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Captial 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 aspect of insurance company regulation. Capital regulation is intended to keep the risk of corporate default at a certain level, thus reducing market inefficiencies caused by information asymmetries and agency conflicts between policyholders and the insurer (Munch and Smallwood, 1981; Filipovic et al., 2009). 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). In the European Union, risk-based capital requirements will be implemented under the future insurance regulation system Solvency II beginning in 2013. Comparisons between different forms of capital standards, especially between the U.S. system and Solvency II and Switzerland's SST, have been made by Eling et al. (2007), Holzmüller (2009), and Cummins and Phillips (2009). Some of the most important differences between the capital standards studied involve model complexity and estimated implementation efforts, their accuracy and risk-sensitivity in economic crises, and the risk of misleading incentives.

The supervision of policy conditions and premium rates had been the usual form of insurance regulation in the European Union, until insurance markets were deregulated by the Third Generation Insurance Directive in 1994. Today, regulatory intervention into insurance pricing and product design is widespread in most markets of Asia and Latin America (OECD, 2003), and also in some particular lines of insurance in certain U.S. states (Tennyson, 2007). Depending on the state and the period under consideration, regulated prices in the United States are found to be either higher or lower than unconstrained prices (Cummins et al., 2001; Harrington, 2002; Grace and Phillips, 2008).

The economic justification for regulatory maximum prices (ceilings) is based on consumer search costs and reduced competition, which increase shareholder market power and may cause excessive profit mark-ups on the premium (Harrington, 1992). Minimum prices (floors), in turn, aim at preventing "go-for-broke" strategies and "destructive competition" and thus act as instruments of solvency regulation (Joskow, 1973; Hanson et al., 1974; Grace and Klein, 2009). Even though the reasoning behind price floors implicitly builds on an interaction between price regulation and insurers' capital structure decisions, there is little theoretical evidence in support of this relationship.[1] Indeed, several important questions are

[1] Existing approaches are discussed in Section 2.

unaddressed by the extant literature: Are risk-based capital requirements more efficient than price floors for solvency regulation of insurance companies? If so, to what extent should regulators invest in risk-based regulation systems? Does it make sense to have capital requirements and set minimum prices at the same time?

This article presents an innovative approach to working out the interdependence between risk-based capital requirements and pricing constraints as instruments of insurance regulation. By comparing the insurer's best-response functions under different regulatory regimes, the model derives implications for designing a welfare-enhancing regulation policy. It explains to what extent risk-based capital requirements are superior to price regulation, and under which conditions capital requirements and price regulation can appropriately coexist.

The model set-up considers a stock insurer that simultaneously decides on its initial equity endowment and the price it will charge for insurance under a shareholder-value maximizing strategy. Shareholder equity endowment causes frictional costs, such as corporate taxation or agency problems. The outcome of consumers' buying decision is modeled by a two-parametric insurance demand function, reacting on the insurance price and the insurer's default risk (quality). In an environment with no regulation or no binding regulatory requirements, the insurer determines its optimal safety level by balancing the demand reaction against the costs of risk management. The latter include the frictional costs of equity as well as change in limited liability protection. Based on the outcome of this tradeoff, the insurer sets a SHV-maximizing premium.

Risk-based capital requirements and pricing constraints influence the insurer's tradeoff different ways. As a binding price floor raises expected profit per insurance contract, the insurer will wish to increase sales and therefore will choose a higher safety level than in the unregulated case. Risk-based capital requirements, on the other hand, set the safety level directly, and the insurer will figure out the combination of equity endowment and premium income that meets the requirement most efficiently. It turns out that risk-based capital regulation has an efficiency advantage over price regulation that increases shareholders' as well as policyholders' benefits. Quantifying these benefits enables to determine a threshold of regulatory investment in a risk-based regulation scheme.

The remainder of the paper is organized as follows. Section 2 takes a look at the relevant literature and places this article within this body of work. Section 3 presents the model framework. Section 4 derives insurer best response functions to regulatory constraints. In particular, we determine the shareholder-value maximizing equity price combination when the insurer is subject to risk-based capital requirements; its optimal safety level and equity endowment if subject to a binding restriction on insurance pricing; and, finally, its optimal strategy if no constraint is binding. Based on these results, we compare the influence exerted by each regulatory measure. Section 5 illustrates the central results with a numerical example and provides graphic interpretations. Section 6 discusses the results in light of the main assumptions. Section 7 concludes.

