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Optimal Regulation, Executive Compensation and Risk Taking by Financial Institutions

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Abstract

We present an equilibrium model of financial institutions in which we examine the optimal regulation of risk taking. Shareholders set compensation to create incentives for management to choose excessive risk levels. To prevent such high levels, regulators use caps on asset risk (traditional bank supervision) and on pay (regulation of compensation) to achieve the socially optimal level of risk. We show that (1) without regulation, equilibrium risk will be higher than the optimal social level; (2) socially optimal risk is procyclical; (3) if there is perfect information using either policy tool can achieve the optimal level of risk; (4) if enforcement is limited or information is asymmetric, direct bank supervision is the more robust policy tool, though social welfare can be improved by employing both policy tools.

Keywords: bank regulation; financial institutions; executive compensation; risk taking; financial crises.

JEL codes: G21, G28.

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1 Introduction

Excessive risk taking by financial institutions was one of the major causes of the 2008 financial crisis (Brunnermeier [2009]). However, there are two main schools of thought as to the factors that brought about the observed increase in asset risk and resulting impairment of financial stability. The first focuses on supervisory inertia and argues that there may have been inadequate regulation and lax supervision and enforcement of existing laws and regulations (Blanchard [2008]; Caprio et al. [2010]; Delis and Staikouras [2011]). The second focuses on executive pay with a dominant component of equity based compensation (Bebchuk et al. [2010a]; Bolton et al. [2015]).

In response to the crisis and its potential causes, policymakers initiated reforms designed to increase the resilience of financial institutions and markets. The Basel III Accord (2011) adopted more stringent regulations regarding the level and quality of capital requirements, risk management, and compensation practices. The Dodd-Frank Wall Street Reform and Consumer Protection Act (2010) prohibits financial institutions from adopting any incentive plan that regulators determine encourages inappropriate risk taking by financial institutions.[1] In 2013, the European Union adopted a provision that limits the amount of bankers' bonuses to the amount of fixed remuneration.

The debate about causes of the crisis and the subsequent regulatory responses highlight important unresolved questions. What is the socially optimal level of risk for financial institutions? How can the regulator best employ the available policy tools to achieve this risk level? In particular, should regulation focus on traditional regulatory policy tools such as direct control of bank risk taking or should it instead cap executive pay?

We address these questions in the context of an equilibrium model of optimal regulation of financial institutions. The socially optimal level of asset risk trades off the benefits to

[1] See the Consumer Protection Act (2010) Section 956 part (b). Greenwood et al. [2017] point out that the regulation of compensation should be simplified.

society from having a well-functioning banking system and the costs that result from the banking system being in distress. We identify conditions under which the socially optimal level of risk is achieved and characterize cases where constraints on enforcement or imperfect information mean that instead a second best level of volatility is realized. Our model provides a setting that enables us to consider the effects of both supervisory inertia and executive pay on risk-taking and thus allows for a better understanding and interpretation of recent events in the financial sector. Our model also has normative policy implications. Specifically, we determine the optimal design of prudential regulation under different scenarios, including cases where employing a combination of policy tools is optimal.

There are three active stakeholders in our model: regulators, stockholders, and management. Each of these act strategically to maximize their payoffs (wealth or social welfare) by, directly or indirectly, affecting the equilibrium level of asset risk. Stockholders determine executive pay in the form of an ownership share awarded to management, who choose the level of asset risk. The regulator sets limits on asset risk and/or executive compensation.

We measure stakeholders' wealth and social welfare in an option pricing framework. This setting allows us to use well-known intuition and results about the sensitivity of option strategies to changes in volatility.[2] Evaluating the effects of changes in asset risk on stakeholders' objectives is thus straightforward and transparent. Our approach is market-value based, in line with work that uses contingent claims pricing to analyze the activity of financial institutions (e.g. Merton [1989], Hugonnier and Morellec [2017], Gornall and Strebulaev [2013], and Sundaresan and Wang [2015]). While our method departs from the traditional utility based approach (Diamond and Dybvig [1983]; Acharya et al. [2016]; Acharya and Volpin [2010], Albuquerque et al. [2016]), it follows the convention in the empirical literature where the risk taking motivation of an executive is measured by the Vega of its equity based compensation, calculated using the standard Black and Scholes [1973] and Merton [1974]

[2]See, for example, Hull [2016].

option pricing models (Low [2009]; and Coles et al. [2006]).

The stakeholder positions are as follows. Management's position has two components. The first is equity-based compensation, which increases with bank asset value. The second component is a loss due to bank failure. This component may include "inside debt," an executive's uninsured pension benefits that would be foregone (Edmans and Liu [2011]; Sundaram and Yermack [2007]; Bolton et al. [2015]), reputation costs (Fama [1980]; Hirshleifer and Thakor [1992]), and loss of specific human capital (Gilson [1989]; Graham et al. [2013]; Raviv and Sisli-Ciamarra [2013]). The two components have opposite sensitivities to changes in asset risk and so, depending on their relative importance, management will have an incentive to increase risk, decrease risk, or target a specific level.

The stockholder is a residual claimholder and the value of her position increases with asset value and asset risk (Jensen and Meckling [1976]; Galai and Masulis [1976]). Stockholders award management compensation packages that provide sufficient incentives for executives to choose the highest possible level of asset risk. This means that unless there is a limit on compensation, a regulatory limit on asset risk will be binding.

The public, as represented by a benevolent regulator, has a position made up of two components. The first is a positive payoff from the social welfare created by a well-functioning banking system (Demirgüç-Kunt and Maksimovic [1998]; Gertler [1998]). The second component is a negative payoff when banks do poorly (fail); this captures the social deadweight cost of financial distress (Shleifer and Vishny [2010]) and Stulz [2016]). The level of asset risk that optimally trades off these two components is socially optimal. In an effort to reach this optimal level the regulator avoids putting in place regulation that may result in either excessive risk-taking or risk avoidance ("credit freeze").

Our model has several implications. First, without regulation, equilibrium asset risk will be set above the socially optimal level. Effective regulation needs to counteract the tendency of shareholders to set compensation incentivizing executives to choose excessive risk levels.

Second, the effectiveness of policy tools arises from the effectiveness of their enforcement. If the regulator can perfectly enforce bounds on asset risk, she will choose the socially optimal level and this level is achieved in equilibrium. If enforcement is limited (supervisory inertia),[3] equity based compensation and risk taking are excessive, resulting in an equilibrium with suboptimal social welfare. Indeed, prior to the 2008 crisis, compensation levels and risk taking were elevated. Our analysis demonstrates that excessive risk taking is a result of *both* supervisory inertia and the structure of executive pay packages. The results are consistent with Stulz [2016], where better governance by stockholders may not make banks safer. Stockholders simply set compensation to align management's incentive with their own. Both benefit from the inability of regulators to tightly control risk and social welfare suffers.

Given the evidence on the restricted regulatory ability to enforce bounds on asset risk, we consider an alternative regulatory tool: a cap on equity based compensation (ownership). The effectiveness of such a cap also depends on enforcement capabilities. If enforcement is perfect the resulting equilibrium solution is identical to the case of a perfectly enforced regulatory upper bound on asset risk. However, when enforcement is limited, asset volatility may rise substantially, with severe adverse effects on social welfare. When enforcement is limited, capping compensation is thus a less robust policy tool than capping asset risk.

Third, the optimal level of risk is procyclical. This pattern reflects the procyclical expected benefits of a well-functioning banking system and the countercyclical expected costs of financial distress. During bad times, when leverage increases, the socially optimal level of risk decreases. There is thus value from dynamically adjusting regulation of financial institutions to changes in the leverage ratio. A lower level of risk can be achieved through either a reduction of the upper bound on allowable risk or by a stricter cap on compensation.

Fourth, if there are frictions, using both policy tools can be welfare improving. This is

[3] This case is probably more realistic because, over the last few decades, as the size and complexity of financial firms have increased, the ability of regulators to control bank asset risk has become more difficult (Berger et al. [2000]; DeYoung et al. [2001]).

the case if the regulator is unable to update regulatory policy tool levels continuously. It is also true if there are information frictions. Management's choice of asset risk depends on the losses it incurs in the case of bankruptcy. That loss has intangible components that are difficult to estimate, and insiders, who are in general better informed, will have more accurate estimates of the relevant losses than regulators. If there is asymmetric information, the cap on compensation may be set incorrectly and result in a large reduction of social welfare due to a suboptimally high level of equilibrium asset risk. In this situation it is beneficial to add the more robust direct regulatory cap on asset risk.

Our work contributes to the literature on regulation of bankers' pay and its interaction with more traditional regulatory measures. Jensen and Meckling [1976] consider the general conflict between executives and debtholders and show that an executive who is paid in equity will be motivated to increase risk if debtholders cannot control the investment choice after debt has been issued. Sundaram and Yermack [2007] consider incentives to increase risk in the presense of inside debt.[4] Such risk shifting is common in banks since creditors' ability to limit it is restricted. Creditors are small and dispersed and bondholders may have explicit (deposit insurance) or implicit (too big to fail) guarantees (Allen et al. [2015] and Anginer et al. [2014]).

John et al. [2000] show that bank risk-taking can be moderated by making deposit insurance premia a direct function of the compensation contract. Bolton et al. [2015] show that linking CEO compensation to firm default risk can reduce risk-taking. Kolm et al. [2016] study the effect of regulation of pay in the presence of boards of directors and capital requirements. Eufinger and Gill [2016] link the regulation of pay to capital requirements and the price of deposit insurance. Thanassoulis and Tanaka [2016] focus on the introduction of clawbacks out of executive pay packages forcing executives to bear losses if bad outcomes

[4] We expand this framework to include equity based compensation other than stock, consider the effect of leverage on risk-taking, and introduce a regulator who aims to maximize social welfare.

are realized. These papers do not model the interactions of regulators, shareholders, and management, something that the following papers do incorporate.

Chaigneau [2013] points out that regulators can affect bank risk-taking by either imposing bounds on equity-based compensation or by sanctioning CEOs of failed banks. Gale et al. [2017] model the behavior of policy makers and stockholders and also find that regulation is needed to curb excessive risk taking. Our approach differs from all of these papers since we analyze the effects of enforcement limits and informational frictions on deviations from socially optimal risk levels, the determinants of which we model directly. Furthermore, these papers do not use a market-value based option pricing framework that makes transparent the incentives to change asset risk. In contrast, authors make specific assumptions about preferences, where usually banks are risk-neutral and managers are risk-averse, while our model analyzes the incentives and actions resulting from the stakeholders' claims.[5]

The rest of the paper is organized as follows: Section 2 presents our framework, the risk-taking motivations of all stakeholders, and the valuation of their claims (positions). Section 3 presents equilibrium results for the case of a regulatory cap on asset risk or executive ownership and considers the effect of changes in leverage. Section 4 shows that, in the presence of informational or policy-enforcement frictions, using both policy tools can be welfare improving. Section 5 concludes.

