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Capital Requirements or Pricing Constraints? An Economic Analysis of Measures for Insurance Regulation*

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Abstract

Depending on the point of time and location, insurance companies are subject to different forms of solvency regulation. In modern regulation regimes, such as the future standard Solvency II in the EU, insurance pricing is liberalized and risk-based capital requirements will be introduced. In many economies in Asia and Latin America, on the other hand, supervisors require the prior approval of policy conditions and insurance premiums, but do not conduct risk-based capital regulation. This paper compares the outcome of insurance rate regulation and risk-based capital requirements by deriving stock insurers' best responses. It turns out that binding price floors affect insurers' optimal capital structures and induce them to choose higher safety levels. Risk-based capital requirements are a more efficient instrument of solvency regulation and allow for lower insurance premiums, but may come at the cost of investment efforts into adequate risk monitoring systems. The paper derives threshold values for regulator's investments into risk-based capital regulation and provides starting points for designing a welfare-enhancing insurance regulation scheme.

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1 Introduction

Risk-based capital requirements are an increasingly significant instrument of insurance regulation. Different forms of risk-based capital requirements have been introduced in Canada (1994), the United States (1994), Japan (1996), Australia (2001), the United Kingdom (2004), the Netherlands, and Switzerland (2006). Recent developments in that direction include the European insurance regulation project Solvency II with risk-based capital requirements in its first pillar, and the Solvency Modernization Initiative of the U.S. association of insurance commissioners, NAIC. The idea of risk-based capital requirements is to limit the insurer's default risk below a regulatory desired level. In Solvency II, e.g., this is specified by the annual ruin probability of 0.5%.

Besides capital requirements, regulatory interventions into insurance pricing and product design is an important feature of insurance regulation. In the European Union, insurance regulation was primarily based upon the prior approval of premiums and policy conditions, until the deregulation in 1994. Today, this form of regulation is still widespread in most markets of Asia and Latin America (OECD, 2003). Also, in several U.S. states, regulators set constraints on insurance premiums (cf. Tennyson, 2007). Empirical analyses for the U.S. market find that regulatory prices are in some cases higher or lower than unregulated premiums (Cummins et al., 2001; Harrington, 2002; Grace and Phillips, 2008). The regulatory objective of price ceilings is to prevent excessive profit mark-ups on insurance premiums. Prices floors, in turn, aim at preventing "destructive competition" and thus act as instruments of solvency regulation (Joskow, 1973; Hanson et al., 1974; Grace and Klein, 2009).

The theoretical literature usually studies the relation between insurer default risk and the insurance premium in one "direction", namely by determining the premium based on a specified level of insurer default risk. In this context, Merton (1977) applies option pricing theory to calculate the price for deposit insurance of banks; similarly, Doherty and Garven (1986) determine the fair premium based on the shareholders' default put option value. This procedure has been transferred to insurance guarantee funds (Cummins, 1988), reinsurance (Gruendl and Schmeiser, 2002), and has been generalized with regard to imperfect competition (Cummins and Danzon, 1997), multiline insurers (Phillips et al., 1998; Myers and Read, 2001; Ibragimov et al., 2010), or corporate taxation (Doherty and Garven, 1986; Gatzert and Schmeiser, 2008a). In the absence of pricing constraints, the insurer's safety level has also been optimized as an endogenous variable subject to insurer profit maximization (Cummins and Danzon, 1997; Zanjani, 2002; Froot, 2007). All these considerations can be meaningful in investigating how insurance prices are influenced by the safety level and by solvency regulation.

The other direction, however, still holds several interesting questions: In which way is the safety level influenced by pricing constraints? Are risk-based capital requirements more efficient than price floors to ensure insurer solvency? If so, how much should regulators invest to implement risk-based capital requirements? Does it make sense to have capital requirements and to set minimum prices at the same time?

This article develops a parsimonious model to investigate the interaction between the insurer's safety level and the insurance premium in both directions. In a first step, the insurer faces risk-based capital requirements, and chooses the shareholder-value-maximizing premium. Here, a higher safety level implies a higher premium, since the expected payoffs to policyholders increase, and because a higher safety level causes higher costs for the insurer's risk management. The model incorporates frictional costs of procuring equity, such as corporate taxes or agency issues. In a second step, the insurer chooses the optimal safety level in the presence of pricing constraints. Now, the insurer balances the potential default-risk-driven fall in insurance demand against shareholders' default put option value and the transaction costs for risk management. Binding price floors increase the insurer's expected profits per contract and thus induce the insurer to attract a larger number of customers by means of a higher safety level. In turn, binding price ceilings reduce the optimal safety level.

To compare risk-based capital requirements with price regulation, the paper derives analytical representations for both outlined relations: The insurer's optimal premium, based on the regulatory desired safety level, and the regulatory price that makes the insurer choose the specified safety level. Do these prices differ? If insurance demand is perfectly elastic with regard to price and insurer default risk, they do not, and hence capital requirements and price regulation will result in the same safety-level/price combination. However, if demand is imperfectly default-elastic, e.g., because policyholders have incomplete risk information, capital requirements lead to a premium below the corresponding price floor. Therefore, risk-based capital requirements make insurance more affordable to purchasers, and also allow for higher shareholder value, as more contracts will be concluded. This welfare advantage justifies regulatory investments in implementing risk-based capital requirements as the main regulatory instrument. A numerical calibration of the model shows that regulatory expenses for risk-based capital regulation may range between 0% and 10% of insurance liabilities, depending on the price and default sensitivities of demand and the magnitude of frictional costs of equity.

Besides measuring the welfare-advantage of risk-based regulation, the paper points out that binding price floors are not necessarily an appropriate tool to enhance insurer safety levels if risk-based capital requirements are also in place: In this case there is a price interval in which price floors are binding and make insurance more expensive, but have no influence on the insurer's safety level.

The remainder of this article is structured as follows. Section 2 presents the model framework. Section 3 derives insurers' best response functions to regulatory constraints and also the optimal strategy in the absence of regulation. Section 4 highlights the implications of insurers' best responses for optimal regulatory policies. Section 5 provides graphic interpretations of the central results and illustrates them with a numerical example. Section 6 discusses the results in light of the existing literature and provides possible extensions. Section 7 concludes.

2 Model framework

The model incorporates three types of actors: the regulator, who imposes restrictions on insurer safety levels and prices; an insurer with limited liability, who chooses an allowed safety level and insurance price under an objective shareholder-value maximization strategy; and a heterogeneous group of consumers, who make their buying decisions based on these figures. The time horizon is the interval [0, 1]. Shareholders are risk neutral and evaluate their future payoffs under the risk-neutral probability measure $\mathbb{Q}$.[1]

At time 0, shareholders endow the company with equity in the amount of K. Due to acquisition expenses, corporate taxation, and agency costs, equity endowment is accompanied by up-front frictional costs, which are modeled by a proportional charge $\tau \geq 0$.[2] At time 1, insurance losses occur in the amount of L_1 , and shareholders receive the insurer's remaining equity of $\max\{A_1 - L_1; 0\}$ under limited liability protection. The insurer's target is to maximize the net shareholder value:

$$SHV = \exp(-r)\mathbb{E}_{\mathbb{Q}}\left[\max\{A_1 - L_1; 0\}\right] - K, \tag{1}$$

with r the risk-free interest rate. Consumers can buy insurance at time 0, and face future losses at time 1. The number of concluded contracts is modeled by a two-parametric demand function $y(p, dr)$, where p is the insurance premium, and dr is the default ratio, which measures the insolvency costs in terms of the value of defaulting claims per dollar of initial liabilities: $dr = \exp(-r)\mathbb{E}_{\mathbb{Q}}\left[\max\{L_1 - A_1; 0\}\right]/L_0$.[3] The demand function may represent the outcome of consumers' decision-making in either the absence or the presence of alternative offers from competitors, it may account for information asymmetries, and there are few restrictions regarding its shape:[4] there is a finite number of potential customers, demand is continuous, twice differentiable, and strictly decreasing in both its arguments.