2 Literature Overview

In the early theoretical literature on capital structures for insurance companies, the insurer faces an exogenous premium that is independent of insurer default risk (cf. Borch, 1981; Munch and Smallwood, 1981). The insurer chooses a profit-maximizing equity level by finding a balance between gains from risky investments under limited liability protection and the chance of profitable projects in future periods. In this setting, the optimal capital structure is a corner solution: either the insurer holds no equity at all, or holds enough equity to rule out any default risk. If the regulator allows higher prices, or if there is a lack of competition, insurers' future profits increase, and the perfect-safety strategy becomes more probable. In a similar context, MacMinn and Witt (1987) show that insurers facing a pricing constraint choose a less risky investment strategy if regulators allow higher prices. McCabe and Witt (1980) show that price ceilings induce insurers to extend the settlement period and thus lower product quality.

Rees et al. (1999) extend this strand of the literature by incorporating consumer reaction to insurer default risk. Their model environment contains a single consumer who is perfectly informed about insurer default risk and an insurer who offers insurance at the consumer's reservation price. Additionally, the insurer is able to hold equity without facing transaction costs. The model implies that insurers will hold sufficient equity to avoid any default risk, even if prices are reduced to the fair premium in a model of Bertrand competition. However, the insurer will decide on a positive default risk if holding equity is costly. Such costs may result from regulatory restrictions on the insurer's investment portfolio (Rees et al., 1999), from corporate income taxation (Froot and Stein, 1998), or from conflicts of interest between managers and owners (Jensen and Meckling, 1976; Laux and Muermann, 2010). The insurer will then choose its value-maximizing safety level by balancing consumer willingness to pay for high-quality insurance against the transaction costs of risk management (cf., e.g., Cummins and Sommer, 1996; Cummins and Danzon, 1997; Zanjani, 2002; Froot, 2007; Laux and Muermann, 2010; Zimmer et al., 2010). Work taking this approach neither accounts for insurance pricing constraints, nor conducts a comparison between different insurance regulation schemes. This article extends the literature on insurers' capital structure decisions by explicitly incorporating regulatory restrictions and insurer best responses. The model employs an option pricing technique (OPT) for pricing insurance contracts with insurer default risk (cf., e.g., Doherty and Garven, 1986; Cummins, 1988; Phillips et al., 1998; Myers and Read, 2001; Gründl and Schmeiser, 2002, 2007; Sherris, 2006; and Ibragimov et al., 2010).

The paper also contributes to financial theory, which typically explains the interaction between price regulation and a firm's capital structure by means of a "bargaining" that takes place between the regulated firm and the regulator (Taggart, 1981; Dasgupta and Nanda, 1993; Spiegel and Spulber, 1994). This sort of model predicts that firms subject to price regulation will increase their insolvency risk so as to induce regulators to choose higher output prices. If regulatory prices do not depend in a predictable way on firms' capital structures, price regulation should be irrelevant in capital management (Taggart, 1981, p. 385 f.). Spence (1975) provides an analysis of the interaction between price regulation and product quality. The model explains that rate-of-return regulation can push product quality toward the social optimum, especially if quality is a capital-using attribute and the profit-maximizing level of quality is low. Allowing for a higher rate of return will increase the level of quality. Our paper extends this literature by examining the influence of regulatory constraints on insurer safety levels, which, in our framework, coincide with product quality. Compared to the existing financial literature, we find a simpler explanation for this interaction, and provide comparisons between capital and price regulation.

3 Model Framework

We formulate the approach in a parsimonious framework that allows describing the insurer's responses to regulatory constraints via closed-form solutions. Several extensions of this set-up are discussed in Section 6. 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. Actions and payoffs take place in the time interval [0, 1].

