series of sequential call options on profits and show that if the cost of risk-taking is ignored bonuses provide the higher risk-taking incentive the shorter is the time between the bonus determination time points and the higher are the bonuses relative to the fixed pay. Then bankers total risk-taking incentive is a joint effect of compensation and risk-taking costs.

We calibrate our model to a sample of US banks and their CEOs' bonuses and show that increasing the effective bonus payment interval to two years from the standard one year has no material effect on risk-taking. However, the relationship between bonus payment interval and risk-taking is nonlinear in a way that lengthening the bonus payment interval would start to have an effect if the original interval were less than one year. Further, capping the bonus to be no larger than fixed salary - an equivalent of the new EU regulation - significantly reduces banks' risk level. For the median bank the risk reduction is 15-30% depending on the specific calibration. The bank-specific effect varies widely and we find some evidence that the bonus cap is most effective in larger banks.

# References

[1] Acharya, V. V., M. Pagano and P. F. Volpin (2014). "Seeking Alpha: Excess Risk Taking and Competition for Managerial Talent."European Corporate Governance

Institute-Finance Working Paper No. 398/2014; AFA 2012 Chicago Meetings Paper, available at http://ssrn.com/abstract=1786699

[2] Anderson, R. C. and D. R. Fraser (2000). "Corporate Control, Bank Risk-taking, and the Health of the Banking Industry." *Journal of Banking and Finance*, 24: 1383–1398.

[3] Balachandran, S., B. Kogut, and H. Harnal (2010). "The Probability of Default, Excessive Risk, and Executive Compensation: A Study of Financial Services Firms from 1995 to 2008." Columbia Business School Research Paper, available at http://ssrn.com/abstract=1914542

[4] Beatty, R. P. and E. J. Zajac (1994). "Managerial Incentives, Monitoring, and Risk Bearing: A Study of Executive Compensation, Ownership, and Board Structure in Initial Public Offerings." *Administrative Science Quarterly*, 39: 313–335.

[5] Bhagat, S. and B. J. Bolton (2013). "Misaligned Bank Executive Incentive Compensation." Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2277917

[6] Bhattacharyya, S. and A. K. Purnanandam (2011). "Risk-Taking by Banks: What Did We Know and When Did We Know It?" AFA 2012 Chicago Meetings Paper, available at http://ssrn.com/abstract=1619472

[7] Black, F. and M. Scholes (1973). "The Pricing of Options for Alternatives Stochastic Processes." *Journal of Political Economy*, 81(3): 637–654.

[8] Boyle, P. P. and W. R. Scott (2006). "Executive Stock Options and Concavity of the Option Price." *Journal of Derivatives*, 13: 72–84.

[9] Coles, J. L., N. D. Daniel, and L. Naveen (2006). "Managerial Incentives and Risk-Taking." *Journal of Financial Economics*, 79: 431–468.

[10] DeYoung, R., E. Y. Peng, and M. Yan (2013). "Executive Compensation and Business Policy Choices at U.S. Commercial Banks." *Journal of Financial and Quantitative Analysis*, 48(1): 165–196.

[11] Duffie, D. (2001). Dynamic Asset Pricing Theory. 3rd ed., Princeton University Press.

[12] Durre, A. C. J. and P. Giot (2005). "An International Analysis of Earnings, Stock Prices and Bond Yields. "ECB Working Paper No. 515, available at `http://ssrn.com/abstract=775426`.

[13] Edmans, A., X. Gabaix, T. Sadzik, and Y. Sannikov (2012). "Dynamic CEO Compensation." *Journal of Finance*, 67(5): 1603–1647.

[14] European Union (2013). Official Journal of the European Union, 27 June 2013, Article 94.

[15] Fahlenbrach, R. and R. M. Stulz (2011). "Bank CEO Incentives and the Credit Crisis." *Journal of Financial Economies*, 99: 11–26.

[16] Gopalan, R., T. Milbourn, F. Song, and A. V. Thakor (2010). "The Optimal Duration of Executive Compensation: Theory and Evidence." AFA 2012 Chicago Meetings Paper, available at SSRN: `http://ssrn.com/abstract=1656603`

[17] Grossman, S. J. and O. D. Hart (1983). "An Analysis of the Principal-Agent Problem." *Econometrica*, 51: 7–45.

[18] Haldane, A.G. (2009). "Banking on the State." BIS Review 139/2009, Bank for International Settlements.

[19] Holmstrom, B. (1979). "Moral Hazard and Observability." *Bell Journal of Economics*, 10(1): 74–91.

[20] Holmstrom, B. (1982). "Moral Hazard in Teams." *Bell Journal of Economics*, 13: 324–340.

[21] Holmstrom, B. (1983). "Equilibrium Long-Term Labor Contracts." *Quarterly Journal of Economics*, 98: 23–54.

[22] Holmstrom, B. (1999). "Managerial Incentive Problems: A Dynamic Perspective." *Review of Economic Studies*, 66(1): 169–182.

[23] Holmstrom, B. and P. Milgrom (1991). "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design." *Journal of Law, Economics, and Organization*, 7: 24–52.

[24] Holmstrom, B. and P. Milgrom (1994). "The Firm as an Incentive System." *American Economic Review*, 84(4): 972–991.

[25] Houston, J. F. and C. James (1995). "CEO Compensation and Bank Risk: Is Compensation in Banking Structured to Promote Risk Taking?" *Journal of Monetary Economics*, 36: 405–431.

[26] Inderst, R. and H. M. Mueller (2004). "Benefits of Broad-based Option Pay."AFA 2005 Philadelphia Meetings, available at `http://ssrn.com/abstract=631050`

[27] Kaplan, S. N. and B. A. Minton (2012). "How Has CEO Turnover Changed." *International Review of Finance*, 12: 57–87.

[28] Kou, S. G. (2002). "A Jump Diffusion Model for Option Pricing." *Management Science*, 48: 1086–1101.