The insurer's initial assets are comprised of premium income in the amount of $y(p, dr) \cdot p$ and equity endowment net of frictional costs, i.e., $A_0 = y \cdot p + (1 - \tau) \cdot K$. The arbitrage-free value of each contract's claim is denoted by μ, and hence the

[1] Cf. (Gatzert and Schmeiser, 2008b, p.2590).
[2] Cf. Zanjani (2002), Froot (2007), Yow and Sherris (2008), Ibragimov et al. (2010).
[3] The default ratio is frequently used when insurance pricing builds on option pricing techniques (cf. Sommer, 1996; Myers and Read, 2001; Gruendl and Schmeiser, 2002; Gatzert and Schmeiser, 2008a,b; Ibragimov et al., 2010). It is incorporated as a parameter for insurance demand, e.g., by Cummins and Danzon (1997) and Yow and Sherris (2008).
[4] If consumers can hardly distinguish between insurer safety levels, y will react weakly to default risk, and y_{dr} may be close to zero; whereas y_{dr} may be large if insurer default risk is observable. Zimmer et al. (2011) provide an experimental estimation of the insurance demand function which could be included in this framework.

insurer's initial liabilities are $L_0 = y \cdot \mu$. Under the risk-neutral measure $\mathbb{Q}$, assets and liabilities evolve according to the following processes:[5]

$$\begin{aligned} \mathrm{d}A_t &= A_0 \cdot \exp\left((r - \sigma_A^2/2)t + \sigma_A W_{A,t}^{\mathbb{Q}}\right) \\ \mathrm{d}L_t &= L_0 \cdot \exp\left((r - \sigma_L^2/2)t + \sigma_L W_{L,t}^{\mathbb{Q}}\right), \end{aligned}$$

with σ_A, σ_L denoting the volatilities of the asset and liability processes, and $W_{A,t}^{\mathbb{Q}}$, $W_{L,t}^{\mathbb{Q}}$ geometric Brownian motions under $\mathbb{Q}$. The Brownian motions are correlated by ρ, i.e.

$$\mathrm{d}W_{A,t}^{\mathbb{Q}} \mathrm{d}W_{L,t}^{\mathbb{Q}} = \rho \mathrm{d}t.$$

This set-up permits determination of the default ratio as follows:[6]

$$dr(s, \sigma) = \Phi(z) - s \cdot \Phi(z - \sigma), \tag{2}$$

with $s = A_0/L_0$ the initial asset-liability ratio, $\sigma = \sqrt{\sigma_A^2 + \sigma_L^2 - 2\rho\sigma_A\sigma_L}$ the portfolio volatility, $z = -\frac{1}{\sigma}\ln(s) + \frac{\sigma}{2}$, and Φ the cumulative distribution function of the standard normal distribution.

Furthermore, the insurer's SHV can be represented as a function of the price p and the default ratio dr. According to Equation 2, $dr(s, \sigma)$ is continuous in both its arguments, strictly decreasing, and strictly convex in s. Thus, $dr(s, \sigma)$ is invertible with respect to s , and by using the corresponding inverse, there is a unique asset-liability ratio $s(dr, \sigma)$ corresponding to dr. SHV is therefore a continuous function of dr and p:[7]

$$SHV(dr, p) = y(dr, p) \cdot \left[p - \mu \cdot (1 - dr) - \frac{\tau}{1 - \tau} \cdot [\mu \cdot s(dr, \sigma) - p]\right] \tag{3}$$

[5] (Cf. Cummins and Danzon, 1997; Phillips et al., 1998; Myers and Read, 2001; Sherris, 2006; Gatzert and Schmeiser, 2008b; Ibragimov et al., 2010).

[6] Cf. Margrabe (1978).

[7] For the derivation, see Appendix A

3 Insurer response to regulatory constraints

3.1 Risk-based capital requirements

First, I consider a binding rule which restricts the insurer's default ratio to the level dr^{reg}. The regulator could set up such a rule as a risk-based capital requirement and require insurers to hold enough equity such that the default ratio does not exceed dr^{reg}.[8] The insurer will ideally respond by adjusting its equity-premium combination as follows:

Proposition 1. *Suppose that risk-based capital requirements restrict the default ratio to dr^{reg}. Then the insurer will choose the following combination of equity and insurance premium:*[9]

$$K^*(dr^{reg}) = y \cdot \left[\mu \cdot s(dr^{reg}, \sigma) - \mu \cdot (1 - dr^{reg}) - \frac{1}{1-\tau} \cdot \frac{y}{-y_p} \right], \tag{4}$$

$$p^*(dr^{reg}) = \underbrace{\mu \cdot (1 - dr^{reg})}_{\substack{\text{Time-0-value of} \\ \text{indemnity payments}}} + \underbrace{\tau \cdot \mu \cdot (s(dr^{reg}, \sigma) - (1 - dr^{reg}))}_{\substack{\text{Transfer of frictional costs} \\ \text{of equity}}} + \underbrace{\frac{y}{-y_p}}_{\substack{\text{Profit} \\ \text{loading}}}, \tag{5}$$

where y is evaluated at the point $(dr^{reg}, p^*(dr^{reg}))$.

The pricing formula based on the regulatory required default ratio dr^{reg} consists of three components: (1) the arbitrage-free value of claims payments to policyholders, which are adjusted for insurer default risk; (2) a premium charge that transfers frictional costs of equity endowment to policyholders; and (3) a profit loading that is always non-negative. If demand is perfectly price elastic, the last component is equal to zero, the second component matches the frictional costs of equity endowment per

[8] This concept is similar to the Solvency Capital Requirements (SCR) under Solvency II, which builds on the risk measure Value-at-Risk. As Gatzert and Schmeiser (2008b) demonstrate, the insurer's default option value can differ substantially, even though the Value-at-Risk is binding, which provides the insurer with an arbitrage opportunity. To avoid this adverse effect, the regulator could specify capital requirements based on the default ratio. For multi-line insurers, such a procedure is described by (Myers and Read, 2001, p. 568 f.).

[9] For convenience, I assume throughout the paper that the optimal equity position is non-negative, i.e., $K^*(dr^{reg}) \geq 0$.

insurance contract, and the net SHV is zero. If demand is imperfectly elastic,[10] the profit loading will be positive, and the second component will exceed the insurer's frictional costs:

$$\tau \cdot \mu \cdot (s(dr^{reg}, \sigma) - (1 - dr^{reg})) = \tau \cdot \left[\frac{K^*(dr^{reg})}{y} + \frac{1}{1-\tau} \cdot \frac{y}{-y_p} \right] > \tau \cdot \frac{K^*(dr^{reg})}{y}. \quad (6)$$

Under the optimal equity-premium combination, the profit loading on the premium exceeds the "traditional" loading, which only refers to the price in-elasticity of demand. As premiums add to the insurer's assets and lower its required equity, the higher premium helps to save frictional costs of equity. From shareholder's perspective, a positive net SHV is possible under capital requirements, if and only if demand is imperfectly price elastic.

The price formula in Equation (5) explains why insurance prices should be inversely related to insurer default risk (in competitive as well as in monopolistic markets). First, the insurer faces fewer expected payments to policyholders, and shareholders have more limited liability protection. Second, a higher default value allows for lower equity endowment, thus decreasing frictional costs. This basic relation between safety and price is in line with the empirical findings of Sommer (1996).