Shareholders are risk neutral and evaluate their future payoffs via an arbitrage-free valuation operator Ψ (cf. Doherty and Garven, 1986). 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 $\tau \geq 0$ (cf., e.g., Zanjani, 2002; Froot, 2007; Yow and Sherris, 2008; Ibragimov et al., 2010). At time 1, insurance losses occur in the amount of L_1, and shareholders receive the insurer's remaining equity $\max\{A_1 - L_1; 0\}$ under limited liability protection. The insurer's target is to maximize the net shareholder value:

$$SHV = \Psi \max\{A_1 - L_1; 0\} - K. \tag{1}$$

Consumers face future losses at time 1, and can buy insurance at time 0. 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 insurer's safety level in terms of the value of defaulting claims per dollar of initial liabilities: $dr = \frac{\Psi \max\{L_1 - A_1; 0\}}{L_0}$.[2] 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:[3] we assume a finite number of potential customers, i.e., $y(0,0) < \infty$, that 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 claims is denoted by μ, and hence the insurer's initial liabilities are

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[2] The default ratio is frequently used when insurance pricing builds on option pricing techniques (cf., e.g., Sommer, 1996; Myers and Read, 2001; Gründl and Schmeiser, 2002; Gatzert and Schmeiser, 2008; 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).

[3] 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. In experimental surveys, participants accept insurance contracts subject to default risk only at significant premium discounts (Wakker et al., 1997; Albrecht and Maurer, 2000) or even completely reject them (Zimmer et al., 2009). Zimmer et al. (2010) provide an experimental estimation of the insurance demand function that could be included in our model.

$L_0 = y \cdot \mu$. The final assets and liabilities are assumed to be log-normally distributed and stochastically dependent (cf., e.g., Yow and Sherris, 2008). Thus, the default ratio can be evaluated using Margrabe's (1978) formula for price an exchange option (cf. Cummins and Danzon, 1997; Phillips et al., 1998; Myers and Read, 2001; Sherris, 2006; Ibragomov et al. 2010):[4]

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

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, ρ the correlation between the log asset return and the log growth rate of liabilities, $z = -\frac{1}{\sigma}\ln(s) + \frac{\sigma}{2} + \frac{r_L - r_f}{\sigma}$, and Φ the cumulative distribution function of the standard normal distribution.

With this model set-up, we can easily formulate the insurer's objective SHV depending on the decision variables price *p* and default risk level *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, we can express each default ratio *dr* in terms of a corresponding asset-liability ratio $s(dr,\sigma)$. SHV can be rewritten as a continuous function in *dr* and *p*:[5]

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

4 Insurer Reaction to Regulatory Restrictions

4.1 Risk-Based Capital Requirements

In a first step, we consider a binding rule that restricts the insurer's default ratio to the level dr^{reg}. The regulator could set up such rule as a risk-based capital requirement and demand

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[4] This representation is consistent with Cummins and Danzon (1997, p. 35 f.) and Phillips et al. (1998, p. 631 f.), who assume the markets for asset and insurance risks to be complete. Since markets for insurance risks are typically subject to stronger information asymmetries and hence are less widespread than markets for insurance assets, we require completeness only for the asset market; the market for insurance risks may be incomplete.

[5] For the derivation, see Appendix A.1.

insurers to hold enough equity such that the default ratio does not exceed dr^{reg}.[6] The insurer will optimally respond by adjusting its equity-premium combination as follows:

Lemma 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 price:[7]

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

$$p^*\left(dr^{reg}\right) = \underbrace{\mu \cdot \left(1 - dr^{reg}\right)}_{\text{Arb.-free value of insurance claims}} + \underbrace{\tau \cdot \left(\mu \cdot s\left(dr^{reg}, \sigma\right) - \mu \cdot \left(1 - dr^{reg}\right)\right)}_{\text{Transfer of frictional costs of equity}} + \underbrace{\frac{y}{-y_p}}_{\text{Profit mark-up}}, \tag{5}$$

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

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 mark-up 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 insurance contract, and the net SHV is zero. If demand is imperfectly elastic,[8] the profit mark-up will be positive, and the second component will exceed the insurer's frictional costs:

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

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[6] This concept is similar to the Solvency Capital Requirements (SCR) under Solvency II, which builds on the value at risk and restricts the annual ruin probability to 0.5%. As Gatzert and Schmeiser (2008) show, 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. T avoid this adverse effect, we suppose that the regulator requires insurer capitalization based on the insurer's portfolio risk, and a regulatory specified default ratio as the confidence level. For multiline insurers, this procedure is also proposed by Myers and Read (2001, p. 568 f).