[29] Korkeamaki, T., E. Liljeblom, and D. Pasternack (2013). "CEO's Total Wealth Characteristics and Implications on Firm Risk."Working Paper, Hanken School of Economics.

[30] Laeven, L. and R. Levine (2009). "Bank Governance, Regulation and Risk Taking." *Journal of Financial Economics*, 93: 259–275.

[31] Laeven, L., L. Ratnovski, and T. Hui (2014). Bank Size, Capital, and Systemic Risk: Some International Evidence. Available at SSRN: http://ssrn.com/abstract=2508910 or http://dx.doi.org/10.2139/ssrn.2508910

[32] Liikanen, E. (2012). "High-level Expert Group on Reforming the Structure of the EU Banking Sector: Final Report."Brussels, 2 Oct 2012.

[33] Low, A. (2009). "Managerial Risk-Taking Behavior and Equity-Based Compensation." *Journal of Financial Economics*, 92: 470–490.

[34] Merton, R. (1971). "Optimum Consumption and Portfolio Rules in a Continuous-Time Model." *Journal of Economic Theory*, 3: 373–413.

[35] Merton, R. (1974). "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates." *Journal of Finance*, 29: 449–470.

[36] Mueller, H. M. and R. Inderst (2005). "Keeping the Board in the Dark: CEO Compensation and Entrenchment."Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=811744.

[37] Murphy, K. J. (2012). "Pay, Politics and the Financial Crisis."Forthcoming in Economic Lessons from the Financial Crisis (edited by Alan Blinder, Andrew Lo and Robert Solow), Russell Sage Foundation.

[38] Myerson, R. (1982). "Optimal Coordination Mechanisms in Generalized Principal-Agent Problems." *Journal of Mathematical Economics*, 10: 67–81.

[39] Panageas, S. and M.M. Westerfield (2009). "High-Water Marks: High Risk Appetites? Convex Compensation, Long Horizons, and Portfolio Choice." *Journal of Finance*, 64: 1–36.

[40] Pathan, S. (2009). "Strong Boards, CEO Power and Bank Risk-Taking." *Journal of Banking and Finance*, 33: 1340–1350.

[41] Rajan, R. G. (2005). "Has Financial Development Made the World Riskier?"NBER Working Paper No. w11728, available at SSRN: http://ssrn.com/abstract=842464

[42] Rogerson, W. (1985). "The First-Order Approach to Principal-Agent Problems." *Econometrica*, 53: 1357–1368.

[43] Sannikov, Y. (2008). "A Continuous-Time Version of the Principal-Agent Problem." *Review of Economic Studies*, 75 (3): 957-984.

[44] Tung, F. and X. Wang (2012). "Bank CEOs, Inside Debt Compensation, and the Global Financial Crisis."Boston University School of Law Working Paper No. 11-49, available at http://ssrn.com/abstract=1570161

[45] Westman, H. (2014). "Crisis Performance of European Banks - Does Management Ownership Matter?" Bank of Finland Discussion Paper 28/2014

# Appendix A: Figures

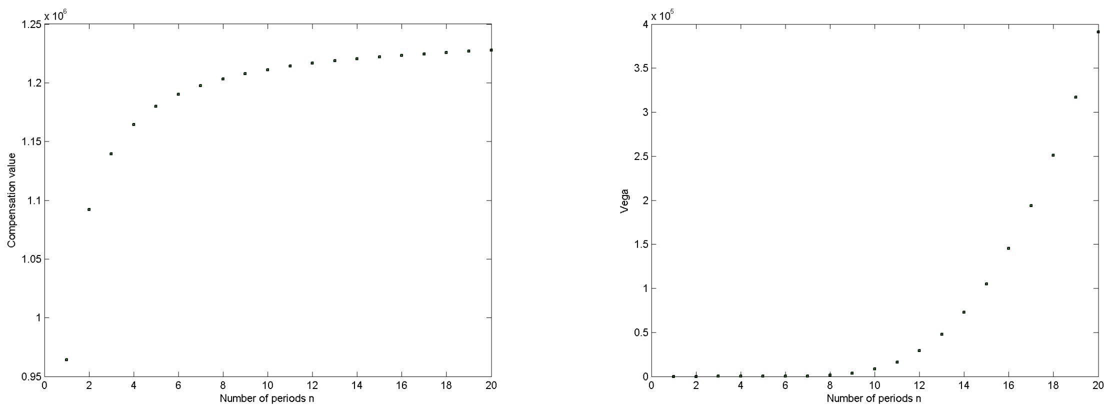


Figure 1: **Compensation value** $(\pi_n)$ **and the corresponding risk-taking incentive** $(\frac{\partial \pi_n}{\partial \sigma_\theta}$**, vega) with respect to the number of periods** $(n)$ **based on Proposition 1.** Parameter values for the median bank in our sample: $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.325\%$, $T = 10$, and $k = 0.0037$. The risk-free rate $r$ is the mean of monthly 1-year interest rate swaps in 2006.