3.2 Price regulation

Next, I explore the insurer's response to a binding pricing constraint p^{reg} and non-binding capital requirements. This situation may occur if the regulator seeks to ensure solvency by imposing restrictions on insurer products and pricing policies rather than by capital regulation. It may also be the case if capital regulation is lax and the insurer is able to adjust its safety level, but is unable to demand the monopoly price (e.g., due to regulatory price ceilings, or subsidized competitors offering comparable insurance contracts below the monopoly price).

[10] This case is in line with the assumption that the insurance market is monopolistic competitive. Since insurers acquire information during the relationship with policyholders, and hence policyholders cannot change to a competitor without incurring costs, this market form is considered more realistic in insurance markets (see D'arcy and Doherty, 1990).

The insurer reacts to the regulatory price p^{reg} by adjusting its equity endowment, and hence its default ratio. The optimal adjustment of the default ratio is specified by the first derivative of SHV with regard to dr:[11].

$$\frac{\partial y}{\partial dr} \cdot \left[p^{reg} - \mu \cdot (1 - dr) - \frac{\tau}{1-\tau} \cdot [\mu \cdot s(dr) - p^{reg}] \right] + y \cdot \mu - y \cdot \mu \cdot \frac{\tau}{1-\tau} \cdot \frac{\partial s}{\partial dr} = 0 \quad (7)$$

Equation 7 represents the trade-off which the insurer makes when deciding whether a marginal increase of dr is to be preferred. The first term is negative and measures the marginal lower profits due to a lower demand for higher default risk. The second term is positive and represents the value of limited liability expansion. The third term reflects marginal savings in the frictional costs of equity, as a higher default ratio allows for a lower asset-liability ratio.

As the solution of Equation 7 in terms of dr would not be comparable to the result of Equation 5, I will, instead, derive a representation for that price p^{reg} that will induce the insurer to attain the default ratio dr^{aim}. Reordering Equation 7 implies that the corresponding price p^{reg} can be written as

$$\begin{aligned} p^{reg}(dr^{aim}) \quad = \quad & \underbrace{\mu \cdot (1 - dr^{reg})}_{\substack{\text{Time-0-value of} \\ \text{indemnity payments}}} + \underbrace{\tau \cdot \mu \cdot (s(dr^{reg}, \sigma) - (1 - dr^{reg}))}_{\substack{\text{Transfer of frictional costs} \\ \text{of equity}}} \\ & + \underbrace{\mu \left(1 - \tau \cdot \left(1 + \frac{\partial s}{\partial dr}\right)\right) \cdot \frac{y}{-y_{dr}}}_{\substack{\text{Corresponding} \\ \text{profit loading}}} \end{aligned} \quad (8)$$

where y and y_{dr} are evaluated at the point $(dr^{aim}, p^{reg}(dr^{aim}))$. If the regulator fixes prices at $p^{reg}(dr^{aim})$, the insurer will optimally react by choosing the default ratio dr^{aim}.

Comparing Equations 5 and 8 reveals that $p^*(d^{reg})$ and $p^{reg}(dr^{aim})$ are very similar in structure. The first two premium components are identical and represent the arbitrage-free value of actual claims payments and the transfer of frictional costs of equity endowment. The third component of Equation 8 describes the premium

[11] For this purpose, p is fixed at p^{reg} in Equation (3)

loading the regulator has to permit so as to induce the insurer to choose the default ratio dr^{aim}. According to Equation 2, the first factor, $\mu \cdot \left(1 - \tau \cdot \left(1 + \frac{\partial s}{\partial dr}\right)\right)$, is always non-negative and strictly decreasing in dr^{aim}.[12] The second factor, $\frac{y}{-y_{dr}} > 0$, represents a loading, the extent of which depends on the default sensitivity of demand.

$p^{reg}(dr^{aim})$ is well-defined for any default ratio as long as there is some reaction in insurance demand, i.e., $y_{dr} < 0$. Hence, regulators may induce insurers to choose any regulatory desired safety level by setting an adequate pricing constraint. If demand is perfectly sensitive with regard to default risk, $y_{dr} = -\infty$, the third premium component collapses, and regulators will not permit a profit loading on the premium, meaning that the net SHV will be zero. This scenario may be realistic if prices are exogenously fixed, consumers are perfectly informed about insurer default risk, and homogeneous insurers compete on quality. Similar to the classic Bertrand model, in equilibrium, insurers will attain a default risk level such that their risk management costs are just covered at the given price. If demand is less than perfectly elastic by default, regulators must allow a positive profit loading, and thus a positive net SHV, in order to induce dr^{aim}. Note that $p^{reg}(dr)$ does not depend on the price elasticity of demand, i.e., regulatory prices are determined irrespective of the profit loading on the non-regulated premium.

3.3 No binding constraints

To discover if capital and pricing constraints are binding, or whether the insurer will exceed a requirement, let us take a look at the insurer's SHV-maximizing strategy in the absence of any constraints. Since Equation 5 follows from the FOC for pricing, and Equation 8 from the FOC for default risk, the insurer's optimal strategy in the absence of binding constraints is found by solving $p^*(dr^*) = p^{reg}(dr^*)$, which is equivalent to

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[12] Since $\frac{\partial dr(s,\sigma)}{\partial s} \in (0, -1]$, $\frac{\partial s(dr,\sigma)}{\partial dr} = \left(\frac{\partial dr(s,\sigma)}{\partial s}\right)^{-1}$ only has values smaller or equal to -1. As $dr(s, \sigma)$ is strictly convex in s , $s(dr, \sigma)$ is strictly convex in dr , and hence $\frac{\partial s(dr,\sigma)}{\partial dr}$ is strictly increasing in dr.

$$\frac{y}{-y_p} = \mu \cdot \left(1 - \tau \cdot \left(1 + \frac{\partial s}{\partial dr}\right)\right) \cdot \frac{y}{-y_p} \tag{9}$$

or

$$\mu - \tau \cdot \mu \cdot \left(1 + \frac{\partial s}{\partial dr}\right) = \frac{y_{dr}}{y_p} \tag{10}$$

Here, the left-hand side represents the value of the extent of shareholders' limited liability protection (the default put option) as well as the reduction of frictional costs, given a marginal increase in the default ratio. The right-hand side measures the conjoint reaction of insurance demand to a marginal change in default risk and the corresponding change in price, as transaction costs for risk management are transferred to policyholders (see Section 4.2). Proposition 2 provides a representation of the optimal asset-liability ratio s^*. Inserting s^* into Equations 2 and 5 leads to the insurer's optimal strategy (dr^*, p^*) in this situation.

Proposition 2. *In the absence of regulatory constraints, the FOC for the default ratio implies that the insurer optimally attains the asset-liability ratio*

$$s^*(x) = \exp\left(-\sigma \cdot \Phi^{-1}[x] - \frac{\sigma^2}{2}\right),$$

with $x = \tau y_p \mu / \left[y_{dr} - (1-\tau) y_p \mu\right]$ *, and* Φ^{-1} *the quantile function of the standard normal distribution.*

By investigating the components of s^* it is possible to discover under which conditions the insurer has an incentive for safety. First, assume $\tau > 0$ and consider the parameters of the demand function. A necessary condition for $s^* > 1$ is $\frac{y_{dr}}{y_p \mu} > 1 + \frac{\tau}{2}$, meaning that demand reacts more strongly to default risk than to price[13]. Intuitively, insurance demand rewards safety and accepts the fact that transaction costs for risk management are transferred via premiums. If this condition is not met, the insurer will want to hold no equity at all. Such a scenario may be realistic if insurance buyers are protected by a guarantee fund or if government bailouts exist. It is also the case if demand is perfectly sensitive with respect to price, but not with re-

[13] In particular, $-y_{dr} < -y_p \mu$ would mean that consumers prefer a price reduction of one dollar to a one dollar DPO reduction.

spect to default risk, e.g., because consumers can perfectly observe prices and choose the cheaper product, but do not have sufficient information about contract quality. Again, the insurer has no incentive to ensure safety, and capital requirements will always be binding.