2 Decision makers: their positions and sensitivities to changes in asset risk

We begin by describing the claimholders' positions. We specify the payoff of each claimholder (the public, represented by the regulator, stockholders, and executives) that depend on the

[5]Some papers argue that excessive risk-taking by managers is a result of competition between risk-neutral banks and talented bankers who are risk-averse (Acharya et al. [2016], Acharya and Volpin [2010], Thanassoulis [2012].

value of the bank's assets, and then analyze how their respective values depend on asset risk. To demonstrate the theoretical results, we calibrate the model to parameters that are typical for US banks over the period before and during the 2008 crisis. The base case parameters are described in Table 1 and their choice is discussed in the appendix.

We consider a financial institution that is financed by equity, S, insured deposits maturing at time T with face value F^D, and subordinated debt with face value F^S and with the same maturity. We assume that asset value follows a geometric Brownian motion and calculate the value of the various claims using the standard Black and Scholes [1973] and Merton [1974] pricing equations. For reference, we report the standard pricing equations in the appendix.

2.1 The public

An important feature of our model is the assumption of real deadweight costs to the economy in the event of severe financial distress of the banking sector (Hoggarth et al. [2002]). The socially optimal level of risk must therefore take into account both a positive payoff from a well-functioning banking system as well as costs of distress. More generally, it is not appropriate to take a narrow view of using the bank's stock price to measure benefits and deposit insurance payouts and losses to bondholders to measure costs. Not only are benefits and costs broader, the holdings of bank equity are also not proportionally distributed across society.[6]

The position of the public has two components. The first component is a positive payoff from the welfare benefit created by a well-functioning banking system. We assume that at debt maturity, if the asset value exceeds the total face value of debt $(F^D + F^S)$, the value of the public welfare is equal to τ_1 units times the residual value of the bank's assets, that is, the difference between the value of the financial institution's assets and the total face

[6]The level of risk that is optimal for the public (a benevolent regulator) will in general differ from the privately optimal level.

value of debt. Thus, the public has positive welfare if the financial institution is solvent and this welfare increases with the bank's equity value. As distance to default increases, public welfare increases.[7]

The second component is a negative payoff due to the cost of financial distress. When the value of assets declines severely it may lead to a sharp reduction in the value of similar assets held by other market participants, which might bring them to financial distress and forced fire sales. This self-reinforcing process can lead to downward spirals and risk becoming systemic. The process severely undermines financial intermediation, leading to reductions of real investment and output (Shleifer and Vishny [2010]; Stein [2012]). To model these deadweight costs of financial distress, we assume that the public loss at debt maturity is proportional to the severity of the financial institution's distress. Thus, the public loss equals a fraction of the difference between the face value of deposits and the value of assets. Similar to Hilscher and Raviv [2014] and Mendicino et al. [2017], we assume that deadweight losses are associated with insured deposits. In contrast, subordinated debt provides no special liquidity services and so we assume that there are no deadweight costs in the case of default.[8] The total position of the public at maturity is equal to:

$$G_T = \tau_1 \max(V_T - F^D - F^S, 0) - \tau_2 \max(F^D - V_T, 0). \tag{1}$$

The position of the public can be replicated by two options. The first is τ_1 units of a long call option on the value of the bank's assets with a strike price equal to the total face value of debt, and the second is τ_2 units of a short put option with a strike price equal to the face value of the insured deposits, F^D.[9] The present value of the position can be written as:

[7] An alternative way to model the public position is to cap the positive welfare from a well-functioning financial system at some lower level of leverage. However, our results are robust to such a modification.

[8] We are about to discuss conditions under which there is a socially optimal level of risk. A necessary condition for this realistic assumption is that $F^S > 0$.

[9] The pricing of the different options and positions is presented in Appendix A.

$$G = \tau_1 Call(V, F^D + F^S, \sigma) - \tau_2 Put(V, F^D, \sigma). \quad (2)$$

We define the leverage ratio of the financial institution in a way similar to Merton [1974]: $LR = (F^D + F^S)e^{-rT}/V$, where we normalize the total face value of the debt to one and express the asset value in terms of leverage: $1/(LRe^{rT})$. Thus, we can substitute the inverse of leverage for asset value and both are directly linked to each other.

A high level of τ_1 reflects large benefits from a well-functioning banking system; a high level of τ_2 reflects large societal costs associated with distress of the banking system. Since the tradeoff depends only on the ratio of the two parameters, we set τ_2 equal to 1 and use τ_1 to measure the relative importance of benefits and costs.

Figure 1 Panel A plots the payoff to the public at maturity for different asset values. This position is commonly referred to as a "risk-reversal" position, and it is composed of a short put option and a long call option with a higher strike price. The two components of the public position have opposite sensitivities to asset risk. As asset volatility increases, both the expected value generated from a well-functioning financial system and the loss due to financial distress increase. We define the level of bank asset volatility that maximizes social welfare as 'optimal' and assume that such a level exists (and that it is not zero). We effectively assume that neither zero asset risk (credit freeze) nor infinite asset risk are socially desirable.[10]

Theorem 1. *The level of asset risk that maximizes the public position increases with the public benefit from a well-functioning financial system relative to social costs in distress,* $\tau_1 > 0$*, and with the size of the subordinated debt* $F^S > 0$*. It decreases with total leverage.*

Proof. See Appendix B □

[10] We assume that an interior maximum for the public position with respect to asset risk exists. Necessary conditions for this are that $\tau_1 > 0$ and $F^S > 0$ (see appendix for a short proof).

The two components of the public position have opposite sensitivities to asset risk. As asset volatility increases, both the expected value generated from a well-functioning financial system and the loss due to financial distress increase. We show that for certain parameter combinations, there are levels of volatility for which these two effects exactly offset resulting in an interior maximum. We define the level of bank asset volatility that maximizes social welfare as 'optimal'.

Figure 2 Panel A presents the value of the public position with respect to asset risk for different levels of leverage. In our numerical analysis, leverage is equal to 0.92, subordinated debt is 6% of the total face value of debt, all debt instruments mature in one year, and the risk-free rate is equal to 3.5%.[11] For both the base case and a higher level of leverage (0.92, 0.95) the public position is hump-shaped with respect to asset risk. The socially optimal level is reached when asset risk is equal to 7.5%. The results are consistent with the regulators' goal of avoiding excessive risk taking of financial institutions (Kim and Santomero [1988]). If leverage is equal to 0.95, the socially optimal risk level decreases to 6.4% (also see Table 2 Panel A). We show that socially optimal risk is procyclical in Section (3.2).

Our model reflects the realities of bank supervision. Consistent with our model's prediction, regulatory policies reflect a desire to target an intermediate level of asset risk and a tendency to make regulation more binding as leverage increases. Bank supervisors and regulators use several different tools to limit bank asset risk. Examples include a cap on the cost of deposit insurance, VaR limits on a bank's distance to default, and minimum capital adequacy. All of these limits become more binding with leverage and target an intermediate level of asset risk. They reflect a tradeoff between the dead weight cost of bank default and the benefit from a well-functioning banking system.

In addition to a regulatory objective we also need to specify a policy instrument. To keep

[11] All other parameters are at their base case values as listed in Table 1. In Appendix C we provide justification for the specific parameter levels.

the model general and applicable to different regulatory settings, we specify the policy tool as a limit on asset risk or executive compensation. We discuss this further in section 3.

2.2 Management

Management responds to incentives provided by stockholders and consequences of financial distress: equity-based compensation and loss due to bank failure. The executive's position has two components. Both are sensitive to the financial institution's asset value and asset risk. The executive holds α units of equity based compensation, which pays at maturity the maximum between zero and the difference between the value of the assets and a strike price of H. We assume that management is compensated in the form of options struck at the current stock price so that $H = V_0$.[12] Assuming instead that equity based compensation only includes stock means that the strike price is equal to the total face value of debt.

The second component is a loss of β units due to bank failure ($0 \leq \beta \leq 1$). This component may include "inside debt," an executive's uninsured pension benefits that would be forgone in the event of failure, loss of future employment opportunities, and loss of reputation. We assume that the payoff at maturity is equal to β times the maximum of zero and the difference between the total face value of debt $(F^D + F^S)$ and asset value, V_T:

$$E_T = \alpha \max(V_T - H, 0) - \beta \max(F^D + F^S - V_T, 0). \tag{3}$$

The value of this position can be replicated by two options: a long position in α units of a call option with a strike price of H and a short position in β units of a put option with a strike price equal to the total face value of the bank's debt:

$$E = \alpha Call(V, H, \sigma) - \beta Put(V, F^D + F^S, \sigma). \tag{4}$$

[12] We assume that in the case of executive stock options, the dilution effect is relatively small and only has a secondary effect on the other liabilities that were issued by the financial institution.

Figure 1 Panel C plots the payoff of the position as a function of asset value. As in the case of the public, this is a "risk-reversal" position, where the components have opposing sensitivities to asset risk. When risk increases, the value of the equity based compensation increases while the value of the inside debt decreases since higher risk results in larger expected losses for the executive.[13] It is therefore possible for the executive to have an interior maximum.

Theorem 2. *The executive's position may have an interior maximum with respect to asset risk if the size of equity based compensation, α, is smaller than the units of loss due to bank failure, β. If $\alpha \geq \beta$ the executive is motivated to always increase risk.*

Proof. See Appendix B □

For an interior solution to exist, the incentives to increase and decrease risk have to exactly offset each other. Since the strike price of the compensation is equal to the stock price, this position is more sensitivity to asset risk than the loss in bank failure. In order for the two effects to offset the units of compensation must therefore be smaller than the loss in the event of default. If the units of compensation are larger than the loss in default, management will always try to increase risk.

All else equal, the level of asset risk that maximizes the value of the executive's position increases with the value of equity based compensation. Figure 3 plots the value of the executive position as a function of asset risk across different levels of compensation. For relatively low and medium levels of equity based compensation, where management's share of the bank's equity, α, is equal to 0.15% or 0.30%[14] (Panels A and B), the relationship between the value of the position and asset risk is hump-shaped and the maximum is achieved when asset risk is equal to 4.54% and 6.54% respectively. When executive ownership increases to

[13] The pricing of the different options and positions is presented in Appendix A.

[14] John et al. [2010] calculate the median value of CEO ownership in financial institution as equal to 0.29%.

a relatively high level of 0.6%, the relationship between the value of the executive's position and asset risk becomes upward sloping. The executive will aim to reach the highest possible level of risk and any limit on that risk set by the regulator will be binding.