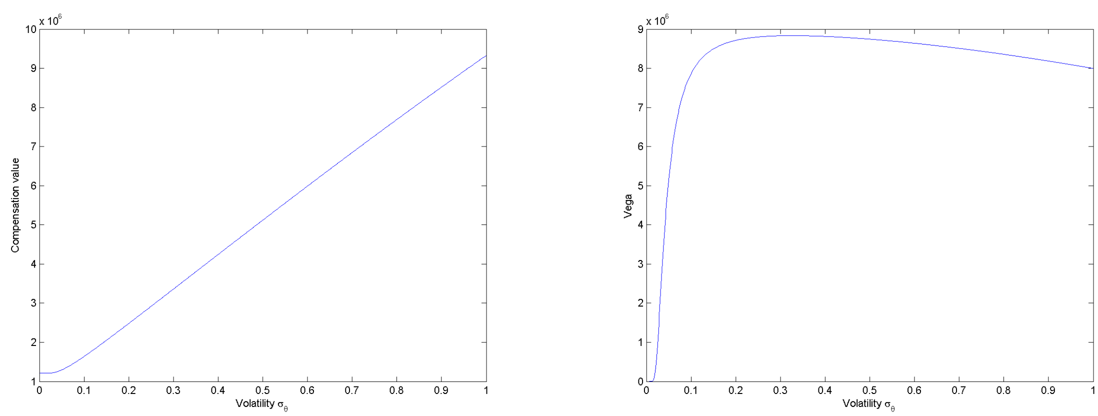


Figure 2: **Compensation value** $(\pi_n)$ **and the corresponding risk-taking incentive** $(\frac{\partial \pi_n}{\partial \sigma_\theta}$**, vega) with respect to the levered volatility** $(\sigma_\theta)$ **based on Proposition 1.** Parameter values for the median bank in our sample: $A(0) = 634,092,000$, $r = 5.325\%$, $T = 10$, $n = 10$, and $k = 0.0037$. The risk-free rate $r$ is the mean of monthly 1-year interest rate swaps in 2006.

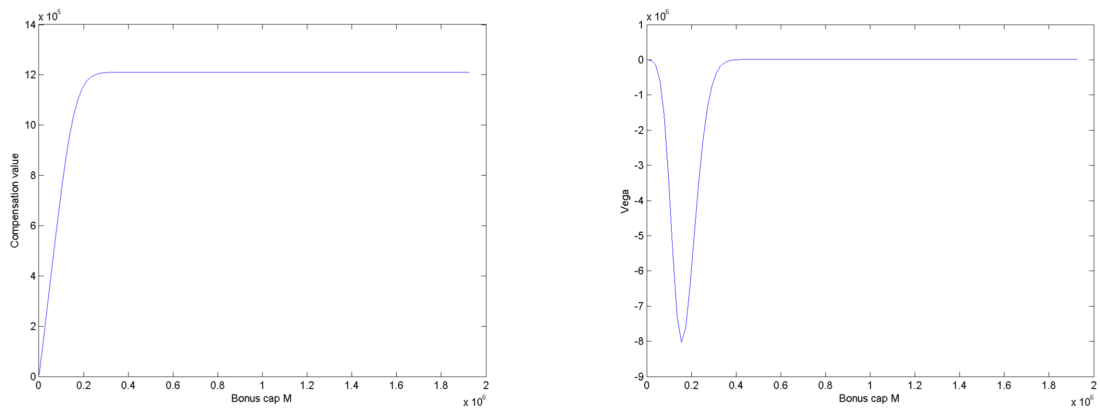


Figure 3: **Compensation value ($\tilde{\pi}_{n,M}$) and the corresponding risk-taking incentive ($\frac{\partial \tilde{\pi}_{n,M}}{\partial \sigma_\theta}$, vega) with respect to the bonus cap ($M$) based on Corollary 3.** Parameter values for the median bank in our sample: $A(0) = 634,092,000$, $\sigma_\theta = 0.0142$, $r = 5.325\%$, $T = 10$, $n = 10$, and $k = 0.0037$. The bonus cap $M$ considered in the figures is between 0 and 3 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.

# Appendix B: Tables

Table 1: **Summary statistics of cash bonus per net income and the levered volatility.** $k$ 2004 is the cash bonus per net income in 2004, average $k$ is the average cash bonus per net income during 2004-2006, $\sigma_\theta$ 2006 is the estimated levered volatility using the quarterly data from 2000Q1 to 2006Q4 and $\sigma_\theta$ 2008 is the estimated levered volatility using the quarterly data from 2000Q1 to 2008Q4.

| Variable | Nonzero obs. | Median | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|---|
| $k$ 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 |
| $\sigma_\theta$ 2006 | 84 | 0.0130 | 0.0166 | 0.0133 | 0.0034 | 0.0740 |
| $\sigma_\theta$ 2008 | 84 | 0.0281 | 0.0475 | 0.0456 | 0.0035 | 0.1748 |

Table 2: **Summary statistics of banks′ cost function parameters based on the levered volatility in 2006.** The levered volatility is the estimated levered volatility using the quarterly data from 2000Q1 to 2006Q4. The bank level cost parameters are such that under them, annual bonuses, and no bonus cap ($n = T, M = \infty$) the optimal $\Delta\sigma_\theta = 0$ in (7), i.e., the parameters are such that the bank does not want to change its risk. Bank size is defined as the natural logarithm of the total asset at 2006Q4. All the correlations are significant at 0.01% level.

| Cost function parameters | Linear function $c_+$ | Linear function $c_-$ | Quadratic function $c_+$ | Quadratic function $c_-$ |
|---|---|---|---|---|
| *Panel A: T cap 10* | | | | |
| Min | 61,950 | 40,565 | 61,950 | 40,565 |
| Max | 7,958,180,441 | 71,445,852 | 3,344,046,911,476 | 71,445,852 |
| Mean | 252,861,912 | 4,195,888 | 123,667,701,303 | 4,195,888 |
| Std | 1,004,099,576 | 8,863,071 | 474,710,596,528 | 8,863,071 |
| Corr with Bank size | 0.4660 | 0.6241 | 0.4836 | 0.6241 |
| Corr with Vega $\left(\frac{\partial \pi_{T,\infty}}{\partial \sigma_\theta}\right)$ | 0.9263 | 0.8351 | 0.9790 | 0.8351 |
| *Panel B: T cap 15* | | | | |
| Min | 92,926 | 60,848 | 92,926 | 60,848 |
| Max | 11,937,270,711 | 107,168,778 | 5,016,070,388,436 | 107,168,778 |
| Mean | 375,734,249 | 6,163,109 | 183,769,086,743 | 6,163,109 |
| Std | 1,505,535,477 | 13,286,411 | 711,797,536,252 | 13,286,411 |
| Corr with Bank size | 0.4672 | 0.6220 | 0.4846 | 0.6220 |
| Corr with Vega $\left(\frac{\partial \pi_{T,\infty}}{\partial \sigma_\theta}\right)$ | 0.9267 | 0.8387 | 0.9794 | 0.8387 |