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

[8] This case is in line with assuming that the insurance market is monopolistically competitive. Since insurers acquire information during the relationship with policyholders, and hence policyholders cannot switch costlessly to a competitor, this market form is considered more realistic in insurance markets (see D'Arcy and Doherty, 1990).

This is because profit mark-ups themselves add to the insurer's assets and lower its required equity. Therefore, the optimal loading on the insurance premium exceeds the "traditional" price loading, which only refers to the price inelasticity of demand, and the insurer saves frictional costs of equity. In total, under a binding capital requirement, shareholders will receive a positive net SHV 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 less expected payments to policyholders, and shareholders have more limited liability protection. Second, a higher default value allows for less equity endowment, thus decreasing frictional costs. This basic relation between safety and price is in line with the empirical finding of Sommer (1996).

4.2 Pricing Constraint

We next explore the insurer's response to a binding pricing constraint p^{reg} and nonbinding 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).

The insurer reacts to the regulatory price p^{reg} by adjusting its equity endowment, and hence its default ratio. The optimal adjustment is specified by the first derivative of SHV with regard to *dr*:[9]

$$\frac{\partial y}{\partial dr}\cdot\left[p^{reg}-\mu\cdot(1-dr)-\frac{\tau}{1-\tau}\cdot\left[\mu\cdot s(dr)-p^{reg}\right]\right]+y\cdot\mu-y\cdot\mu\cdot\frac{\tau}{1-\tau}\cdot\frac{\partial s}{\partial dr}=0\,. \qquad (6)$$

This equation represents the tradeoff the insurer makes when deciding whether a marginal increase of *dr* is preferable. The first term is negative and measures the marginal lower profits due to 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 of the frictional costs of equity, as a higher default ratio allows for a lower asset-liability ratio.

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[9] For this purpose, fix p at p^{reg} in Equation (3).

As the solution of Equation (6) in terms of *dr* would not be comparable with the result in Equation (5), we will instead derive a representation for that price p^{reg} that will induce the insurer to aim at a certain default ratio dr^{aim}. Reordering Equation (6) implies that the corresponding price p^{reg} can be written as

$$p^{reg}\left(dr^{aim}\right)=\underbrace{\mu\cdot\left(1-dr^{aim}\right)}_{\substack{\text{Arb.-free value of}\\ \text{insurance claims}}}+\underbrace{\tau\cdot\left(\mu\cdot s\left(dr^{aim},\sigma\right)-\mu\cdot\left(1-dr^{aim}\right)\right)}_{\text{Transfer of frictional costs of equity}}+\underbrace{\mu\cdot\left(1-\tau\cdot\left(1+\frac{\partial s}{\partial dr}\right)\right)\cdot\frac{y}{-y_{dr}}}_{\text{Required loading}}\ , \quad (7)$$

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

Comparing Equations (5) and (7) reveals that $p^{*}\left(dr^{reg}\right)$ and $p^{reg}\left(dr^{aim}\right)$ 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 (7) describes the premium loading the regulator needs to permit so as to induce the insurer to choose the default ratio *dr*. Equation (2) implies that 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}.[10] The second factor, $\frac{y}{-y_{dr}}>0$, represents a mark-up the extent of which depends on the default risk sensitivity of insurance demand.

$p^{reg}\left(dr^{aim}\right)$ is well-defined for any default ratio as long as there is some reaction of 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, regulators will not permit a profit mark-up on the premium, and 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 homogenous insurers compete on quality. Similar to the classic Bertrand

[10] 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 takes values smaller or equal to –1. Since $dr(s,\sigma)$ 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.