Higher losses due to bank failure and higher leverage tend to decrease the risk level chosen by the executive. As losses due to bank failure increase, incentives to increase risk are reduced, since an increase of asset risk now results in a larger increase in expected losses in the event of default. The proposal of Bolton et al. [2015] to link CEO compensation to firm default risk, in order to reduce risk-taking, is equivalent in our model to an increase in the executive's loss due to bank failure, and will motivate the executive to take less risk.[15] Higher leverage also results in a reduction of the optimal level of asset risk. Figure 2 Panel C presents the effect of leverage on asset risk. When leverage increases from 0.92 to 0.95 and executive ownership equals 0.35%, the maximum decreases from 7.5% to 5.1%.

We can also consider the special case of setting the strike price of the equity based compensation equal to the leverage ratio, as in Sundaram and Yermack [2007]. In this case, the executive's only compensation is in the form of common stock and leverage has no effect on the risk-taking motivation of the executive. Unlike the general case where the executive position is maximized at some intermediate level, in this case there is always a corner solution. The relationship between the value of the executive's position and asset risk is either positive or negative depending on the relationship between α and β. If upside benefits (α) dominate, there is an incentive to increase risk; if downside costs (β) are larger, the executive will try to reduce risk. The intuition is that the payoff function has only two linear segments and is therefore either convex (higher risk is preferred) or concave (risk reduction is preferred).

[15]In principle another regulatory policy tool could be to increase executives' negative payoff in the event of failure by mandating payments or wealth losses. In our model such a policy is practically equivalent to setting a cap on compensation. Differences arise only as a result of distributional considerations. We therefore do not model this policy tool directly.

2.3 Stockholder

The stockholder holds the bank's equity and pays out compensation to management. The stockholder's position is equal to the residual value of the financial institution minus the equity based compensation awarded to the executive. The stockholder's payoff at maturity T is equal to:

$$S_T = max(V_T - F^D - F^S, 0) - \alpha \max(V_T - H, 0). \tag{5}$$

This position can be replicated by two options. The first is a long position in a call option with a strike price equal to the total face value of debt. The second is a short position of α units of a call option with a strike price equal to H, the strike price of the equity based compensation. The stockholder's payoff at debt maturity as a function of asset value is presented in Figure 1 Panel B. The present value of the stockholder's position is equal to:

$$S = Call(V, F^D + F^S, \sigma) - \alpha Call(V, H, \sigma). \tag{6}$$

In the special case where the executive only has equity compensation, $H = F^D + F^S$, the stockholder's position can be replicated by a single option:

$$S = (1 - \alpha)Call(V, F^D + F^S, \sigma). \tag{7}$$

The value of the stockholder's position increases with asset risk and asset value and decreases with executive ownership. Figure 2 Panel B illustrates these effects in the context of our calibration.

3 Risk-taking and executive compensation with regulatory limits on asset risk or executive ownership

In our model we represent bank supervision and regulation through two policy tools: limits on asset risk and on executive compensation. We discuss the strategies of the three stakeholders, characterize the equilibrium, and present stakeholders' optimal decisions. We first consider the case of full control over a cap on asset risk and the effect of changes in leverage on the optimal policy. We next analyze the case of limits to the regulatory ability to enforce the maximum level of asset risk and then consider the regulator instead limiting compensation.

3.1 Full ability of the regulator to cap asset risk

We model the strategic interactions of all stakeholders as a sequential game with complete and perfect information. We solve the game by backwards induction and characterizes the behavior of all stakeholders. The executive move last and chooses the level of asset risk that maximizes the value of her position, σ^*, given an upper bound on asset risk set by the regulator and the units of equity based compensation (managerial ownership) awarded by the stockholders. Stockholders move second and maximize the value of their position, S^*, by choosing the level of equity based compensation awarded to the executive, α^*, subject to regulatory limits on asset risk or compensation. The regulator moves first and chooses the upper bound on asset risk, σ_{UBound}, that maximizes the value of the public position, G^*. We define the equilibrium set of parameters and payoffs as: $\langle(\sigma^*, \alpha^*, \sigma^*_{UBound}), (E^*, S^*, G^*)\rangle$.

We initially assume an environment of complete and perfect information, where each claimholder is fully informed about the payoff functions, strategies, and actions of all other players. This assumption is relaxed when considering the case of asymmetric information. In the baseline case we assume that the regulator can impose any upper bound on asset risk, $\sigma_{UBound} \in [0, \infty)$. Stockholders can choose any level of executive ownership, $\alpha \in [0, 1]$, and management can decide on any level of asset risk between zero and the upper bound on asset risk, $\sigma \in [0, \sigma_{UBound}]$.

Theorem 3. *Assuming full control over a cap on asset risk, the regulator sets the upper bound equal to the socially optimal level of risk and that level is chosen by management:* $\sigma^* = \sigma^*_{UBound} = \sigma_{MaxPub}$.

Proof. See Appendix B □

The intuition of the proof reflects the incentives of the three stakeholders (the complete proof is in the Appendix). Stockholder's payoff behaves like a call option, which increases in value with higher risk. The stockholder will choose a compensation package for management that incentivizes executives to choose the level of asset risk that is optimal for stockholders. This desire to increase risk means that the public has to set the limit on asset risk equal to its social optimum. The result is that the regulator sets the upper bound on asset risk equal to the level that maximizes the public position σ_{MaxPub}. The stockholder awards the executive with the units of equity compensation that maximize the value of the stockholder's position at this level of risk. Since the value of the stockholder's position decreases with executive ownership (a direct transfer from stockholders to management), stockholders award the minimum ownership to the executive that contains sufficient motivation to choose risk equal to the regulatory limit. The executive, given her ownership of α^*, chooses the level of asset risk that maximizes the value of her position σ_{MaxEx}, resulting in risk being set at the upper bound: $\sigma_{MaxEx} = \sigma^* = \sigma^*_{UBound}$.

In the special case of no regulatory limit on asset risk, executives will choose the highest level possible given the investment opportunities available to the bank. We assume that there is a natural upper limit on risk-taking.

Corollary 1. *If there is no regulation, asset risk is equal to its natural upper bound and lies above the socially optimal level:* $\sigma^* = \sigma_{Max} > \sigma_{MaxPub}$.

Proof. If there is no regulatory limit on asset risk regulation, asset risk will be set equal to its natural upper bound. This is a special case of Theorem 3. □

The only way to reduce asset risk from its natural upper bound toward the socially optimal level is through regulation. This can be in the form of a cap on asset risk or on executive compensation. In our numerical example we set the natural upper limit to asset risk to 30% (Sundaresan and Wang [2015]).

Using our base case parameter values results in asset risk of $\sigma_{MaxEx} = \sigma^* = \sigma^*_{UBound} =$ 7.5% – the upper bound on asset risk and the socially optimal level (Figure 2 Panel A). At this or any higher level of ownership the constraint on asset risk set by the regulator will bind since the executive will be motivated to choose this level of risk with any ownership equal to or greater than α^*. The equilibrium position values are reported in Table 2 Panel A. They are 89 for the stockholders, 0.15 for management, and 23.8 for the public. When interpreting the values of the stakeholder positions it is useful to keep in mind that we set $\tau_2 = 1$ and so the public position cannot be directly compared to the other two.

Figure 4 shows the effect of the regulatory upper bound on equilibrium asset risk, executive compensation and stakeholder position values. Panel B plots the levels of executive ownership awarded by the stockholder for different regulatory upper bounds on asset risk (σ_{UBound}). For relatively low levels of upper bounds on asset risk (between 0% and 2%) it is not worth it for the stockholder to incentivize management to take on risk, resulting in zero equity based compensation and zero risk (Panel A). For any regulatory limit above 2%, it is optimal for the stockholder to award the executive the amount of ownership which will motivate her to take the maximum possible level of asset risk allowed by the regulator. This level needs to increase since the expected risk of failure also increases with risk (Panel B).

The regulator, taking these actions into account, sets the upper bound on asset risk to be equal to the level that maximizes the public position (Panel C). In equilibrium the regulatory upper bound on asset risk, σ^*_{UBound}, the level of risk chosen by the executive, σ^* and the level of risk that maximizes social welfare, σ_{MaxPub} are equal.

As pointed out above, we follow the standard convention of executive pay packages setting the option strike price equal to the stock price. Relaxing this assumption would create another choice variable for stockholders. In addition to the amount of compensation, stockholders could choose the strike price of the options awarded to management. Our focus on a single dimension of the pay package facilitates the model's transparency and allows for an easier understanding of the relationship between the direct regulation of bank activities (setting an upper bound on risk) and the regulation of executive compensation (setting an upper bound on compensation).

3.2 The effect of leverage

The leverage of the financial sector in the period from 2000 to 2007 remained almost constant (Kalemli-Ozcan et al. [2012]). However, during the 2008 financial crisis the leverage of many financial institutions increased in response to sizable declines in asset value (Adrian and Shin [2010] and Gorton and Metrick [2012]). In this section we analyze the effect of a change in leverage on asset risk.

Proposition 1. *Socially optimal asset risk is procyclical: as asset value increases, and leverage decreases, optimal asset risk increases. The effect of leverage on compensation is ambiguous and depends on the size of the change in the socially optimal level of risk.*

When leverage increases, the probability of a loss due to bank failure increases and the expected benefit from a healthy financial sector decreases. The optimal level of risk (from the public's perspective) is therefore lower. At this lower level, the probability (and cost) of failure is lower and social welfare is again maximized. The effect on the executive's position is similar. Expected losses in the event of failure are higher and expected gains from high asset risk are lower. Given the same level of compensation, management will reduce the level of asset risk. The effect of leverage on executive ownership depends on which reduction in asset risk is larger. If the reduction in the socially desirable asset risk is smaller, the executive will choose a lower level and compensation will rise to get back up to the new limit on asset risk. If the reduction in the regulatory limit is larger, the new cap on asset risk will lie below the level of asset risk desired by management so that stockholders will reduce compensation while still ensuring that the cap on asset risk is hit. The effect of leverage on compensation thus depends on the relative sensitivity of the public position and the executive position to asset risk.