Table 3: **Summary statistics of banks′ cost function parameters based on the levered volatility in 2008.** The levered volatility is the estimated levered volatility using the quarterly data from 2000Q1 to 2008Q4. Compared to Table 2 the years 2007 and 2008 have been added in the earnings volatility estimation period to account for a possible forward-looking tail risk element in banks earnings volatility projections at the end of 2006. The bank level cost parameters are such that under them, annual bonuses, and no bonus cap ($n = T, M = \infty$) the optimal $\Delta\sigma_\theta = 0$ in (7), i.e., the parameters are such that the bank does not want to change its risk. Bank size is defined as the natural logarithm of the total asset at 2006Q4. All the correlations are significant at 0.01% level.

| Cost function parameters | Linear function $c_+$ | Linear function $c_-$ | Quadratic function $c_+$ | Quadratic function $c_-$ |
|---|---|---|---|---|
| *Panel A: T cap 10* | | | | |
| Min | 235,472 | 40,565 | 235,472 | 40,565 |
| Max | 7,874,341,302 | 71,445,852 | 2,988,580,403,048 | 71,445,852 |
| Mean | 511,172,797 | 4,195,888 | 189,378,609,029 | 4,195,888 |
| Std | 1,147,524,019 | 8,863,071 | 420,351,067,500 | 8,863,071 |
| Corr with Bank size | 0.6301 | 0.6241 | 0.6216 | 0.6241 |
| Corr with Vega $\left(\frac{\partial \pi_{T,\infty}}{\partial \sigma_\theta}\right)$ | 0.9001 | 0.8351 | 0.9063 | 0.8351 |
| *Panel B: T cap 15* | | | | |
| Min | 353,207 | 60,848 | 353,207 | 60,848 |
| Max | 11,811,512,052 | 107,168,778 | 4,482,870,642,910 | 107,168,778 |
| Mean | 748,269,690 | 6,163,109 | 279,132,415,665 | 6,163,109 |
| Std | 1,716,650,986 | 13,286,411 | 630,136,124,623 | 13,286,411 |
| Corr with Bank size | 0.6311 | 0.6220 | 0.6209 | 0.6220 |
| Corr with Vega $\left(\frac{\partial \pi_{T,\infty}}{\partial \sigma_\theta}\right)$ | 0.9041 | 0.8387 | 0.9089 | 0.8387 |

Table 4: **Risk reduction of levered volatility $\sigma_\theta$ due to bonus cap $M$ and longer bonus interval $\Delta$ under different cost functions, maximum CEO tenure, and levered volatility in 2006.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2006Q4.

| | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case II: Bonus interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case IV: Bonus interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | | | | | |
| Min | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Max | 97.10% | 99.70% | 0.00% | 0.00% | 98.30% | 99.70% | 0.00% | 0.00% | 92.10% | 96.60% |
| Mean | 16.32% | 24.65% | 0.00% | 0.00% | 11.50% | 21.13% | 0.00% | 0.00% | 6.68% | 13.82% |
| Std | 31.27% | 37.99% | 0.00% | 0.00% | 26.37% | 34.71% | 0.00% | 0.00% | 21.16% | 28.05% |
| *Panel B: T cap 15* | | | | | | | | | | |
| Min | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Max | 95.60% | 99.90% | 0.00% | 0.00% | 91.90% | 99.40% | 0.00% | 0.00% | 95.40% | 99.00% |
| Mean | 19.30% | 34.00% | 0.00% | 0.00% | 12.67% | 26.77% | 0.00% | 0.00% | 7.95% | 19.01% |
| Std | 33.09% | 40.70% | 0.00% | 0.00% | 26.60% | 37.77% | 0.00% | 0.00% | 22.22% | 32.38% |

Table 5: **Risk reduction of levered volatility $\sigma_\theta$ due to bonus cap $M$ and longer bonus interval $\Delta$ under different cost functions, maximum CEO tenure, and levered volatility in 2008.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2008Q4. Compared to Table 4 the years 2007 and 2008 have been added in the earnings volatility estimation period to account for a possible forward-looking tail risk element in banks earnings volatility projections at the end of 2006.

| | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case II: Bonus interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,\infty}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case IV: Bonus interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,\infty}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | | | | | |
| Min | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Max | 98.90% | 99.90% | 0.00% | 0.00% | 98.30% | 99.70% | 0.00% | 0.00% | 95.90% | 98.00% |
| Mean | 21.84% | 27.85% | 0.00% | 0.00% | 17.99% | 26.36% | 0.00% | 0.00% | 12.86% | 23.65% |
| Std | 37.02% | 41.13% | 0.00% | 0.00% | 34.15% | 38.70% | 0.00% | 0.00% | 30.03% | 35.01% |
| *Panel B: T cap 15* | | | | | | | | | | |
| Min | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Max | 98.80% | 99.90% | 0.00% | 0.00% | 97.50% | 99.70% | 0.00% | 0.00% | 95.90% | 99.00% |
| Mean | 25.09% | 37.11% | 0.00% | 0.00% | 19.47% | 33.03% | 0.00% | 0.00% | 14.97% | 31.74% |
| Std | 39.12% | 43.47% | 0.00% | 0.00% | 34.62% | 41.71% | 0.00% | 0.00% | 31.30% | 39.07% |

Table 6: **Risk reduction and bank size under levered volatility in 2006.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2006Q4. Bank size is defined as the natural logarithm of the total asset at 2006Q4. The regression models: reduction of levered volatility = $\alpha$ + $\beta \cdot$ bank size + error. Robust standard errors are reported in parentheses. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively. Number of observations in all the regression models is 78.