In the opposite case, i.e., $\frac{y_{dr}}{y_p \mu} \to \infty$, demand is perfectly elastic to default risk, but not so to price. The insurer then aims to avoid any default risk, i.e., s^* tends to infinity (as does the price). Capital requirements and price floors will always be non-binding and solvency regulation is not necessary.

Next, let us assume that $\frac{y_{dr}}{y_p \mu} > 1 + \frac{\tau}{2}$, and consider the border case $\tau \to 0$, meaning that the insurer is able to hold unrestricted equity without incurring transaction costs. In this case, it will choose to hold an infinite amount of equity so as to avoid all default risk.[14] Again, capital requirements will always be non-binding. Price floors can be binding, but will have no influence on the insurer's safety level. In summary, a positive default risk is optimal only in the presence of frictional costs of equity ($\tau > 0$), whereas indirect costs of capital related to the risk premiums that shareholders demand for bearing undiversifiable risks do not solely imply insurer default risk.

4 Implications

4.1 Comparison of capital requirements and price floors

Based on the findings on insurer response to regulation, it is possible to make comparisons between regulatory constraints on capital levels and on pricing. Assume that the insurer's strategy in the absence of regulatory constraints is uniquely characterized by the FOC in Equation 8, and let s^*, dr^* and p^* denote the optimal asset-liability ratio, default ratio, and price, respectively. Furthermore, let $p^*(.)$ denote the insurer's optimal price in response to a given default ratio according to Equation 5.

[14] This result is consistent with Rees et al. (1999, p. 61), Zanjani (2002, p. 288), and Froot (2007, p. 293).

In the case that the regulator seeks to restrict the default ratio to $dr^{aim} \in (0, dr^*)$, the following proposition allows the comparison of capital and price requirements as instruments of solvency regulation.

Proposition 3. *Let $dr^{aim} \in (0, dr^*)$ be the regulatory desired default ratio. It yields $p^*(dr^{aim}) < p^{reg}(dr^{aim})$.*

Proposition 3 has several implications. To start with, $p^{reg}(dr^{aim}) > p^*(dr^{aim}) \geq p^*$ implies that the regulator has to implement a binding price floor in order to decrease insurer default risk by price regulation. The reason is that the price floor raises the insurer's expected profits per contract, and thus provides the insurer with an incentive to attract a larger number of customers by choosing a higher safety level.[15]

Even more interesting, it follows that risk-based capital requirements are a more efficient instrument than price floors for solvency regulation, as they allow for lower insurance prices: when confronted with risk-based capital requirements at the level $dr^{aim} < dr^*$, the insurer responds by choosing the price $p^*(dr^{aim})$, which is lower than the corresponding price floor $p^{reg}(dr^{aim})$, which would also lead to dr^{aim}. As the safety level is identical and only the prices differ, capital regulation is therefore superior to price regulation from the consumers' perspective.

The intuition behind this result is that risk-based capital requirements enable the insurer to choose the most efficient combination of equity endowment and premium income, and a part of the ensuing efficiency gain will be transferred to policyholders. Formally, the price restriction leads away from the optimal equity-premium combination given by Proposition 1. As the solution of Proposition 1 maximizes SHV, we can also conclude that price floors are detrimental for shareholders, and shareholders would also advocate risk-based capital requirements. Even though the price floor allows for higher profits per insurance contract, it cuts demand, and in sum decreases the shareholder value.

Next, let us take a look at the distance $p^{reg}(dr^{aim}) - p^*(dr^{aim})$, and its influencing factors. This distance measures the efficiency advantage and thus yields the maxi-

[15] See also Equation 7.

mum cost at which implementing risk-based capital requirements is still preferable to price regulation.[16]

Equations 5 and 8 give the length of this interval:

$$\Delta p = p^{reg}(dr^{aim}) - p^{*}(dr^{aim}) = \underbrace{\mu\left(1 - \tau \cdot \left(1 + \frac{\partial s}{\partial dr}\right)\right) \cdot \frac{y}{-y_{dr}}}_{\text{Required loading on the price floor}} - \underbrace{\frac{y}{-y_p}}_{\substack{\text{Profit} \\ \text{loading}}} \quad . \tag{11}$$

The distance Δp reflects the profit loadings on the price floor and on the optimal premium under capital requirements. The expression can easily be calculated for some corner cases. If price sensitivity of demand becomes large, i.e., $y_p \to -\infty$, the insurer tends to offer insurance at the fair premium, and profit mark-ups disappear. The required price floor, however, is unaffected by y_p, and hence the efficiency advantage of price floors increases. If, in turn, default sensitivity of demand becomes large ($y_{dr} \uparrow$), price floors will be effective at lower levels, and thus the efficiency advantage of risk-based capital regulation decreases.[17] Furthermore, Δp will be large if a small change in default risk causes a large change in the amount of frictional costs. This is the case if τ is high, i.e., if there are severe frictional costs of holding equity, and if $\frac{\partial s}{\partial dr}$ takes a high negative value. The latter will occur if the portfolio risk is high, and if dr^{aim} is close to zero. In all these cases, regulators have to allow for a high profit loading on the premium to induce dr^{aim} by means of a price floor, and risk-based capital requirements will lead to a considerable premium reduction.

4.2 Price floors in the presence of capital requirements

Can price floors effectively enhance insurer safety levels when risk-based capital requirements are in place? What effect does rate suppression have on insurer safety levels? To investigate these questions, I place a weak restriction on the shape of the demand function, which allows more insight into insurer reaction to price regulation.

[16] Assume that all implementation costs will be borne by insurance market participants, and insurers will pass them on to policyholders.

[17] At the extremes, i.e., for $y_{dr} \to \infty$ and $y_p < \infty$, the insurer tends to set its default risk to zero, capital requirements are always non-binding, and price floors are always effective.

For this purpose, assume that

$$\frac{y_{dr}(dr,p)}{y(dr,p)} \text{ is non-increasing in } p. \tag{12}$$

The interpretation of this assumption is that consumers who buy insurance even at high prices are at least as sensitive to default risk as consumers are who only buy at low prices. Appendix E shows that the assumption is fulfilled for several frequently employed demand functions. Now, it can be shown that the price interval $(p^*(dr^{aim}), p^{reg}(dr^{aim}))$ defines the area in which price floors are binding, but do not enhance insurer safety levels if risk-based capital requirements are also in place.

Proposition 4. *Assume that the regulator demands risk-based capital requirements at the level dr^{aim} and that $y(dr,p)$ fulfills the statement in line 12. Then each price floor in the interval $(p^*(dr^{aim}), p^{reg}(dr^{aim}))$ is binding, but does not induce a default ratio below dr^{aim}.*

When confronted with capital requirements and a price floor in the aforementioned interval, the insurer will countervail the higher premium by choosing less initial equity endowment per contract in order to maintain the default ratio. Thus, the price floor reduces the insurer's potential to shift risks from policyholders to shareholders, and instead risk is spread among policyholders. It is notable that such a situation is detrimental for policyholders as well as for shareholders: Policyholders are worse off, since the price floor makes insurance more expensive, but does not enhance quality; SHV also decreases, since the price floor leads the insurer away from the SHV-maximizing strategy. However, once the regulator sets up a price floor which is higher than $p^{reg}(dr^{aim})$, it will overrule the capital requirement, and effectively enhance safety.