In the numerical example, leverage increases from 0.92 to 0.95 as a result of a decline in the value of assets. For the new level of 0.95 the value of the public position is maximized at a lower level of risk equal to 6.4% compared to a base case level of 7.5% (Figure 2 Panel A and Table 2). However, the executive, given the old level of stock ownership, would reduce asset risk from 7.5% to 5.1% (Figure 5 Panel A). To achieve the new upper bound of 6.4% the stockholder increases executive ownership to 0.42% (Figure 2 Panel A and Figure 5 Panel B). The numerical example is consistent with the Dot.com crisis of 2001. As a result of a decrease in the value of assets and resulting increase in leverage of financial institutions, stockholders reacted by increasing the executives' equity based compensation, either by awarding them ownership or changing the strike of their stock options (Narayanan and Seyhun [2008]; Faulkender et al. [2010]; and Bebchuk et al. [2010b]).[16] In the complementary event, when leverage decreases from 0.92 to 0.90, the value of the public position is maximized

[16]We note that the response of executive compensation to the Dot.com crisis tells us something about the public value of a well-functioning banking system. The fact that compensation increased means that the public value was high. If it had been low, the increase in leverage would have resulted in a reduction of executive compensation. In that case, the drop in the socially optimal level would have been larger and stockholders would have reduced compensation.

at a higher level of risk of 8.2% (Table 2 line 3), where executive ownership declines to 0.33%.

3.3 Limited ability of the regulator to set maximum asset risk

The regulator may not be able to enforce an effective upper limit on asset risk, especially in the case of large and complex financial institutions. This may be due to "supervisory inertia," potentially the result of inadequate supervisory review processes, lenient laws and regulations, or lax enforcement. We model such a setting by assuming that the regulator can only enforce an upper bound on asset risk that is greater than the socially optimal level: $\sigma_{UBound} \in [\sigma_{MinReg}, \infty)$, where: $\sigma_{MinReg} > \sigma_{MaxPub}$, and σ_{MinReg} is the minimum level that the regulator can set as an upper bound on asset risk.

The stockholder now increases the equity based compensation up to the point where the executive is motivated to choose the new upper bound on asset risk so that $\sigma^* = \sigma^*_{UBound} = \sigma_{MinReg}$ (see Figure 4 Panel B). As the upper bound on asset risk increases, the position values of the executive and the stockholder increase, while the value of the public position decreases below relative to its level when stricter enforcement was possible (Figure 4 Panel C).

Proposition 2. *If enforcement of asset risk caps is limited (supervisory inertia), $\sigma_{MinReg} > \sigma_{MaxPub}$, the executive will choose this higher level of asset risk, $\sigma^* = \sigma^*_{UBound} = \sigma_{MinReg}$, and executive ownership increases to provide the necessary incentives to choose this level.*

Proof. See Appendix B □

Proposition 2 highlights the two necessary conditions for executives to engage in excessive risk taking: an increase in equity based compensation and supervisory inertia. It also sheds light on the link between the two. Regulatory inability to strictly enforce limits on asset risk results in higher executive stock ownership and sub-optimally higher levels of risk. We note that the proposition provides an explanation for the patterns in risk and compensation prior to the 2008 financial crisis. During those years both executives' equity based pay as well as risk-taking increased (Bebchuk et al. [2010b] and Hovakimian et al. [2012]), where some claim that there was insufficient supervisory oversight on risk-taking (Blanchard [2008]; Caprio et al. [2010]; Delis and Staikouras [2011]).

We demonstrate these results numerically. We set executive ownership to 0.35% as in Section (3.1) and all other parameters to their base case values. Assume that the lowest enforceable regulatory limit on asset risk is 10%: $\sigma^*_{UBound} = \sigma_{MinReg} = 10\%$. In this case the stockholder will increase executive ownership from 0.35% to 0.44% and will increase the level of asset risk to 10% (as compared to the socially optimal level of 7.5%). The value of the executive position increases from 0.15 to 0.20 and the stock value increases from 89 to 95. Meanwhile, the value of the public's position declines from 23.8 to 23.1 (Table 2).

3.4 Full ability of the regulator to cap executive ownership

We next show that limits on equity-based compensation can replace direct supervisory limits on risk-taking if both can be fully enforced. This means that optimally set limits on compensation are more effective than imperfectly controlled bank risk-taking.

Proposition 3. *If the regulator can impose any level of maximum executive ownership,* $\alpha_{UBound} \in [0, 1]$*, the stockholder will award ownership equal to the cap,* $\alpha^* = \alpha_{UBound}$*, and the executive will choose the socially optimal level of risk,* $\sigma_{MaxPub} = \sigma^*$*.*

This result follows directly from Theorem 3 and the resulting equilibrium is identical. The only difference is that the policy instrument used by the regulator is a cap on compensation. As before, the stockholder benefits from higher risk and will choose the most high-powered incentives possible, thus setting compensation equal to α^*_{UBound}. At that level, management chooses the socially optimal level of asset risk and the regulatory position is maximized. If enforcement is perfect, capping risk or ownership thus results in the same level of risk.

3.5 Limited ability of the regulator to enforce a cap on executive ownership

Using a cap on ownership as the policy instrument can be very costly if it cannot be precisely enforced. The reason is a nonlinear relationship between the cap on compensation and asset risk, which is in contrast to the linear relationship between the regulatory limit on asset risk and the actual chosen level of asset risk (Figure 4 Panel A). Once compensation reaches a certain level, management has an incentive to choose risk that is as high as possible (see, for example, Figure 3 Panel C). At slightly lower levels of compensation, small changes in the cap result in very large changes of chosen asset risk. As a result, without any direct regulatory limit on asset risk, the equilibrium level may be very high and lead to large reductions in social welfare.

Figure 6 Panel A shows the relationship between the cap on ownership and equilibrium asset risk. In contrast to the linear relationship between a risk cap and actual risk, this relationship is convex. Even a slight inability to control ownership can lead to a large increase in equilibrium asset risk. Social welfare, as captured by the value of the public position, declines sharply as the cap on ownership increases (Figure 6 Panel C).

The intuition for the nonlinearity is related to theorem (2). For a sufficiently high level of executive ownership the upside effect of an increase in asset risk starts dominating the downside risk of failure and so an internal solution for the executive no longer exists. Stockholders therefore no longer increase compensation as the cap increases (Figure 6 Panel B). Prior to reaching this point, a small increase in the limit on executive ownership has a large effect on asset risk.

4 Combining both policy tools

So far we have assumed that the regulator chooses one policy tool, either setting a limit on asset risk or on executive compensation. We next show that, in the case of limited enforcement and in the presence of frictions, using both tools can be welfare improving. We focus on two frictions; first, an inability to costlessly update policy tool levels in response to market movements, and, second, asymmetric information between regulators and executives regarding losses faced by the executive in bankruptcy.

4.1 Costs of updating policy tool levels

If bank asset value and leverage change over time, using both policy tools will be welfare improving. Since the effect of a cap on executive ownership on risk taking depends on leverage, a change in leverage means that the previous cap on ownership may no longer be optimal. As leverage increases, the cost to the executive due to bank failure increases while the value of the equity based compensation decreases. At the old compensation level the executive may choose to reduce asset risk below the new level that is socially optimal (see proposition 1). Motivating management to increase risk is only possible if the cap on ownership is increased. Similarly, higher leverage is associated with a lower socially optimal level of asset risk so the previous, higher, bound on risk may no longer be desirable.

If policy could be continuously updated and there is no cost of switching across tools, there is no gain from using two policy tools at any one time. One of them (the one that is more binding) will always be preferred or the regulator is indifferent between both. However, if leverage can change after policy is set, it can be welfare improving to use both tools. This is likely since there are costs to updating policy levels, for example a lag between the decision to change a policy tool and that change taking effect. If there are switching costs using both is also desirable since the tool that is more binding may change.

We illustrate the intuition for the case of two policy tools using our numerical example. We choose caps on asset risk and ownership that would, if used by themselves, result in the same equilibrium level of asset risk. In the base case of limited enforcement (Table 2, Panel B), the regulator can enforce a cap on asset risk of 10%. The corresponding cap on equity ownership that will results in the same equilibrium choice of asset risk is 0.44%.

We vary leverage and assume that the regulator chooses either one of the two policy tools or both. If leverage increase to 0.95 and there is only a limit on asset risk, stockholders will increase ownership to 0.51% in order to encourage the executive to take a risk level of 10%. If, instead, there is also a limit on ownership, equilibrium asset risk is 6.8%, only slightly above the new socially optimal level of 6.4%. The public position in the case of one policy tool is 13.1, compared to 15 if the regulator uses two tools (Table 2, Panel B).

If leverage declines to 0.90 and there is only a limit on ownership, asset risk will increase to 11.7%. A limit on asset risk would reduce the level to 10%. The public position is equal to 29.8, only slightly below the socially optimal level of 30.1; if there is only a cap on ownership it is equal to 28.9 (Table 2, Panel B).

What we show in the numerical example holds more generally. Assume that at some initial level of leverage the regulator is indifferent between the two policy tools since both lead to the same level of asset risk in equilibrium. If leverage increases, the constraint on ownership is binding, and asset risk declines if it is in place. If leverage decreases, the constraint on asset risk is binding, and asset risk does not increase if it is in place. Since the base case is one of limited enforcement and a resulting equilibrium level of asset risk above its optimum, adding constraints and reducing asset risk relative to the one-policy-tool levels is welfare improving.

4.2 Asymmetric information about executive loss due to bank failure

We now relax the assumption of perfect information and assume that management and stockholders are better informed than the regulator about the executive's loss in bank failure, β. This loss depends partly on intangible assets that decline in value when the bank fails, including the reputation of the executive and non-diversifiable human capital in the financial institution. It is likely that the regulator will have only limited information about these assets. Specifically, we assume that the regulator believes the loss in the event of failure to be higher than its actual value.

As losses due to bank failure increase, the value of the executive's position is maximized with a higher level of equity-based compensation since higher-powered incentives are necessary to counterbalance higher expected losses. Even if the regulator can perfectly enforce a compensation limit, if the regulator erroneously believes that the loss in the event of failure is high, the limit on equity-based compensation and resulting risk levels will be sub-optimally high, welfare will be lower than in the case of perfect information. Since stockholders and executives benefit, they will not disclose private information that may reduce the assessment of less informed regulator.

Proposition 4. *If the regulator believes the executive's loss due to bank failure to be higher than the actual level, $\beta < \beta^G$, the regulatory cap on ownership will be too high and motivate the executive to choose a higher level of asset risk than the level that maximizes the public position, $\sigma_{MaxPub} < \sigma^*$.*

The strategic interaction across the players is the same as in Section (3.4), where the regulator sets a cap on executive ownership, α^*_{UBound}, and is able to enforce this cap. However, now the regulator erroneously believes the loss due to bank failure to be higher than its actual level, $\beta < \beta^G$. To allow stockholders to compensate executives for this higher level, the regulator sets a higher upper bound on equity-based compensation than would be needed if there was perfect information. The resulting equilibrium level of asset risk lies above the level that maximizes the public position, $\sigma_{MaxEx} = \sigma^* > \sigma_{MaxPub}$. The value of both the executive and stockholder positions are higher, while social welfare is lower.