| Dependent variable | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | |
| Constant | -0.5402** | -0.8710*** | -0.3705* | -0.7082*** | -0.1780 | -0.3760* |
| | (0.2203) | (0.2010) | (0.2122) | (0.2095) | (0.1688) | (0.2068) |
| Bank size | 0.0718 | 0.1141*** | 0.0496** | 0.0939*** | 0.0250 | 0.0525** |
| | (0.0236) | (0.0211) | (0.0230) | (0.0223) | (0.0182) | (0.0221) |
| $R^2$ | 0.1256 | 0.2147 | 0.0841 | 0.1741 | 0.0332 | 0.0834 |
| *Panel B: T cap 15* | | | | | | |
| Constant | -0.5010** | -0.8788*** | -0.2875 | -0.7780*** | -0.0755 | -0.3320 |
| | (0.2259) | (0.2213) | (0.2027) | (0.2190) | (0.1564) | (0.2282) |
| Bank size | 0.0709*** | 0.1245*** | 0.0423* | 0.1068*** | 0.0158 | 0.0533** |
| | (0.0240) | (0.0225) | (0.0217) | (0.0229) | (0.0164) | (0.0241) |
| $R^2$ | 0.1092 | 0.2225 | 0.0602 | 0.1902 | 0.0121 | 0.0645 |

Table 7: **Risk reduction, bank size, crisis return, and systemic risk under levered volatility in 2006.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2006Q4. Bank size is defined as the natural logarithm of the total asset at 2006Q4, crisis return is bank-level stock return from 2 Jul 2007 to 31 Dec 2008, and systemic risk is defined as the product of bank size and stock crisis return. The regression models: reduction of levered volatility = $\alpha + \beta_1 \cdot$ bank size + $\beta_2 \cdot$ crisis return + $\beta_3 \cdot$ systemic risk + error. Robust standard errors are reported in parentheses. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively. Number of observations in all the regression models is 75.

| Dependent variable | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | |
| Constant | -0.5774 | -1.0366*** | -0.4187 | -0.8526** | -0.3376 | -0.4974 |
| | (0.3787) | (0.3378) | (0.3672) | (0.3641) | (0.3156) | (0.3849) |
| Bank size | 0.0742* | 0.1324*** | 0.0530 | 0.1097** | 0.0416 | 0.0649 |
| | (0.0439) | (0.0395) | (0.0424) | (0.0425) | (0.0362) | (0.0446) |
| Crisis return | -0.1871 | -0.4004 | -0.2055 | -0.3582 | -0.3812 | -0.3279 |
| | (0.6138) | (0.5855) | (0.5959) | (0.6058) | (0.4607) | (0.6009) |
| Systemic risk | 0.0156 | 0.0433 | 0.0165 | 0.0383 | 0.0375 | 0.0321 |
| | (0.0692) | (0.0656) | (0.0669) | (0.0684) | (0.0514) | (0.0679) |
| $R^2$ | 0.1250 | 0.2177 | 0.0873 | 0.1756 | 0.0452 | 0.0849 |
| *Panel B: T cap 15* | | | | | | |
| Constant | -0.6972* | -1.0736*** | -0.4637 | -0.8861** | -0.2957 | -0.6018 |
| | (0.4050) | (0.3714) | (0.3504) | (0.4180) | (0.2847) | (0.4223) |
| Bank size | 0.0926* | 0.1447*** | 0.0614 | 0.1192** | 0.0410 | 0.0839* |
| | (0.0468) | (0.0423) | (0.0403) | (0.0486) | (0.0329) | (0.0487) |
| Crisis return | -0.4513 | -0.4748 | -0.4089 | -0.2583 | -0.4364 | -0.5729 |
| | (0.6301) | (0.5663) | (0.5718) | (0.6092) | (0.3982) | (0.6399) |
| Systemic risk | 0.0485 | 0.0490 | 0.0428 | 0.0291 | 0.0483 | 0.0641 |
| | (0.0705) | (0.0621) | (0.0636) | (0.0688) | (0.0440) | (0.0718) |
| $R^2$ | 0.1117 | 0.2242 | 0.0646 | 0.1887 | 0.0268 | 0.0736 |

Table 8: **Risk reduction and bank size under levered volatility in 2008.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2008Q4. Compared to Table 6 the years 2007 and 2008 have been added in the earnings volatility estimation period to account for a possible forward-looking tail risk element in banks earnings volatility projections at the end of 2006. Bank size is defined as the natural logarithm of the total asset at 2006Q4. The regression models: reduction of levered volatility = $\alpha + \beta \cdot$ bank size + error. Robust standard errors are reported in parentheses. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively. Number of observations in all the regression models is 78.

| Dependent variable | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | |
| Constant | -0.8319*** | -0.9670*** | -0.6621*** | -0.8936*** | -0.3122 | -0.5866** |
| | (0.2436) | (0.2141) | (0.2388) | (0.2252) | (0.2329) | (0.2497) |
| Bank size | 0.1073*** | 0.1272*** | 0.0860*** | 0.1182*** | 0.0450* | 0.0841*** |
| | (0.0260) | (0.0224) | (0.0256) | (0.0238) | (0.0250) | (0.0259) |
| $R^2$ | 0.1997 | 0.2276 | 0.1508 | 0.2218 | 0.0535 | 0.1372 |
| *Panel B: T cap 15* | | | | | | |
| Constant | -0.6320** | -0.9523*** | -0.5236** | -0.8547*** | -0.2682 | -0.5585** |
| | (0.2716) | (0.2398) | (0.2445) | (0.2485) | (0.2277) | (0.2777) |
| Bank size | 0.0902*** | 0.1352*** | 0.0734*** | 0.1210*** | 0.0427* | 0.0895*** |
| | (0.0288) | (0.0241) | (0.0261) | (0.0256) | (0.0242) | (0.0285) |
| $R^2$ | 0.1264 | 0.2301 | 0.1068 | 0.2003 | 0.0442 | 0.1247 |