4.3 Price ceiling

The considerations above have shown that binding price floors can be used as an instrument for solvency regulation. In turn, regulators are often concerned about the affordability of insurance, and prescribe upper bounds for the permissible insurance premium. If such a price ceiling is binding, it will undermine the insurer's incentives for safety:

Proposition 5. *Assume that the regulator sets up a price ceiling* p^{reg} *below the unregulated price* p^*. *Then the insurer will react by choosing a higher default ratio, i.e.* $dr^*(p^{reg}) > dr^*$.

An important concept for price regulation is the fair premium, which reflects the insurer's costs of offering insurance at a specified default risk level.[18] In this framework, the fair premium can be formulated as

$$p^{fair}(dr^{aim}) = \underbrace{\mu \cdot (1 - dr^{aim})}_{\substack{\text{Time-0-value of} \\ \text{indemnity payments}}} + \underbrace{\tau \cdot \mu \cdot \big(s(dr^{aim}, \sigma) - (1 - dr^{aim})\big)}_{\text{Frictional costs of equity}}.^{19} \tag{13}$$

The fair premium accounts for shareholders' limited liability protection as well as the frictional costs corresponding to the specified default risk level dr^{aim} , and implies that SHV is zero. However, unless demand is perfectly elastic with regard to default risk, or the regulator restrict default risk by means of other measures, this type of rate suppression induces the insurer to deviate from dr^{aim}:[20]

Proposition 6. *Assume that* $y_{dr} < \infty$ *and that there are no binding capital requirements. Confronted with a pricing constraint at the fair premium* $p^{fair}(dr^{aim})$*, the insurer will choose a default ratio that is strictly higher than* dr^{aim}.

It is notable that the incentive for higher default risk may exist, even if demand is perfectly price sensitive, and the insurer would choose $p^{fair}(dr^{aim})$ under capital requirements. In fact, binding capital requirements seem to be the only way to prevent the default risk increase, while purely monitoring and adjusting the regulated price to the insurer's new default ratio are insufficient. Insurers have manifold possibilities for risk shifting after contracts have been purchased, and thus there

[18] Cf. Doherty and Garven (1986), who determine the fair premium in an OPT framework.
[19] For applications and modifications of the fair premium concept based on OPT, see Myers and Read (2001), Sherris (2006), as well as Gatzert and Schmeiser (2008b).
[20] Note that the proof of Proposition 6 does not require the condition in line 12.

might be an opportunity for positive SHV until the regulator becomes aware of the risk shifting. Examples for insurers' risk shifting opportunities include shifts in the asset allocation towards riskier investments, a less cautious underwriting policy or insufficient reinsurance protection.

The empirical literature reports several adverse effects of regulatory rate suppression. Klein et al. (2002) find that insurers subject to price regulation lower their capital levels, which is in line with Proposition 5. Harrington and Danzon (2000) report that rate regulation in workers' compensation insurance leads to increased loss costs, indicating that rate regulation lowers the insurer's incentives for loss control. For the US automobile insurance market, Weiss et al. (2010) obtain similar results.

5 Numerical examples

5.1 Model parameters

In the following, I use a numerical example to illustrate the results graphically and to examine the influence of parameter changes. For the asset-liability model, I consider the following parameterization:[21] $\mu = 250, \sigma_A = 5\%, \sigma_L = 20\%, \rho_{AL} = 0\%$, and $r = 0\%$. For the insurance demand function, I use the function that showed the best fit in an experiment involving insurance purchase behavior in the presence of default risk (see Zimmer et al. (2011)):

$$y(p, dr) = n \cdot exp\left(-f_p \cdot p - f_d \cdot dr\right), \tag{14}$$

where n represents the market size, and f_p, f_d measure demand sensitivity to price and default risk. This type of function implies $\frac{y}{-y_p} = \frac{1}{-f_p}$ and $\frac{y}{-y_p} = \frac{1}{f_d}$, and thus all equations describing the insurer's best response functions are closed-form solutions

[21] The parameterization of the asset-liability model follows the empirical study of Yow and Sherris (2008). $\sigma_A = 5\%$ is consistent with the estimated volatility parameter of their asset model (cf. Yow and Sherris, 2008, pp. 306-308), $\mu = 250\$$ and $\sigma_L = 20\%$ may represent the expectation value and volatility of liability insurance claims (cf. Yow and Sherris, 2008, p. 209). As the measures in the subsequent analysis build on risk-neutral valuation, I can omit the drift rates under empirical probabilities.

(see Equations 5, 6, and 8). For the carrying charge τ and the parameters of the demand function, I apply different values and examine their influence. In the base scenario, $\tau = 10\%$, $f_p = 7.2\%$, and $f_d = 40$.[22]

5.2 Capital and price regulation

The insurer's optimal strategies are depicted in Figure 1. The solid line provides the insurer's optimal price corresponding to a given default ratio (Section 3.1, Equation 5), and the dashed line describes the insurer's optimal default ratio under price regulation (Section 3.2, Equations 7, 8). The intersection between these lines (Fig. 1, Point C) yields the outcome of optimizing both the default ratio and the price, thus describing the strategy in the absence of binding constraints (Section 3.3, Proposition 2). In the base scenario, the unregulated strategy is $dr^* = 1.0\%$ and $p^* = 269.54$.

If the regulator restricts the default ratio by means of risk-based capital requirements to $dr^{reg} = 0.5\%$, the insurer will raise the price to $p^*(0.5\%) = 272.91$ (Fig. 1, Point A). Alternatively, the regulator could achieve the same default ratio by means of the price floor $p^{reg}(0.5\%) = 280.42$ (Fig. 1, Point B). According to Proposition 3, capital requirements are the more efficient instrument for solvency regulation, and permit a premium reduction of $\Delta p = 280.42 - 272.91 = 7.51$ in the base scenario. Furthermore, the interval between 272.91 and 280.42 defines the area of price floors which are binding, but do not enhance the insurer's safety level if capital requirements at the default ratio 0.5% are also in place (Proposition 4).

Vice versa, let us analyze the consequences of a binding price ceiling. If the regulator does not enforce capital requirements and suppresses the premium by 1% below the unregulated price, i.e., $p^{reg} = 0.99 \cdot 269.54 = 266.84$, the insurer will respond by increasing the default ratio to 1.24% (Fig. 1, Point D). Hence, the price reduction of 1% implies a default risk increase by 24%.

[22] Under the insurer's SHV-maximizing equity-price combination, this parameter set implies that the price elasticity of demand is equal to 19.41, and the default elasticity is equal to 0.4, both of which are similar to the empirically estimated parameters in (Yow and Sherris, 2008, p. 318).

5.3 Influence of the sensitivity parameters of demand

I next investigate the variation in the results if the default sensitivity of demand increases from $f_d = 40$ to $f_d = 50$, e.g., due to higher risk transparency in the market. As depicted in Figure 2, the dashed line moves downwards, and this has two consequences: Firstly, the intersection with the solid line moves to the top left, i.e. insurance will become safer and more expensive. Secondly, price regulation becomes more effective, and the insurer will attain the default ratio 0.5% already at the price floor 276.14. Since the response function to capital regulation, $p^*(dr)$, is not affected, the efficiency advantage of capital regulation over price floor decreases.

The gray arrows in Figure 2 illustrate the consequences of $f_d \to \infty$. At the limit, the dashed line will be congruent with the fair premium $p^{fair}(dr)$ (see Equation 8). Also, the solid line will move to $p^{fair}(dr)$ if $f_p \to \infty$ (see Equation 5). Hence, the response functions to capital and price regulation are identical if demand reacts infinitely strong to price and default risk, $f_d \to \infty$, $f_p \to \infty$.