We illustrate this effect in our numerical example assuming that the actual loss due to bank failure is equal to either 0.5% or 0.4% of the bank's asset value, while the regulator estimates the loss to be 0.6% (as in the base case). As in Section (3.1), the regulator sets a cap on executive ownership of 0.35% and that is what the stockholder chooses. Equilibrium asset risk is equal to 9.4% and 16.6% for actual levels of β equal to 0.5% and 0.4% respectively (Table 3 and Figure 7). Both are substantially higher than the base case optimal risk level of 6.4%.

The position values for the stockholders and the executive are higher than in the case of symmetric information. The value of the executive position equals 0.16 and 0.18 (β equal to 0.5% or 0.4%), compared to 0.15 in the base case, and the value of the stockholder position equals 93 and 117, compared to 89 in the base case. The value of the public position is reduced to 23.4 and 15.2, compared to the base case level of 23.8 (Table 2, Panel C, lines 11 and 12).[17]

Risk levels are very sensitive to executive losses in default, a pattern that underscores the inability of caps on ownership to control equilibrium risk in a robust way. Table 3 reports equilibrium risk levels for different caps on ownership and executive losses in default. Each column shows the convex relationship ownership and risk reflected in Figure 6 Panel A. The rows show that there is also a convex relationship between executive losses in default and risk. Small errors in knowledge of executive losses in default can thus result in large effects

[17]We note that there is no loss in welfare if, instead, the regulator sets an upper bound on asset risk and that upper bound can be perfectly enforced. This insight directly implies that using both tools is in general better and the result also underscores the higher robustness of setting a limit on asset risk. We consider the case of limited enforcement (supervisory inertia) next.

on equilibrium risk.

4.3 Asymmetric information and two policy tools

In the case of asymmetric information and a limited ability of the regulator to enforce an upper limit on asset risk, it can again be welfare improving to use both policy tools.

Theorem 4. *If there is asymmetric information between the executive and the regulator regarding the executive's loss due to bank failure, $\beta < \beta^G$, and limited ability of the regulator to set an upper bound on asset risk, $\sigma_{MinReg} > \sigma_{MaxPub}$, using both policy tools simultaneously (setting an upper bound on asset risk and a cap on executive ownership) can be welfare improving.*

The uninformed regulator sets a limit on executive ownership which is based on a greater-than-actual perceived executive loss due to bank failure: $\beta < \beta^G$. In addition to the cap on compensation, the regulator also sets an upper bound on the level of asset risk, but can only choose a limit above the socially optimal level.

In equilibrium, there are two possible scenarios. First, the regulator sets a cap on compensation which, if awarded, motivates the executive to choose a level of asset risk that is lower than the limit: $\sigma^*_{UBound} > \sigma^* > \sigma_{MaxPub}$. In this case the effective constraint is the cap on executive ownership, and the public is better off than if there had only been a limit on asset risk. Second, the difference between the regulator's assessment and the actual level of loss due to bank failure is relatively high. In this case the constraint on ownership is not binding, $\alpha^*_{UBound} > \alpha^*$, since a lower level of compensation leads to management choosing the upper bound on asset risk, $\sigma^*_{UBound} = \sigma^* > \sigma_{MaxPub}$. In this case the effective constraint is the limit on risk and the public is better off than in the case of only using a cap on executive ownership.

In terms of our numerical illustration, we assume that the regulator can set an upper bound on asset risk of 10% and believes that the executive's exposure to losses due to bank failure equals $\beta = 0.6\%$. The regulator sets the upper bound to compensation equal to $\alpha = 0.35\%$. In the first case, the loss is instead equal to $\beta = 0.5\%$, the stockholder awards the executive with ownership equal to the cap level, and the executive chooses a level of risk equal to 9.4%. In equilibrium the public position is equal to 23.4 (Table 2 Panel C and Figure 7 Panel A), compared to 23.8 if asset risk was at the optimum. Without the cap on executive ownership asset risk would be 10% and the public position would be 23.1.

In the second case the executive's loss due to bank failure is equal to $\beta = 0.4\%$ of assets. With a constraint on asset risk of 10% that level is achieved in equilibrium by setting executive ownership to $\alpha = 0.33\%$ (Figure 7 Panel B, Table 2 Panel C). Without an upper bound on risk, equilibrium asset risk would be 16.6%, as in the case of only using a cap on executive ownership (Figure 7 Panel A, Section 4.2). The higher risk level means that the value of the public position declines from 23.1 to 15.2.

Although using both policy tools simultaneously increases the value of the position of the public, the cost of using both tools should be considered. However, our numerical example highlights that benefits can be large and thus will, in general, exceed the costs. Specifically, adding a cap on asset risk can substantially reduce the chance that a limited enforcement on ownership or an ownership level that is erroneously set too high leads to significantly elevated levels of asset risk, resulting in large costs to society. Using both policy tools means that very high levels of asset risk and corresponding low levels of social welfare will not be achieved.

The decision of the optimal mix of policy tools is then one of assessing the limitations of using one policy tool in isolation. If the regulator is confident that she can fully enforce a cap on asset risk - that there is no regulatory inertia – then, as we have shown, this is sufficient. If not, two policy tools should be used.

5 Conclusion

In this paper we present an equilibrium model of financial institutions. The regulator sets caps on either asset risk (traditional bank supervision) or executive pay (regulation of compensation) in order to limit the amount of risk taken and to bring it as close as possible to the socially optimal level. These limits counteract the desire of stockholders to increase risk and affect their choice to award compensation contracts to management that reflect these goals.

We show that (a) the socially optimal level of risk is higher if benefits from a well-functioning banking system are relatively higher than costs of distress, (b) optimal risk-taking is higher in good times, (c) without government regulation, social welfare is reduced since shareholders choose compensation and management chooses risk levels that are higher than their socially optimal levels, (d) if enforcement is perfect, a cap on asset risk (traditional bank supervision) or on pay (regulation of compensation) delivers the socially optimal level of risk, (e) a cap on asset risk is a more robust policy tool than a cap on compensation, and (f) if enforcement is limited or if information is imperfect using both policy tools can improve welfare. Our model is market-value based and can thus draw on well-known results from option pricing. This makes empirical applications to actual option-based compensation contracts straightforward and it allows for a transparent understanding of the incentives faced by different stakeholders.

Since the financial crisis there has been widespread debate about the regulation of financial institutions, in particular the question of how to curb excessive risk-taking. Our model highlights the drivers of high risk-taking and analyzes the consequences of different policy actions. In particular we show that only a combination of supervisory inertia and loose regulation of executive pay can produce suboptimally high levels of risk. Elevated risk thus came about because there were inadequate caps on *both* risk taking and compensation.

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A Valuing the claimholder positions

The values of the executive, stockholder, and the public positions are equal to replicating portfolios of plain vanilla options. To value these options we use the standard Black and Scholes [1973] and Merton [1974] assumptions. The value of the firm's assets follows a geometric Brownian motion (GBM), where the drift under the risk-neutral measure is equal to the risk-free rate, r, and σ is the instantaneous constant standard deviation of the assets' rate of return. The general pricing equations for the call and put options is given by:

$$Call(T,K) = VN(d(K)) - e^{-rT}KN(d(K) - \sigma\sqrt{T}) \tag{A.1}$$

$$Put(T,K) = e^{-rT}KN(\sigma\sqrt{T} - d(K)) - VN(-d(K)) \tag{A.2}$$

where K is the option strike price, $N()$ is the cumulative normal density and the function $d(K)$ is defined as:

$$d(K) = \frac{\ln(V/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}} \tag{A.3}$$

B Proofs of Theorems

Theorem 1. *The level of asset risk that maximizes the public position increases with the public benefit from a well-functioning financial system relative to social costs in distress,* $\tau_1 > 0$*, and with the size of the subordinated debt* $F^S > 0$*. It decreases with total leverage.*

Proof. The public position is composed of τ_1 units of long call options with a strike price of $F^D + F^S$ and τ_2 units of short put options with a strike price equal to the face value of the insured deposit F^D. To find the maximum value of the position we first calculate the derivative of the position with respect to asset risk:

$$\frac{\partial G}{\partial \sigma} = \frac{\tau_1 \partial Call(V, F^D + F^S, \sigma) - \tau_2 \partial Put(V, F^D, \sigma)}{\partial \sigma} \tag{B.1}$$

$$\frac{\partial G}{\partial \sigma} = \frac{\tau_1 V \sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V, F^D + F^S)^2}{2}} - \frac{\tau_2 V \sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V, F^D)^2}{2}} \tag{B.2}$$

where:

$$d(S, K) = \frac{\ln(\frac{S}{K}) + (r + \frac{\sigma^2}{2})T}{\sigma \sqrt{T}}$$

We can rearrange equation (B.2):

$$\frac{\partial G}{\partial \sigma} = \frac{V \sqrt{T}}{\sqrt{2\pi}} \left(\tau_1 e^{-\frac{d(F^D + F^S)^2}{2}} - \tau_2 e^{-\frac{d(F^D)^2}{2}} \right). \tag{B.3}$$

Next, we express equation (B.3) as:

$$\frac{\partial G}{\partial \sigma} = \frac{V \sqrt{T}}{\sqrt{2\pi}} (\tau_1 a - \tau_2 b) \tag{B.4}$$

where: $a = e^{-\frac{d(V, F^D + F^S)^2}{2}}$ and $b = e^{-\frac{d(V, F^D)^2}{2}}$.

It is clear from Equation (B.4) that as τ_1 increase the expression a increase as well. The expression $d(S, K)$ has a greater sensitivity to asset risk, σ, as $ln(\frac{S}{K})$ is closer to zero. Since $F^D + F^S$ always greater than F^D and both expressions are lower than V for a solvent bank, an increase in asset risk would have a stronger negative effect on the expression a and consequently the increase in τ_1 would be offset by and increase in asset risk.

As the size of the subordinated debt increase the expression a increase as well, and as in the case of an increase in τ_1 the increase is offset by an increase in asset risk, which has a greater effect on the expression $d()$ as the term $\ln(S/K)$ is closer to one.

An increase in leverage cause to an increase of both expressions a and b, since it has a negative effect on the expression $d(S,K)$. However, the effect is greater as K is lower and consequently the increase in b is greater than the increase in a. This change can be offset and move again the derivative to the value of zero by decreasing asset risk.