Table 9: **Risk reduction, bank size, crisis return, and systemic risk under levered volatility in 2008.** The bank-level bonus cap is the CEO's salary in 2006 if the bonus interval is one year, the bank-level bonus cap is twice of the CEO's annual salary in 2006 if the bonus interval is two years, and the bank-level bonus cap is five times the CEO's annual salary in 2006 if the bonus interval is five years. $\sigma^*_{T,\infty}$ is the estimated levered volatility using the quarterly data from 2000Q1 to 2008Q4. Compared to Table 7 the years 2007 and 2008 have been added in the earnings volatility estimation period to account for a possible forward-looking tail risk element in banks earnings volatility projections at the end of 2006. Bank size is defined as the natural logarithm of the total asset at 2006Q4, crisis return is bank-level stock return from 2 Jul 2007 to 31 Dec 2008, and systemic risk is defined as the product of bank size and stock crisis return. The regression models: reduction of levered volatility = $\alpha + \beta_1 \cdot$ bank size + $\beta_2 \cdot$ crisis return + $\beta_3 \cdot$ systemic risk + error. Robust standard errors are reported in parentheses. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively. Number of observations in all the regression models is 75.

| Dependent variable | Case I: Bonus cap $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T,S}}{\sigma^*_{T,\infty}}\right)$ | | Case III: Bonus cap & interval of 2 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/2,2S}}{\sigma^*_{T,\infty}}\right)$ | | Case V: Bonus cap & interval of 5 years $\left(\frac{\sigma^*_{T,\infty}-\sigma^*_{T/5,5S}}{\sigma^*_{T,\infty}}\right)$ | |
|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *Panel A: T cap 10* | | | | | | |
| Constant | -0.8033** | -1.0955*** | -0.5193 | -0.9320** | -0.3133 | -0.5518 |
| | (0.3991) | (0.3595) | (0.3813) | (0.3845) | (0.3467) | (0.3886) |
| Bank size | 0.1016** | 0.1416*** | 0.0662 | 0.1214*** | 0.0410 | 0.0740 |
| | (0.0461) | (0.0412) | (0.0441) | (0.0445) | (0.0399) | (0.0449) |
| Crisis return | -0.0946 | -0.3213 | 0.0917 | -0.1833 | -0.1961 | -0.2259 |
| | (0.6144) | (0.6091) | (0.6098) | (0.6033) | (0.6551) | (0.6153) |
| Sytemic risk | 0.0027 | 0.0350 | -0.0220 | 0.0165 | 0.0079 | 0.0059 |
| | (0.0691) | (0.0682) | (0.0685) | (0.0680) | (0.0726) | (0.0674) |
| $R^2$ | 0.2016 | 0.2283 | 0.1657 | 0.2211 | 0.0777 | 0.1684 |
| *Panel B: T cap 15* | | | | | | |
| Constant | -0.8646** | -1.0635*** | -0.6257 | -0.8600** | -0.3238 | -0.5496 |
| | (0.4284) | (0.3768) | (0.3930 ) | (0.4201) | (0.3357) | (0.4326) |
| Bank size | 0.1151** | 0.1454*** | 0.0826* | 0.1183** | 0.0467 | 0.0816 |
| | (0.0490) | (0.0425) | (0.0452) | (0.0483) | (0.0387) | (0.0497) |
| Crisis return | -0.5707 | -0.3556 | -0.3367 | -0.1304 | -0.2317 | -0.2786 |
| | (0.7263) | (0.5947) | (0.6889) | (0.6196) | (0.6350) | (0.6415) |
| Sytemic risk | 0.0584 | 0.0332 | 0.0296 | 0.0066 | 0.0172 | 0.0112 |
| | (0.0808) | (0.0634) | (0.0766) | (0.0679) | (0.0700) | (0.0695) |
| $R^2$ | 0.1298 | 0.2298 | 0.1102 | 0.2050 | 0.0531 | 0.1520 |

Table 10: **Bank-level average risk reduction based on Cases I, III, and V in Tables 4 and 5.** Stock crisis return is bank-level stock return from 2 Jul 2007 to 31 Dec 2008 and systemic risk is defined as the product of bank size and stock crisis return. Bank size is defined as the natural logarithm of the total asset at 2006Q4. The correlation between stock crisis return and reduction of $\sigma_\theta$, bank size, and systemic risk are -0.1570, -0.3416***, and 0.9683*** respectively; the correlation between reduction of $\sigma_\theta$ and bank size, systemic risk are 0.3992*** and -0.2133* respectively; the correlation between bank size and systemic risk is -0.5250***. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively.