5.4 Threshold for investment in a risk-based regulatory scheme

In the base scenario, the optimal premium under risk-based capital requirements is lower by 7.51 than the corresponding price floor. Assume that the current solvency regulation system is based on price floors, the costs of regulation are borne by policyholders, and insurance contracts are homogeneous. In this environment, changing to a risk-based capital requirement system of regulation will be advantageous to both policyholders and shareholders if the regulator invests up to 7.51 per contract (or 3.0% of insurance liabilities) in such a scheme. With higher default sensitivity of demand, the threshold shrinks to 3.2 per contract (or 1.3% of insurance liabilities). Ceteris paribus, there is less potential to lower insurance prices by shifting from price floors to capital regulation if the demand reacts strongly to default risk. Vice versa, the threshold enlarges to 5.9% of liabilities if default sensitivity is only $f_d = 30$ (see Table 1). In this case, policyholders have less power to control insurer default risk, making capital regulation more justifiable.

Figure 3 compares these results to scenarios with higher price sensitivity of demand ($f_d = 9.0\%$ instead of 7.2%) and higher frictional costs ($\tau = 12.5\%$ instead of 10.0%). Higher price sensitivity induces the insurer to demand lower profit mark-ups on the premium if default risk is controlled by capital requirements (irrespective of the default sensitivity). Hence, the threshold at which risk-based regulation becomes superior increases by 1.1 percentage points of insurance liabilities. Furthermore, frictional costs of equity increase the efficiency advantage of risk-based capital regulation, because the insurer becomes more reluctant to hold equity and aims at increasing default risk. Hence, the regulator must increase the price floor to counteract this incentive, particularly if demand is only weakly default sensitive. In the latter case ($\tau = 12.5\%$, $f_d = 30$), the threshold for investment in risk-based insurance regulation is 7.9% .

6 Discussion

6.1 Multiple risk management instruments

To model the insurer's optimal safety level, the framework in this paper considers the equity level as a variable, while the risk profile of the asset-liability portfolio is fixed; this procedure is similar to Cummins and Danzon (1997), Zanjani (2002) or Yow and Sherris (2008). In contrast, insurer risk-taking could be modeled by the fraction of risky investments in the insurer's assets (cf. MacMinn and Witt, 1987; Filipovic et al., 2009), or the purchase of reinsurance. Presumably the basic results of this paper can be transferred to models with multiple risk management instruments: Risk-based capital regulation only requires insurers to comply with the desired safety level, while the choice of risk management instruments is not restricted. Hence, insurers can choose the most efficient mix of instruments, such as equity, reinsurance, or alternative risk transfer. Singular regulatory requirements, such as pricing constraints, underwriting limits or investment guidelines impose additional restraints on the insurer's risk management strategy, and lead away from the most efficient combination. The company therefore faces higher costs for offering insurance, and insurance contracts will be more expensive for policyholders.

6.2 Reference to the bank regulation literature

Similar to the analysis of capital requirements and price floors in insurance regulation, the bank regulation literature provides a discussion about deposit rate ceilings as a regulatory instrument. Hellmann et al. (2000) show that deposit rate ceilings can prevent banks from investing their capital in risky assets, as they increase the bank's franchise value. Repullo (2004) sets up a model with imperfect competition by employing Salop's (1979) circular road model. The author shows that both risk-based capital requirements and deposit rate ceilings can ensure that banks invest in prudent assets. However, risk-based capital requirements allow for higher deposit rates. These results are consistent with Proposition 3 in this article, even though the model specifications differ: particularly because insurance claims are stochastic and insurance demand is affected by the insurer's safety level.[23] An interesting extension of the proposed model in this article would be the implementation of the derived response function into a competition model, such as in Salop (1979).

6.3 Interest rate guarantees in life insurance

The paper shows that in the presence of capital requirements, there is a price interval in which price floors are binding and make insurance more expensive, but have no effect on insurer safety levels. In this situation, price floors decrease both consumer welfare and shareholder value and are thus detrimental to total welfare. One real-life example of such a situation is European endowment and private pension insurance, which is subject to maximum discount rates for calculating actuarial provisions. This restriction effectively serves as an upper boundary for the guaranteed interest rate which is included in the contract or, conversely, as a minimum premium for each unit of guaranteed insurance benefit (price floor). Once the EU framework for insurance regulation, Solvency II, comes into force, life insurers are also subject to risk-based capital requirements. According to Proposition 4, the interest rate restriction will either be ineffective with regard to life insurers' safety levels, or will

[23] Hellmann et al. (2000) and Repullo (2004) assume that depositors have complete deposit insurance protection against bank default risk.

override, and thus make redundant, the Solvency II capital requirements. In either case, the result will not be optimal for welfare. It will be interesting to see whether or not the interest rate constraint is effective and, if so, how the situation could be improved. These questions could be answered by extending and calibrating the model to a life insurance context.

7 Conclusion

The paper studies the interaction between price regulation and optimal safety levels of insurance companies. It shows that rate suppression induces insurers to reduce their safety levels. Binding price floors, in turn, induce higher safety levels and thus act as a regulatory instrument for solvency regulation. If insurance demand is less than perfectly elastic with regard to default risk, risk-based capital requirements turn out to be more efficient than price floors, as they lead to lower insurance prices, and therefore increase welfare.

Quantification of the potential welfare advantage of risk-based regulation can support public policymakers in their decision whether to implement risk-based regulatory standards or to rely on product and price regulation. The analytical representation of the insurer's response shows that risk-based capital requirements are superior, especially if insurance demand reacts strongly to price and weakly to insurer default risk, if holding equity causes severe frictional costs, and if insurance claims exhibit a high volatility.

The paper provides several starting points for future research. The predicted influence of price regulation on insurer default risk could be subjected to empirical tests. Further, additional research should be conducted to estimate regulatory costs, e.g., due to the implementation of risk models, or the supervision of these models by regulatory agencies. These results could be balanced against the efficiency advantage of risk-based capital requirements, which is quantified in this article. Finally, the paper illustrates that using multiple regulatory instruments, such as capital requirements and price floors, can lead to suboptimal outcomes. As discussed in section 6.3, this question could be explored by translating the framework into a life insurance context.

Appendix

A Derivation of Equation 3

Given the portfolio volatility σ and the default ratio dr, the insurer's asset-liability ratio must fulfill

$$s(dr,\sigma) = \frac{A_0}{L_0} = \frac{y(dr,p)\cdot p + (1-\tau)\cdot K}{y(dr,p)\cdot\mu}, \tag{15}$$

where the second equation follows from the definition of A_0 and L_0. Solving Equation (15) for K gives the corresponding initial equity endowment:

$$K = y(dr,p)\cdot\frac{s(dr,\sigma)\cdot\mu - p}{1-\tau}. \tag{16}$$

Inserting this equation and the definition $dr = \exp(-r)\mathbb{E}_{\mathbb{Q}}\left[\max\{L_1 - A_1; 0\}\right]/L_0$ into Equation (1) implies that:

$$\begin{aligned}
SHV(dr,p) &= \exp(-r)\mathbb{E}_{\mathbb{Q}}\max\{A_1 - L_1; 0\} - K \\
&= \exp(-r)\mathbb{E}_{\mathbb{Q}}[A_1 - L_1 + \max\{L_1 - A_1; 0\}] - K \\
&= A_0 - L_0 + L_0\cdot dr - K \\
&= y(dr,p)\cdot p + (1-\tau)\cdot K - y(dr,p)\cdot\mu\cdot(1-dr) - K \\
&= y(dr,p)\cdot\left[p - \mu\cdot(1-dr) - \frac{\tau}{1-\tau}\cdot[\mu\cdot s(dr,\sigma) - p]\right].
\end{aligned}$$

B Proof of Proposition 1

The first-order condition for pricing is

$$\begin{aligned}
&\frac{\mathrm{d}}{\mathrm{d}p}SHV(dr^{reg},p) = 0 \\
\Leftrightarrow\quad & y_p\cdot\left[p - \mu\cdot(1-dr^{reg}) - \frac{\tau}{1-\tau}\cdot[\mu\cdot s(dr^{reg},\sigma) - p]\right] + \frac{y}{1-\tau} = 0.
\end{aligned}$$

Solving the latter equation for p and inserting the result into Equation (16) yields the statement.