□

Theorem 2. *The executive's position may have an interior maximum with respect to asset risk if the size of equity based compensation, α, is smaller than the units of loss due to bank failure, β. If $\alpha \geq \beta$ there is no internal solution.*

Proof. The executive position is composed of α units of long call options with a strike price of H and β units of short put options with a strike price equal to the total face value of debt $F^D + F^S$. To find the maximum value of the position we first calculate the derivative of the position with respect to asset risk:

$$\frac{\partial E}{\partial \sigma} = \alpha \frac{\partial Call(V,H,\sigma)}{\partial \sigma} - \beta \frac{\partial Put(V,F^D+F^S,\sigma)}{\partial \sigma} \tag{B.5}$$

$$\frac{\partial E}{\partial \sigma} = \frac{\alpha V\sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V,H)^2}{2}} - \frac{\tau_2 V\sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V,F^D+F^S)^2}{2}} \tag{B.6}$$

where:

$$d(S,K) = \frac{\ln(\frac{S}{K}) + (r + \frac{\sigma^2}{2})T}{\sigma\sqrt{T}}.$$

By rearranging Equation (B.6) the derivative can be decomposed into two components, where the first one is always positive:

$$\frac{\partial E}{\partial \sigma} = \frac{V\sqrt{T}}{\sqrt{2\pi}} \left(\alpha e^{-\frac{d(V,H)^2}{2}} - \beta e^{-\frac{d(V,F^D+F^S)^2}{2}} \right). \tag{B.7}$$

Equation (B.7) can be expressed as well as:

$$\frac{\partial E}{\partial \sigma} = \frac{V\sqrt{T}}{\sqrt{2\pi}}(\alpha a - \beta b) \tag{B.8}$$

where: $a = e^{-\frac{d(V,H)^2}{2}}$ and $b = e^{-\frac{d(V,F^D+F^S)^2}{2}}$.

There is an interior maximum for the executive position with respect to asset risk in cases where the value of the derivative is equal to zero. Expressions a and b in Equation (B.8) are positive for any leverage, strike price and asset risk. Moreover, since the value of expression d decreases with the option strike price, K, the value of expression a is greater than expression b since the strike price of the executive position is positive as: $H > F^D + F^S$. Therefore, if the units of executive loss due to bank failure, β, are greater than the units of equity based compensation, α, there may be a level of asset risk that result in an interior maximum for the executive position.

When the performance linked compensation of the executive is composed solely of stock the strike price, H, is equal to the total face value of the debt, $F^D + F^S$, and expressions a and b are equal. Therefore, the derivative will be always positive (negative) in the case that α is greater (smaller) than β and the value of the executive position will always increase (decrease) with asset risk. □

Theorem 3. *Assuming full control of claimholders over their decisions, the regulator sets the upper bound on asset risk equal to the socially optimal level of risk and that same level is chosen by management:* $\sigma^* = \sigma^*_{UBound} = \sigma_{MaxPub}$.

Proof. We outline the proof in three steps. First, we find the risk level that maximizes the value of the public position, σ_{MaxPub}:

$$\sigma_{MaxPub} = \arg\max_{\sigma} G(\sigma, V, F^D, F^S). \tag{B.9}$$

In the case that the public position has an interior maximum with respect to asset risk, as described in Theorem 1, the solution to Equation (B.9) can be calculated by setting the derivative of the public position with respect to asset risk to zero:

$$\frac{\partial G}{\partial \sigma} |_{\sigma=\sigma_{MaxPub}} = 0. \tag{B.10}$$

We can rewrite this as:

$$\frac{\partial G}{\partial \sigma} = \frac{\tau_1 V \sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V,F^D+F^S)^2}{2}} - \frac{\tau_2 V \sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(V,F^D)^2}{2}} \tag{B.11}$$

where:

$$d(k) = \frac{\ln(S/K) + (r + \frac{\sigma^2}{2})T}{\sigma\sqrt{T}}.$$

The benevolent regulator will limit asset risk to this level. We thus next calculate the units of equity compensation (awarded to the executive) which maximize the value of the stockholder's position at this level of risk. The value of the stock increases with asset risk. However, asset risk is bounded at the level of σ^*_{UBound}. Moreover, as executive ownership increases, the value of the stockholder' position decreases. Therefore, the stockholder will award the minimum ownership to the executive that still motivates her to take a level of risk which is equal to the regulatory upper bound. This is done by searching for the units of equity compensation that equalize to zero the derivative of the executive position with respect to asset risk, while fixing the level of asset risk to the regulatory upper bound on asset risk, σ^*_{UBound}:

$$\frac{\partial E(\sigma = \sigma^*_{UBound})}{\partial \sigma} |_{\alpha=\alpha^*} = 0 \tag{B.12}$$

The derivative of Equation (B.12) can be calculated as follows:

$$\frac{\partial E(\sigma = \sigma^*_{UBound})}{\partial \sigma} = \frac{\alpha^* S\sqrt{T}}{2\pi} e^{-\frac{d(H)^2}{2}} - \frac{\beta S\sqrt{T}}{\sqrt{2\pi}} e^{-\frac{d(F^D+F^S)^2}{2}}. \tag{B.13}$$

In the third step, the executive, given her ownership of α^*, chooses the level of asset risk that maximizes the value of her position σ_{MaxEx}:

$$\sigma_{MaxEx} = \arg\max_{\sigma} E(\sigma, \alpha^*, \beta, V, F^D, F^S). \tag{B.14}$$

This level is calculated by using Equation (B.13) and the result is the level of risk which equals the upper bound on asset risk: $\sigma_{MaxEx} = \sigma^* = \sigma^*_{UBound}$. □

Proposition 1. *If all claimholders have full control over their decisions, in equilibrium, a financial institution's asset risk will decrease with leverage. The effect of leverage on compensation is ambiguous and depends on the size of the change in the socially optimal level of risk.*

Proof. The public position receives its maximum with respect to asset risk when the derivative of the position with respect to asset risk is equal to zero, as expressed in Equation (B.3):

$$\frac{\partial G}{\partial \sigma} = \frac{V\sqrt{T}}{\sqrt{2\pi}} \left(\tau_1 e^{-\frac{d(F^D+F^S)^2}{2}} - \tau_2 e^{-\frac{d(F^D)^2}{2}} \right) = 0$$

The equation is equal to zero either when $V = 0$ or when the two expressions are equals:

$$\tau_1 e^{-\frac{d(F^D+F^S)^2}{2}} = \tau_2 e^{-\frac{d(F^D)^2}{2}} \tag{B.15}$$

Under the assumption that $\tau_1 < \tau_2$ and both are positive, we can normalize τ_2 to one $\tau_1 \in [0, 1]$. Thus, equation(B.15) can be rewritten as:

$$d(F^D + F^S)^2 - \ln(\tau_1) = d(F^D)^2 \tag{B.16}$$

The equation can be further developed and written as:

$$(\frac{\ln(V/(F^D + F^S)) + (r + \frac{\sigma^2}{2})T}{\sigma\sqrt{T}})^2 - \ln(\tau_1) = (\frac{\ln(V/F^D) + (r + \frac{\sigma^2}{2})T}{\sigma\sqrt{T}})^2 \tag{B.17}$$

A decrease in the bank's asset value , V, has an equal effect on the expressions $ln(V/F^D)$ and $ln(V/(F^D + F^S))$. However, the decrease has a greater effect on the power of the expression as the size of the denominator decreases. Consequently (B.17) becomes inequality, where the left hand side is greater than the expression on the right hand side. The value of the equation can be set back to zero by lowering the level of asset risk, σ. Although the two expression has negative sensitivity to σ, the expression $ln((V/(F^D))/\sigma\sqrt{T})^2$ is more sensitive to a change in σ than $(ln(V/(F^D))/\sigma\sqrt{T})^2$.

□

Proposition 2. *If the minimum level that the regulator can set as an upper bound on asset risk is greater than the level that maximizes the position of the public (supervisory inertia),* $\sigma_{MinReg} > \sigma_{MaxPub}$, *then, in equilibrium, the executive will choose this level of asset risk:* $\sigma^* = \sigma^*_{UBound} = \sigma_{MinReg}$. *Consequently, executive ownership is greater than in the case* *where the regulator can enforce asset risk that maximizes the public position.*

Proof. The public position is hump shaped with respect to asset risk and receives its maximum value when asset risk is equal σ_{MaxPub}. The regulator, can enforce an upper limit on asset risk which is greater than that level. Since the public position is hump shaped and is downward sloping for any level of risk above σ_{MaxPub}, the public position is maximized at the lowest level of risk that the regulator can enforce as the upper bound on asset risk, σ_{MinReg}. □

C Choice of Base Case Parameters

Maturity (T): Following Marcus and Shaked [1984] and Ronn and Verma [1986] a one-year maturity is reasonable given the annual frequency of regulatory audits, because if the market value of the assets is found to be less than the value of total liabilities in an audit, regulators have the ability to seize the bank.

Leverage ratio of the financial institution (LR): We define the leverage ratio $LR = e^{-rT}F/V$. We set the total face value of the financial institution's debt $(F^D + F^S)$ to 1,000, and calculate for each level of leverage ratio the appropriate level for a firm's asset value, V. The leverage ratio is set to 0.92, similar to the median level reported by John et al. [2010] for 143 bank holding companies between 1993 and 2007.

Percentage of managerial ownership. The parameter α is the percentage of ownership of the executive in the bank's equity. John et al. [2010] calculate the median value of CEO ownership in financial institutions as 0.29%. However, one standard deviation in their study is equal to 3.97%. Thus, all the results in our numerical analysis are within the range of one standard deviation.

Units of loss due to bank failure. The parameter β is the percentage loss of the executive in financial distress as a percentage of the total value of assets. Recently, Graham et al. [2013]

find that bankruptcy causes a decline in annual wages of 30% of pre-bankruptcy wages and the decrease in wages persists (at least) for five years post-bankruptcy. Bennett et al. [2016] use data of bank's executive between 2006 and 2012 and find out that on average 26.8% of a the pay is linked to performance. In the context of our model, these numbers imply a loss in bankruptcy of 0.5% of assets. For our numerical example we choose a range between 0.45% and 0.6% of assets.

Face value of subordinated debt. The face value of the subordinated debt is set to 6% of the total debt's face value. We define subordinated debt as any liabilities which are not insured by the government. This level is reasonable given the wide range of levels documented empirically. Belkhir [2013], analysis U.S. commercial banks between 1995 and 2009, finds that the average value of the subordinated debt tranche is equal to 1.79% of total liabilities. John et al. [2010] find that deposits constitute 81% of the total debt for an average bank.

Risk-free rate. We set the risk-free rate r to 3.5% to match the average short-term U.S. Treasury rates over the period between 1991 and 2008.

The units of welfare benefit created by a well-functioning banking system held by the public, τ_1, and units of loss to the public in financial distress, τ_2. We normalize the units of loss to the public in case of financial distress, τ_2, to the level of one and choose the units of welfare created by a well-functioning financial system, τ_2, so that the public position is maximized at a level of asset risk of 7.5%. This level is reasonable: Sundaresan and Wang [2015] report that the average asset volatility of financial institutions from 2000 to 2013 is 10%; Mehran and Rosenberg [2008] find an average of 5.3%.