| Bank name | Total asset ($ million), 2006 | Stock crisis return,% | Systemic risk | Reduction of $\sigma_\theta$,% |
|---|---|---|---|---|
| U S BANCORP | 219,232.00 | -24.65 | -3.03 | 95.28 |
| BOSTON PRIVATE FINL HOLDINGS | 5,763.54 | -75.23 | -6.51 | 94.45 |
| PNC FICIAL SVCS GROUP INC | 101,820.00 | -33.01 | -3.81 | 92.78 |
| KEYCORP | 92,337.00 | -75.72 | -8.66 | 91.85 |
| UNITED COMMUNITY BANKS INC | 7,101.25 | -47.61 | -4.22 | 91.28 |
| STERLING FICIAL CORP/WA | 9,828.65 | -69.55 | -6.39 | 88.28 |
| WASHINGTON MUTUAL INC | 346,288.00 | -100.00 | -12.76 | 86.51 |
| REGIONS FICIAL CORP | 143,369.02 | -76.51 | -9.08 | 75.05 |
| NORTHERN TRUST CORP | 60,712.20 | -19.50 | -2.15 | 71.43 |
| EAST WEST BANCORP INC | 10,823.71 | -58.94 | -5.47 | 68.72 |
| HUDSON CITY BANCORP INC | 35,506.58 | 29.44 | 3.08 | 68.27 |
| SOUTH FICIAL GROUP INC | 14,210.52 | -81.06 | -7.75 | 67.79 |
| INVESTORS FICIAL SVCS CP | 11,558.21 | 40.03 | 3.74 | 61.66 |
| TD BANKNORTH INC | 40,159.09 | | | 60.10 |
| SVB FICIAL GROUP | 6,081.45 | -51.09 | -4.45 | 58.50 |
| MARSHALL & ILSLEY CORP | 56,230.26 | -71.60 | -7.83 | 53.54 |
| COMMERCE BANCORP INC/NJ | 45,271.82 | 1.95 | 0.21 | 49.99 |
| WACHOVIA CORP | 707,121.00 | -89.41 | -12.04 | 47.40 |
| BANK OF AMERICA CORP | 1,459,737.00 | -71.45 | -10.14 | 41.22 |
| BANK OF NEW YORK MELLON CORP | 103,370.00 | -35.98 | -4.15 | 40.52 |
| SUNTRUST BANKS INC | 182,201.61 | -66.08 | -8.00 | 35.30 |
| WELLS FARGO & CO | 481,996.00 | -16.98 | -2.22 | 25.29 |
| TRUSTCO BANK CORP/NY | 3,161.19 | -4.61 | -0.37 | 25.12 |
| WILMINGTON TRUST CORP | 11,157.00 | -46.96 | -4.38 | 23.31 |
| ZIONS BANCORPORATION | 46,970.23 | -68.52 | -7.37 | 21.32 |
| NATIONAL CITY CORP | 140,190.84 | -94.69 | -11.22 | 16.63 |
| HANMI FICIAL CORP | 3,725.24 | -88.09 | -7.24 | 14.61 |
| FIRSTMERIT CORP | 10,252.57 | -2.88 | -0.27 | 11.79 |
| JPMORGAN CHASE & CO | 1,351,520.00 | -35.85 | -5.06 | 11.56 |
| COMERICA INC | 58,001.00 | -67.40 | -7.39 | 11.26 |
| CASCADE BANCORP | 2,249.31 | -71.22 | -5.50 | 7.98 |
| CATHAY GENERAL BANCORP | 8,026.51 | -30.09 | -2.70 | 7.35 |
| MERCANTILE BANKSHARES CORP | 17,716.03 | | | 5.28 |
| UCBH HOLDINGS INC | 10,346.41 | | | 4.51 |
| POPULAR INC | 47,403.99 | -67.89 | -7.31 | 4.14 |
| SYNOVUS FICIAL CORP | 31,854.77 | -73.29 | -7.60 | 3.44 |
| WEBSTER FICIAL CORP | 17,097.47 | -80.86 | -7.88 | 1.92 |
| BB&T CORP | 121,351.00 | -33.70 | -3.95 | 1.90 |
| CITY NATIONAL CORP | 14,884.38 | -36.67 | -3.52 | 1.73 |
| BBVA COMPASS BANCSHARES INC | 34,199.76 | 23.55 | 2.46 | 1.71 |
| UMPQUA HOLDINGS CORP | 7,344.24 | -38.50 | -3.43 | 1.39 |
| ASSOCIATED BANC-CORP | 20,861.38 | -36.27 | -3.61 | 0.96 |
| CORUS BANKSHARES INC | 10,057.79 | -93.37 | -8.61 | 0.28 |
| TCF FICIAL CORP | 14,669.73 | -51.23 | -4.91 | 0.23 |
| FIRSTFED FICIAL CORP/CA | 9,295.59 | -96.99 | -8.86 | 0.13 |
| PROSPERITY BANCSHARES INC | 4,586.77 | -10.79 | -0.91 | 0.04 |
| BANK OF HAWAII CORP | 10,571.82 | -13.58 | -1.26 | 0.00 |
| CULLEN/FROST BANKERS INC | 13,224.19 | -5.78 | -0.55 | 0.00 |
| DOWNEY FICIAL CORP | 16,209.39 | -99.85 | -9.68 | 0.00 |
| FIFTH THIRD BANCORP | 100,669.00 | -79.54 | -9.16 | 0.00 |
| M & T BANK CORP | 57,064.91 | -47.11 | -5.16 | 0.00 |
| HUNTINGTON BANCSHARES | 35,329.02 | -66.09 | -6.92 | 0.00 |
| STERLING BANCORP/NY -OLD | 1,885.96 | -12.31 | -0.93 | 0.00 |
| FIRST MIDWEST BANCORP INC | 8,441.53 | -44.19 | -3.99 | 0.00 |
| COLONIAL BANCGROUP | 22,784.25 | -91.82 | -9.21 | 0.00 |
| WESTAMERICA BANCORPORATION | 4,769.34 | 13.41 | 1.14 | 0.00 |
| CENTRAL PACIFIC FICIAL CP | 5,487.19 | -70.07 | -6.03 | 0.00 |
| CHITTENDEN CORP | 6,431.80 | 17.51 | 1.54 | 0.00 |
| FIRST BANCORP P R | 17,390.26 | 1.00 | 0.10 | 0.00 |
| GLACIER BANCORP INC | 4,467.74 | -7.80 | -0.66 | 0.00 |
| FIRST INDIANA CORP | 2,162.11 | 68.40 | 5.25 | 0.00 |
| INDEPENDENT BANK CORP/MI | 3,429.90 | -87.26 | -7.10 | 0.00 |
| PROVIDENT BANKSHARES CORP | 6,295.89 | -70.86 | -6.20 | 0.00 |
| WASHINGTON FEDERAL INC | 9,069.02 | -38.56 | -3.51 | 0.00 |
| FIRST FINL BANCORP INC/OH | 3,301.60 | -18.06 | -1.46 | 0.00 |
| SUSQUEHANNA BANCSHARES INC | 8,225.13 | -29.48 | -2.66 | 0.00 |
| UNITED BANKSHARES INC/WV | 6,717.60 | 3.04 | 0.27 | 0.00 |
| IRWIN FICIAL CORP | 6,237.96 | -91.37 | -7.98 | 0.00 |
| MAF BANCORP INC | 11,120.50 | 30.91 | 2.88 | 0.00 |
| ANCHOR BANCORP WISCONSIN INC | 4,539.69 | -89.50 | -7.54 | 0.00 |
| STERLING BANCSHARES INC/TX | 4,117.56 | -46.67 | -3.88 | 0.00 |
| ASTORIA FICIAL CORP | 21,554.52 | -34.81 | -3.47 | 0.00 |
| GREATER BAY BANCORP | 7,371.13 | 22.02 | 1.96 | 0.00 |
| DIME COMMUNITY BANCSHARES | 3,173.38 | 0.91 | 0.07 | 0.00 |
| WILSHIRE BANCORP INC | 2,008.48 | -26.36 | -2.00 | 0.00 |
| BROOKLINE BANCORP INC | 2,373.04 | -6.91 | -0.54 | 0.00 |
| FIRST NIAGARA FICIAL GRP | 7,945.53 | 21.67 | 1.95 | 0.00 |
| BANK MUTUAL CORP | 3,451.39 | -0.43 | -0.04 | 0.00 |