C Proof of Proposition 2

The first-order condition for the default ratio in the absence of constraints, Equation (10), implies that

$$\frac{\partial dr}{\partial s} = \left(\frac{\partial s}{\partial dr}\right)^{-1} = -\frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu}. \tag{17}$$

Let φ denote the density function of the standard normal distribution, and $\bar{z} = z - \frac{\sigma}{2} = -\frac{1}{\sigma}\ln(s)$. Using Equation (2), the left-hand side of Equation (17) can be rewritten as

$$\begin{aligned}
\frac{\partial dr}{\partial s} &= -\frac{\varphi(z)}{\sigma s} + s \cdot \frac{\varphi(z-\sigma)}{\sigma s} - \Phi(z-\sigma) \\
&= \frac{\varphi(z)}{\sigma s}\left(-1 + s \cdot \frac{\varphi(z-\sigma)}{\varphi(z)}\right) - \Phi(z-\sigma) \\
&= \frac{\varphi(z)}{\sigma s}\left(-1 + s \cdot \exp\left[-\frac{1}{2}\left[\left(\bar{z} - \frac{\sigma}{2}\right)^2 - \left(\bar{z} + \frac{\sigma}{2}\right)^2\right]\right]\right) - \Phi(z-\sigma) \\
&= \frac{\varphi(z)}{\sigma s}\left(-1 + s \cdot \exp[\bar{z}\sigma]\right) - \Phi(z-\sigma) \\
&= \frac{\varphi(z)}{\sigma s}\left(-1 + s \cdot \exp[-\ln(s)]\right) - \Phi(z-\sigma) \\
&= -\Phi(z-\sigma)
\end{aligned}$$

Replacing $\frac{\partial dr}{\partial s}$ by the right-hand side of Equation 17 implies that

$$\begin{aligned}
& -\Phi(z-\sigma) = -\frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu} \\
\Leftrightarrow \quad & \Phi\left(-\frac{1}{\sigma}\ln(s) - \frac{\sigma}{2}\right) = \frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu} \\
\Leftrightarrow \quad & -\frac{1}{\sigma}\ln(s) - \frac{\sigma}{2} = \Phi^{-1}\left[\frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu}\right] \\
\Leftrightarrow \quad & s = \exp\left(-\sigma \cdot \Phi^{-1}\left[\frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu}\right] - \frac{\sigma^2}{2}\right).
\end{aligned}$$

D Proof of Proposition 3

At the limit, $dr^{reg} \to 0$, it yields

$$p^{reg}(dr^{reg}) - p^*(dr^{reg}) = \mu \cdot \left(1 - \tau \cdot \big(1 + \underbrace{\frac{\partial s}{\partial dr}}_{\to -\infty}\big)\right) \cdot \underbrace{\frac{y}{-y_{dr}}}_{<\infty} - \underbrace{\frac{y}{-y_p}}_{<\infty}$$

$$\to \quad \infty \text{ (for } dr^{reg} \to 0).$$

As $p^{reg}(dr^{reg}) - p^*(dr^{reg}) \neq 0$ for $dr^{reg} \in (0, dr^*)$, and both functions are continuous in this interval, we have $p^{reg}(dr^{reg}) - p^*(dr^{reg}) > 0 \; \forall \; dr^{reg} \in (0, dr^*)$.

E Examples for demand functions that fulfill Eq. 12

I show that the statement in line 12 is fulfilled by some common demand functions.
(1) Linear demand (cf. Yow and Sherris, 2008, p. 311): $y(dr, p) = \alpha - \beta \cdot p - \gamma \cdot dr$.

$$\frac{y_{dr}(dr, p)}{y(dr, p)} = \frac{-\gamma}{y(dr, p)} \text{ decreases in } p \text{ (as } y(dr, p) \text{ decreases in } p)$$

(2) Constant default-risk elasticity of demand: $\epsilon_{dr} \equiv -y_{dr}/(y/dr)$.

$$\frac{y_{dr}(dr, p)}{y(dr, p)} = -\frac{\epsilon_{dr}}{dr} \text{ is constant in } p.$$

(3) Exponential demand (cf. Zimmer et al., 2011): $y(dr, p) = n \cdot \exp\left(-f_p \cdot p - f_d \cdot dr\right)$.

$$\frac{y_{dr}(dr, p)}{y(dr, p)} = -\frac{1}{f_p} \text{ is constant in } p.$$

F Proof of Proposition 4

Let $p^{reg} := p^{reg}(dr^{aim})$ and $p \in (p^*(dr^{aim}), p^{reg})$. It yields:

$$
\begin{aligned}
& \frac{1}{y(dr^{aim},p)} \cdot \frac{\mathrm{d}SHV}{\mathrm{d}\ dr}\bigg|_{(dr^{aim},p)} \\
= \ & \frac{y_{dr}(dr^{aim},p)}{y(dr^{aim},p)} \cdot \left[\frac{p}{1-\tau} - \mu \cdot (1-dr^{aim}) - \frac{\tau}{1-\tau} \cdot \mu \cdot s(dr^{aim})\right] + \mu - \mu \cdot \frac{\tau}{1-\tau} \cdot \frac{\partial s}{\partial dr} \\
> \ & \frac{y_{dr}(dr^{aim},p^{reg})}{y(dr^{aim},p^{reg})} \cdot \left[\frac{p^{reg}}{1-\tau} - \mu \cdot (1-dr^{aim}) - \frac{\tau}{1-\tau} \cdot \mu \cdot s(dr^{aim})\right] + \mu - \mu \cdot \frac{\tau}{1-\tau} \cdot \frac{\partial s}{\partial dr} \\
= \ & \frac{1}{y(dr^{aim},p^{reg})} \cdot \frac{\mathrm{d}SHV}{\mathrm{d}\ dr}\bigg|_{(dr^{aim},p^{reg})} = 0.
\end{aligned}
$$

Confronted with the regulatory price p, the insurer could increase SHV by choosing a higher default ratio than dr^{aim}. This, however, is not permitted due to capital requirements, and the insurer therefore stays with dr^{aim}.

G Proof of Proposition 5

Let $p < p^* = p^*(dr^*)$. Running the calculation analogously to the proof of Proposition 4, it follows that

$$
\frac{1}{y(dr^*,p)} \cdot \frac{\mathrm{d}SHV}{\mathrm{d}\ dr}\bigg|_{(dr^*,p)} > \frac{1}{y(dr^*,p^*)} \cdot \frac{\mathrm{d}SHV}{\mathrm{d}\ dr}\bigg|_{(dr^*,p^*)} = 0,
$$

meaning that the insurer aims at a higher default ratio than dr^* in the presence of the price ceiling.

H Proof of Proposition 6

Let $p^{fair} = p^{fair}(dr^{aim})$. At the point $\left(dr^{aim}, p^{fair}\right)$ it yields:

$$
\begin{aligned}
&\left.\frac{\mathrm{d}SHV}{\mathrm{d}\ dr}\right|_{\left(dr^{aim}, p^{fair}\right)} \\
= \ & y_{dr}(dr^{aim}, p^{fair}) \cdot \underbrace{\left[\frac{p^{fair}}{1-\tau} - \mu \cdot (1 - dr^{aim}) - \frac{\tau}{1-\tau} \cdot \mu \cdot s(dr^{aim})\right]}_{=0} \\
&+ y(dr^{aim}, p^{fair}) \cdot \mu \cdot \big(1 - \frac{\tau}{1-\tau} \cdot \underbrace{\frac{\partial s}{\partial dr}}_{<0}\big) > 0,
\end{aligned}
$$

and thus, the insurer will optimally attain a higher default ratio than dr^{aim}.