The strike price of the equity based compensation (H). We set the strike price to be equal to the asset value, based on the convention in the market to set the strike price of stock options as being at-the-money.

Table 1: **Summary of base case parameters.** For a detailed description of the choice of base case parameters please refer to Appendix C.

Parameter	**Source**	**Symbol**	**Base Value**
Leverage ratio	John, Mehran and Qian (2010)	LR	0.92
Face value of total debt		F	1,000
Value of the firm's assets		V	1,049.57
Time to maturity	Marcus and Shaked (1984) and Ronn and Verma (1986).	T	1
Risk-free rate	Kenneth French's database	r	3.5%
Executive ownership	John, Mehran and Qian (2010)	α	0.3%
Executive loss in bank failure		β	0.6%
Face value of subordinated debt	Belkhir (2012)	F^S	60
Bank's asset risk	Mehran and Rosenberg (2008), Sundareasan and Wang (2014)	σ	7.5%
Strike of the equity based compensation		H	1,049.57
Units of welfare created by a well-functioning banking system	Sundareasan and Wang (2014)	τ_1	0.276
Units of loss due to financial distress		τ_2	1

Table 2: **Equilibrium outcomes for different policy regimes and information levels.** This table presents equilibrium solutions for different policy tools (caps on risk or compensation), levels of policy control, leverage ratios, and information. Each row specifies the regulatory setting and the values for the parameters that are varied (parameters that are not specified are set to their base case levels). In the columns we report leverage; equilibrium levels of decision variables; and the stakeholder position values. Panel A reports the case of full regulatory control; Panel B the case of limited regulatory control; and Panel C the case of asymmetric information about losses to management in case of bankruptcy.

	Regulatory policy tools and information	**Leverage**	**Decisions variables (in %)**				**Position value**		
			Executive ownership (α^*)	**Asset risk** (σ^*)	**Limit on asset risk** (σ^*_{UBound})	**Limit on executive ownership** (α^*_{UBound})	**Stock**	**Executive position**	**Public position**
Panel A: Full regulatory control									
1	$\sigma_{UBound} \in [0,\infty)$	0.92	0.35	7.5	7.5	NA	89	0.15	23.8
2	$\sigma_{UBound} \in [0,\infty)$	0.95	0.42	6.4	6.4	NA	58	0.07	15.2
3	$\sigma_{UBound} \in [0,\infty)$	0.90	0.33	8.2	8.2	NA	111	0.21	30.1
4	$\alpha_{UBound} \in [0,\infty)$	0.92	0.35	7.5	NA	0.35	89	0.15	23.8
Panel B: Limited regulatory control									
5	$\sigma_{UBound} \in [0.10,\infty)$	0.92	0.44	10.0	10.0	NA	95	0.20	23.1
6	$\sigma_{UBound} \in [0.10,\infty)$	0.95	0.51	10.0	10.0	NA	70	0.10	13.1
7	$\alpha_{UBound} \in [0.44\%,\infty)$	0.92	0.44	10.0	NA	0.44	95	0.20	23.1
8	$\alpha_{UBound} \in [0.44\%,\infty)$	0.90	0.44	11.7	NA	0.44	119	0.30	28.9
9	$\alpha_{UBound} \in [0.44\%,\infty)$, $\sigma_{UBound} \in [0.10,\infty)$	0.95	0.44	6.8	10.0	0.44	59	0.08	15.0
10	$\alpha_{UBound} \in [0.44\%,\infty)$, $\sigma_{UBound} \in [0.10,\infty)$	0.90	0.40	10.0	10.0	0.44	115	0.26	29.8
Panel C: Asymmetric information									
11	β^G=0.6%,β=0.5%	0.92	0.35	9.4	NA	0.35	93	0.16	23.4
12	β^G=0.6%,β=0.4%	0.92	0.35	16.6	NA	0.35	117	0.18	15.2
13	β^G=0.6%,β=0.5%, $\sigma_{UBound} \in [0.1,\infty)$	0.92	0.35	9.4	10.0	0.35	93	0.16	23.4
14	β^G=0.6%,β=0.4%, $\sigma_{UBound} \in [0.1,\infty)$	0.92	0.33	10.0	10.0	0.35	95	0.15	23.1

Table 3: **The effect of executive ownership and loss in bank failure on asset risk.** This table presents equilibrium levels of asset risk for combinations of executive ownership α (rows) and losses to executives in the event of failure β (columns). We report the value of asset risk (in %) that maximizes the value of the executive position for the specific parameter combination. All other parameters are identical to those in Table 1.

		Units of loss due to bank failure (in %)			
		0.40	**0.50**	**0.55**	**0.60**
Executive ownership (in %)	**0.30**	10.4	7.7	7.0	6.5
	0.35	16.6	9.4	8.2	7.5
	0.4	22.4	12.0	9.9	8.7
	0.50	30.0	18.8	12.7	10.4

Figure 1: **The value of the claimholders' positions at debt maturity versus asset value.** The figure shows the payoffs at maturity as a function of asset value. Panel A presents the public's payoff. Panel B presents the stockholder's payoff and Panel C presents the payoff to the executive. All other parameters are identical to those in Table 1.

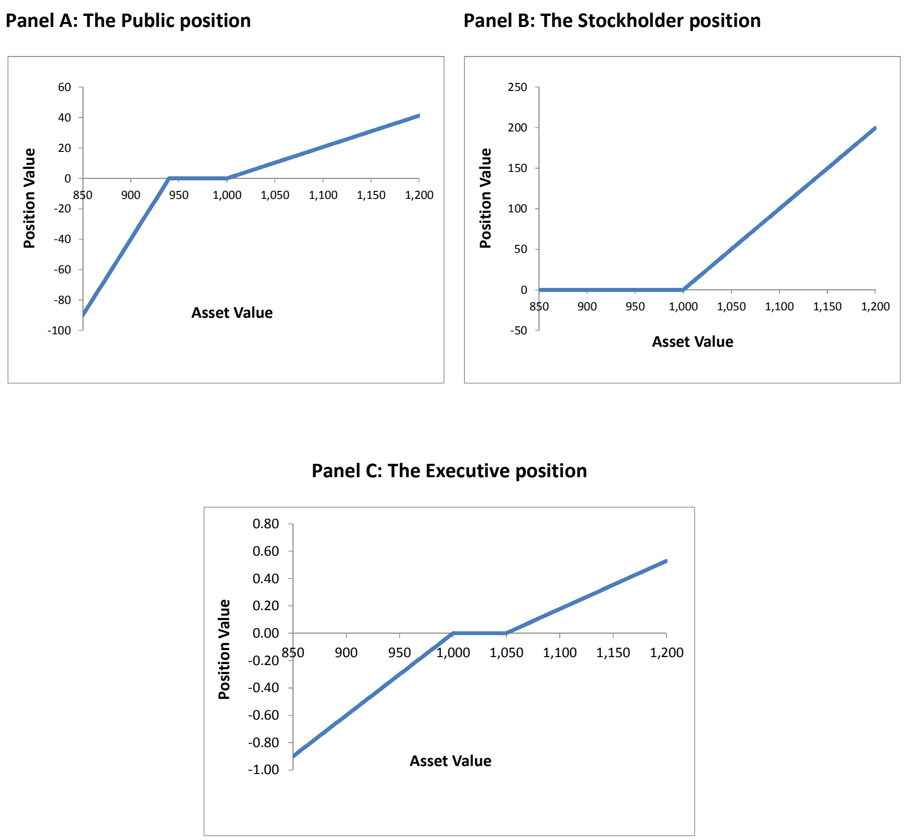
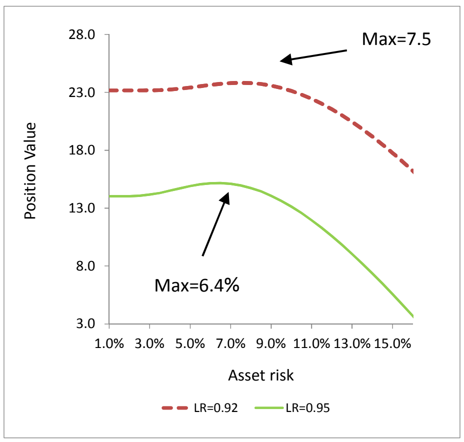
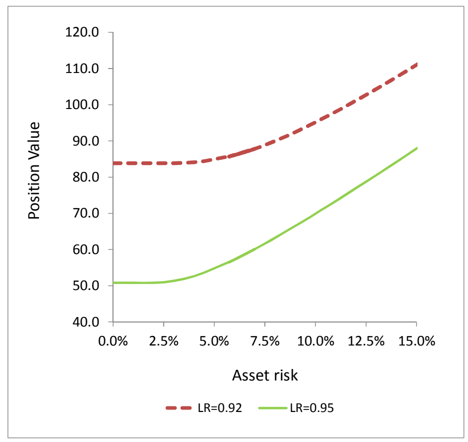


Figure 2: **The value of the claimholders' positions versus asset risk.** The figure shows the effect of asset risk on the values of claimholders' positions. Panel A presents the public's position, Panel B presents the stockholder's position, and Panel C presents the position of the executive. Equity based compensation is equal to α=0.35%. Leverage is set either to 0.92 or 0.95. All other parameters are identical to those in Table 1.

Panel A: The Public position



Panel B: The Stockholder position



Panel C: The Executive position

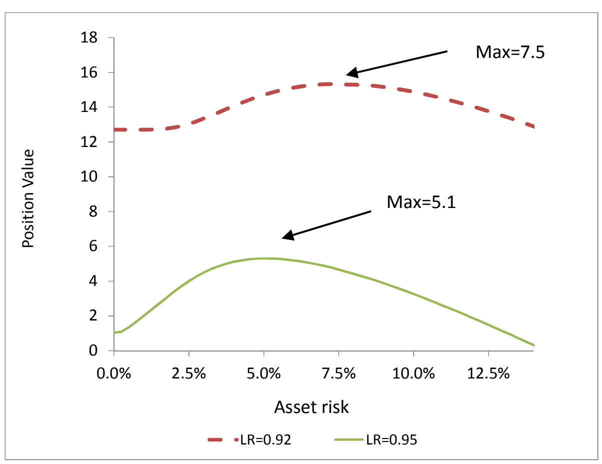
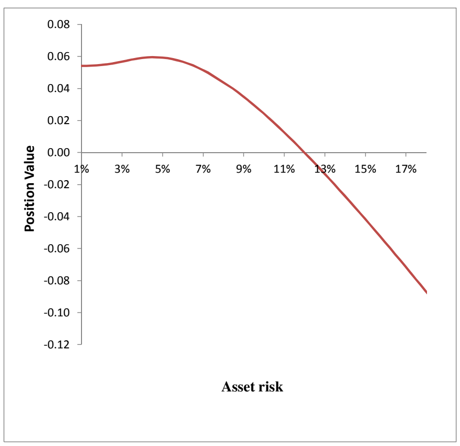
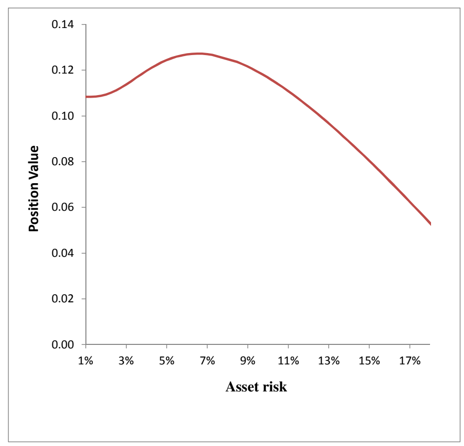


Figure 3: **The effect of asset risk on the executive's position.** The figure presents the value of the executive's position versus asset risk. The level of equity based compensation is either low (α=0.15%), moderate (α=0.3%) or high (α=0.6%). All other parameters are identical to those in Table 1.