Table 11: **Bank buy-and-hold returns ("crisis return" from 2 Jul 2007 to 31 Dec 2008).** The estimated models are of the form: *crisis return* $= constant + \sum_i \beta_i x_i + \varepsilon$, where constant is the first row of the table, $x_i$ is the $i$'th explanatory variable measured at the end of 2006, $\beta_i$ is the slope coefficient of $x_i$ and it is reported in the $(i+1)$'th row of the table, and $\varepsilon$ is an error term. The risk-taking incentive is measured as the model vega ($\frac{\partial \pi_n}{\partial \sigma_\theta}$, equation (6)). CEO tenure (cap 10) is parameter $T$ with 10 year tenure cap and vega 2006 (cap 10) is the corresponding model vega. Different columns correspond to different regression models with different explanatory variable sets. Regression models (4)A.2 - (4)G have the same sample of banks. Robust standard errors are reported in parentheses. Statistical significance at the 1%, 5%, or 10% level is indicated by ***, **, and *, respectively.

| | (4)A.1 | (4)A.2 | (4)B | (4)C | (4)D | (4)E | (4)F | (4)G |
|---|---|---|---|---|---|---|---|---|
| Constant | -0.0085 | -0.6299** | -0.3768 | -0.6244** | -0.6502** | -0.6314* | -0.7496 | -0.7855* |
| | (0.2742) | (0.3131) | (0.3527) | (0.3055) | (0.3189) | (0.3672) | (0.4828) | (0.3955) |
| Vega 2006 | 3.70E-07 | 1.53E-06 | 1.78E-06 | -2.28E-06 | 1.53E-06 | 1.54E-06 | 1.53E-06 | 1.71E-06 |
| (cap 10) | (5.77E-07) | (3.25E-06) | (3.14E-06) | (6.54E-06) | (3.30E-06) | (3.30E-06) | (3.34E-06) | (3.33E-06) |
| Cash bonus per | 25.9756 | 14.9919 | 16.4440 | 16.7405 | 14.5235 | 14.9419 | 12.6661 | 18.6147 |
| net income, $k$ | (15.7032) | (18.6139) | (18.7932) | (18.8132) | (18.1735) | (19.5358) | (20.7289) | (20.1046) |
| CEO tenure | -0.0277 | -0.0123 | -0.0001 | -0.0121 | -0.0124 | -0.0129 | -0.0114 | -0.0099 |
| (cap 10), $T$ | (0.0189) | (0.0160) | (0.0171) | (0.0149) | (0.0168) | (0.0174) | (0.0162) | (0.0148) |
| CEO tenure | -0.0121 | -0.0066 | -0.0060 | -0.0072 | -0.0059 | -0.0066 | -0.0061 | -0.0056 |
| until end 2006 | (0.0083) | (0.0093) | (0.0095) | (0.0096) | (0.0097) | (0.0095) | (0.0094) | (0.0098) |
| Levered earnings | -0.0970* | -1.7346 | -1.9707 | 0.4098 | -1.7228 | -1.7381 | -1.6860 | -1.8985 |
| volatility, $\sigma_\theta$ | (0.0576) | (2.2346) | (2.1721) | (4.0308) | (2.2816) | (2.2821) | (2.3152) | (2.3192) |
| Book equity, $A$ | -2.83E-06** | -2.46E-06* | -2.97E-06** | -5.49E-06 | -2.47E-06** | -2.46E-06* | -2.13E-06 | -2.28E-06* |
| | (1.32E-06) | (1.24E-06) | (1.21E-06) | (4.22E-06) | (1.20E-06) | (1.25E-06) | (1.52E-06) | (1.24E-06) |
| Leverage, $\theta$ | -0.0252 | 0.0216 | 0.0119 | 0.0167 | 0.0157 | 0.0217 | 0.0247 | 0.0208 |
| | (0.0163) | (0.0256) | (0.0286) | (0.0250) | (0.0310) | (0.0285) | (0.0280) | (0.0266) |
| Market-to-book | 0.1109 | 0.1053 | 0.0986 | 0.1093 | 0.1241 | 0.1056 | 0.1030 | 0.1018 |
| equity ratio | (0.0677) | (0.0780) | (0.0770) | (0.0810) | (0.0874) | (0.0847) | (0.0819) | (0.0799) |
| Real estate loans/ | | | -0.4078 | | | | | |
| total loans | | | (0.3607) | | | | | |
| Trading assets/ | | | | 3.0156 | | | | |
| total assets | | | | (3.5621) | | | | |
| Nonperforming | | | | | 1.2736 | | | |
| loans/total loans | | | | | (2.9257) | | | |
| Liquidity ratio (average | | | | | | -0.0171 | | |
| cash/average assets) | | | | | | (0.7267) | | |
| Deposit ratio | | | | | | | 0.1467 | |
| (deposit/total assets) | | | | | | | (0.4059) | |
| Cost-income ratio | | | | | | | | 0.3576 |
| | | | | | | | | (0.5918) |
| No. of obs | 67 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| $R^2$ | 0.2143 | 0.1837 | 0.2193 | 0.1951 | 0.1870 | 0.1837 | 0.1852 | 0.1903 |