I Figures

Figure 1: Insurer's optimal strategies under capital regulation or price regulation (base scenario)

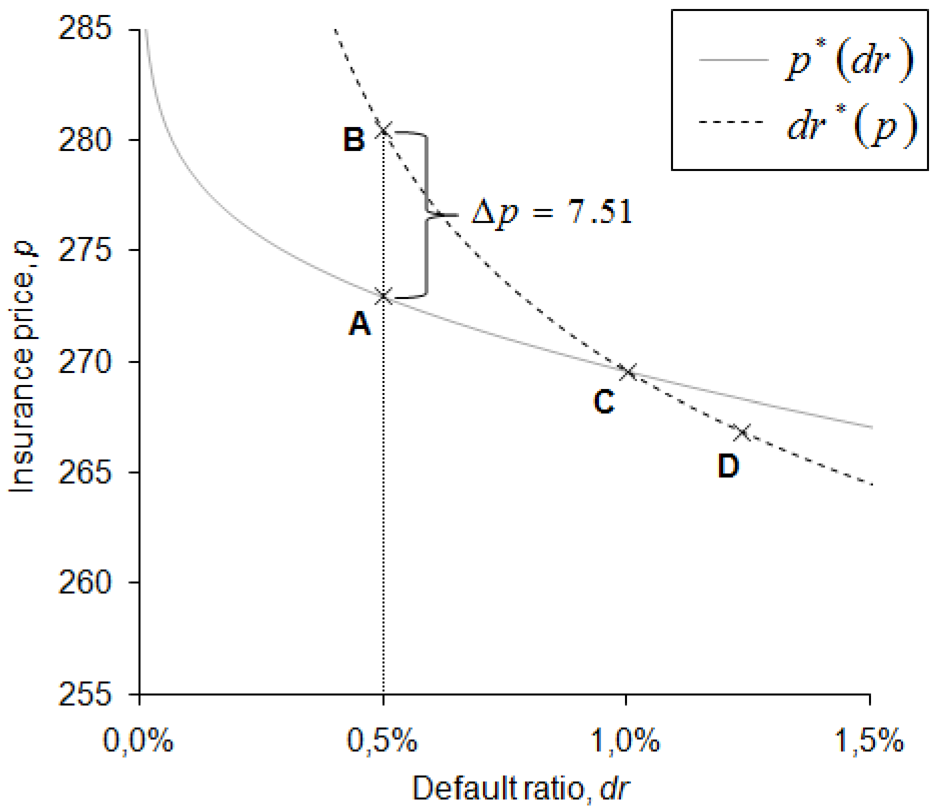


Figure 2: Insurer's optimal strategies under capital regulation or price regulation; default sensitivity of demand $f_d = 40, 50, \infty$.

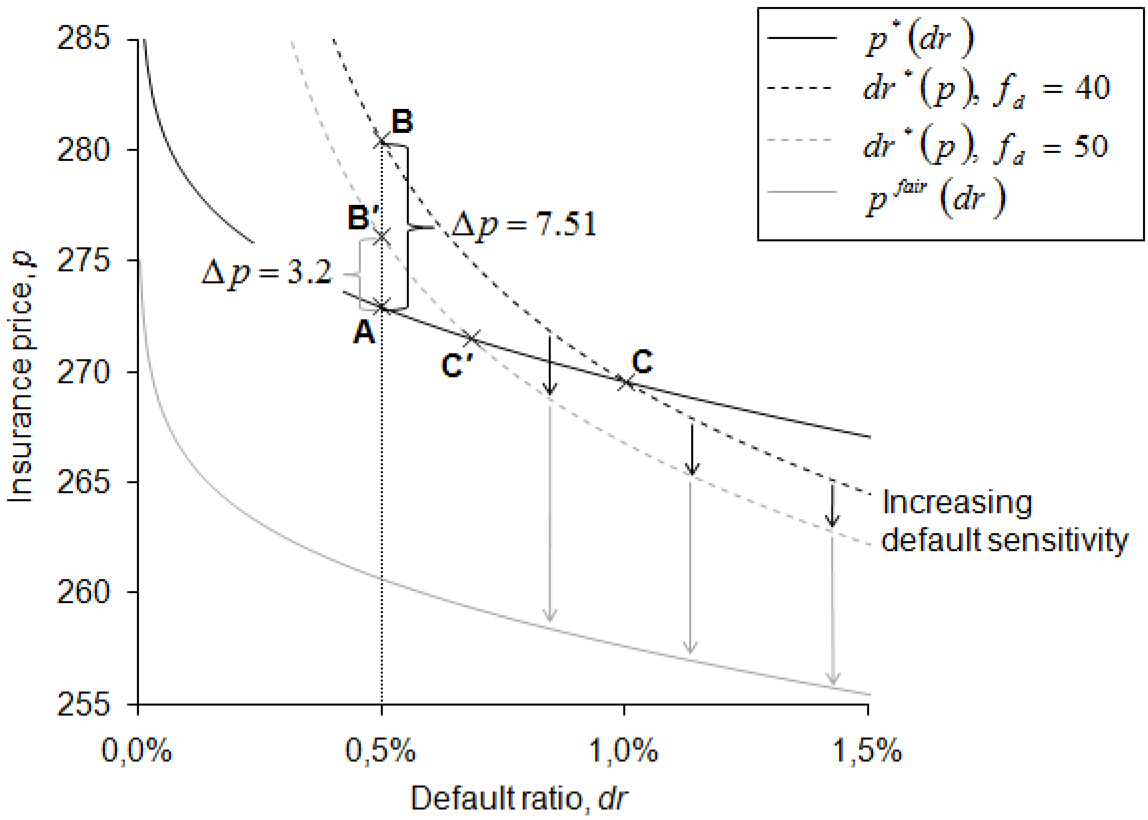
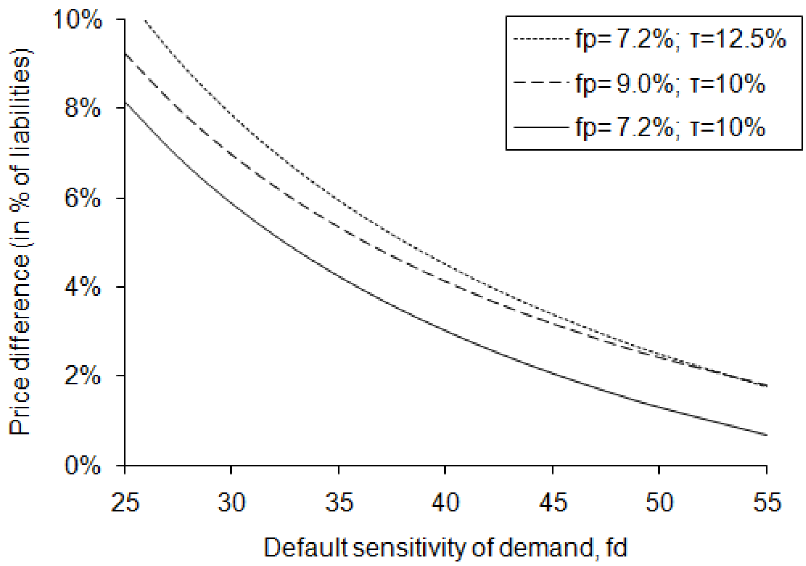


Figure 3: Price difference (in % of liabilities) between insurance premium under risk-based capital requirements and price floor corresponding to default ratio 0.5%.



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