Panel A: "Low" equity compensation (α=0.15%)



Panel B: "Medium" equity compensation (α=0.30%)



Panel C: "Large" equity compensation (α=0.6%)

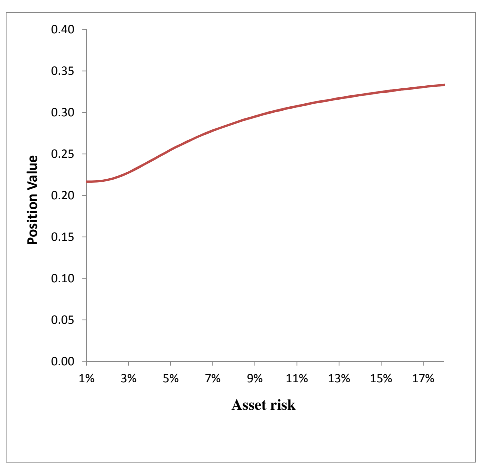


Figure 4: **The effect of a regulatory upper bound on asset risk.** For the case when the regulator sets an upper bound on asset risk, the figure shows various outcomes as functions of this upper limit. Panel A presents the level of asset risk chosen by the executive; Panel B shows the level of executive ownership awarded by the stockholder; Panel C shows the position values for the three claimholders. All other parameters are identical to the base case parameters presented in Table 1.

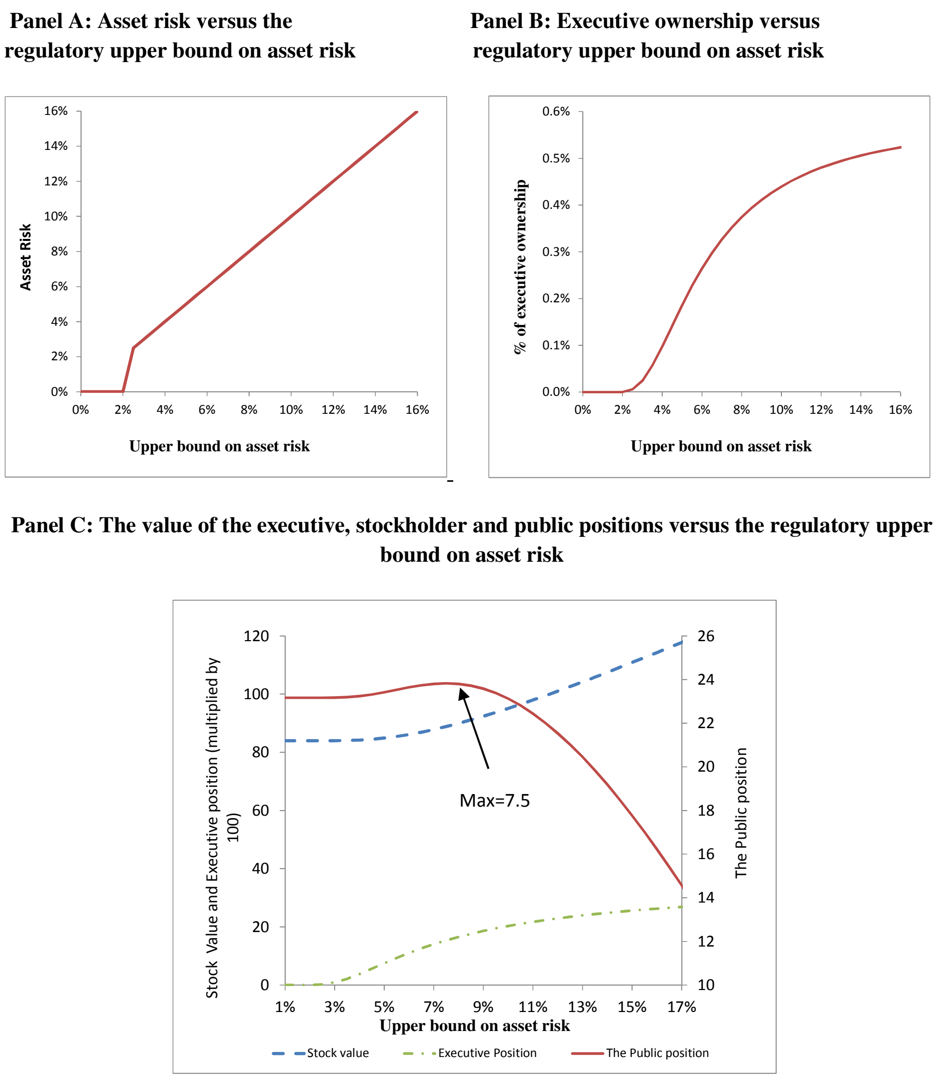
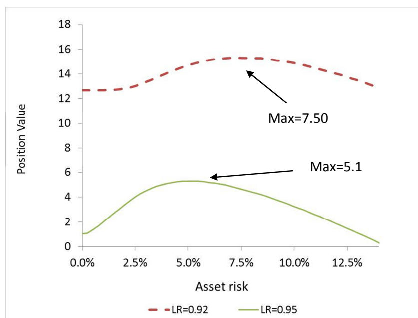


Figure 5: **The effect of leverage and executive ownership on equilibrium asset risk.** The figure shows the executive's position value as a function of asset risk for different levels of leverage, which is either equal to 0.92 or 0.95. In Panel A the executive ownership is equal to 0.35%; in Panel B executive ownership is 0.42% of equity. All other parameters are identical to the base case parameters presented in Table 1.

Panel A: Executive ownership equals 0.35%.



Panel B: Executive ownership equals 0.42%

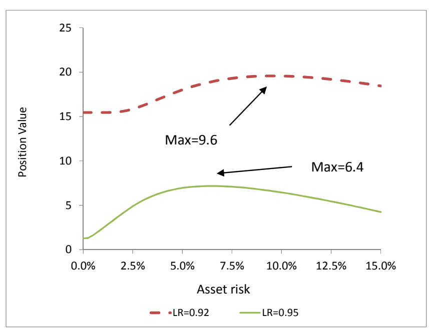


Figure 6: **The effect of a regulatory upper bound on equity ownership.** For the case when the regulator sets an upper bound on the level of equity ownership, the figure shows various outcomes as functions of this upper limit. Panel A presents the level of asset risk chosen by the executive; Panel B shows the level of executive ownership awarded by the stockholder; Panel C shows the position values for the three claimholders. All other parameters are identical to the base case parameters presented in Table 1.

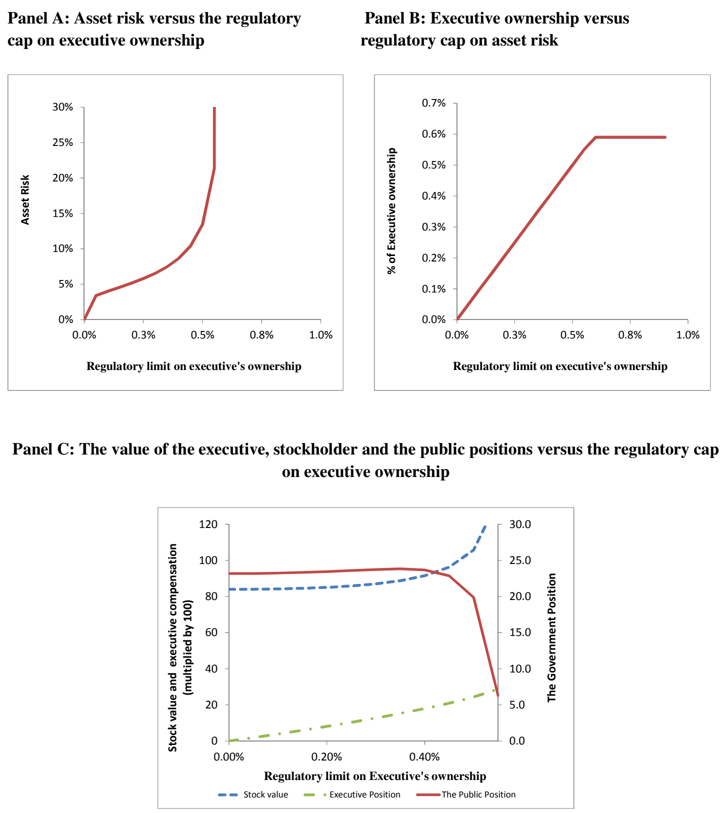
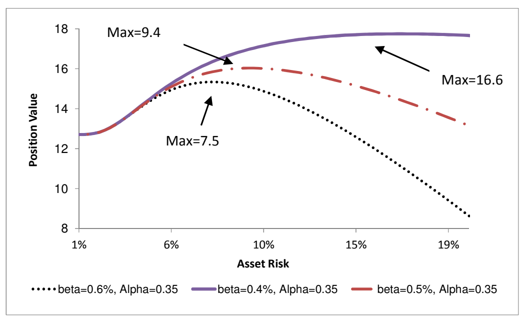


Figure 7: **The effect of asymmetric information on risk taking.** The figure shows the effect of asymmetric information about losses in the event of bank failure. We present executive position values as a function of asset risk. Panel A shows executive choices for different levels of β and no cap on asset risk. Panel B shows equilibrium outcomes when there is also a constraint on asset risk: If actual losses in the event of failure are high (β=0.5%), the cap on executive ownership is binding; if losses in failure are small (β=0.4%), the cap on asset risk is binding and, in equilibrium, compensation adjusts.

Panel A: Limit on executive ownership only



Panel B: Using both policy tools