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 with regard to default risk, regulators must allow a profit mark-up to achieve dr^{aim}, and shareholders will receive a positive net SHV. Note that $p^{reg}(dr)$ does not depend on the price elasticity of demand, i.e., regulatory prices are determined irrespective of the profit mark-up on the unregulated premium.

These observations have important implications for price regulation at the "fair" premium, which is frequently invoked in order to prevent excessive profits for shareholders and is proposed by Doherty and Garven (1986) in an OPT framework. In our setting, the "fair" premium is specified by

$$p^{fair}\left(dr^{aim}\right)=\underbrace{\mu\cdot\left(1-dr^{aim}\right)}_{\substack{\text{Arb.-free value of}\\ \text{insurance claims}}}+\underbrace{\tau\cdot\left(\mu\cdot s\left(dr^{aim},\sigma\right)-\mu\cdot\left(1-dr^{aim}\right)\right)}_{\text{Transfer of frictional costs of equity}}.$$ [11]

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 regulators restrict insurer default risk by means of other measures, rate suppression to the "fair" premium induces the insurer to deviate from dr^{aim} and to increase the default ratio:

Proposition 1. *Assume that there are no capital requirements at the level* dr^{aim}*, and that* $y_{dr}<\infty$*. Confronted with a pricing constraint at the "fair" premium* $p^{fair}\left(dr^{aim}\right)$*, the insurer will choose a default ratio that is strictly higher than* dr^{aim}*.*

In particular, the "fair" premium causes a default risk increase even if insurance demand is perfectly elastic with regard to *price*, and $p^{fair}\left(dr^{aim}\right)$ would be the insurer's optimal choice if the default ratio were restricted to dr^{aim}. Empirical observation of regulatory rate suppression inducing insurers to lower their capital levels and to take higher default risk is provided by Klein et al. (2002).

[11] 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 (2008). Using the Capital Asset Pricing Model, rate regulation with fair profit margins for shareholders has been proposed by Biger and Kahane (1978), Fairley (1979), Hill (1979), Hill and Modigliani (1987), and Myers and Cohn (1987).

4.3 No Binding Constraints

To discover whether capital and pricing constraints are binding, or whether the insurer will over-meet 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 (7) 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

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

or

$$\mu - \tau \cdot \mu \cdot \left(1 + \frac{\partial s}{\partial dr}\right) = \frac{y_{dr}}{y_p}. \tag{8}$$

Here, the LHS represents the value of the extension of shareholders' limited liability protection (the default put option) as well as the reduction of frictional costs, given a marginal increase of the default ratio. The RHS 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*

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

with $x = \frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu}$, *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, we 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.[12] Intuitively, insurance demand rewards safety and accepts that transaction costs for risk management are transferred via premiums. If this condition is not met, the insurer will wish to hold no equity at all. Such a scenario may be realistic if insurance buyers are protected by a guarantee fund or assume government bailouts. It is also the case if demand is perfectly sensitive with respect to price, but not with respect to default risk, e.g., because consumers can perfectly observe prices and prefer the cheaper product, but do not have sufficient information about contract quality. Again, the insurer has no incentive for 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 in default risk, but not so in price. The insurer then seeks to avoid any default risk, i.e., s^* tends to infinity (as does the price). Capital requirements and price floors will always be nonbinding and solvency regulation is unnecessary.

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.[13] Again, capital requirements will always be nonbinding. 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 premia that shareholders demand for bearing undiversifiable risks do not solely imply insurer default risk.

4.4 Comparisons

Based on the previous results, we can make comparisons between regulatory constraints and derive policy implications. Assume that the insurer's strategy in the absence of regulatory

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[12] In particular, $-y_{dr} < -y_p \mu$ would mean that consumers prefer a 1-Dollar price reduction to a 1-Dollar DPO reduction.

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

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).

Assume 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. We have $p^*(dr^{aim}) < p^{reg}(dr^{aim})$.*

Proposition 3 highlights several essential findings. To enhance insurers' safety levels, the regulator must require a price floor above the unregulated price, as $p^{reg}(dr^{aim}) > p^*(dr^{aim}) \geq p^*$. The reasoning behind this 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. However, Proposition 3 also implies that risk-based capital requirements are a more efficient instrument for solvency regulation than price floors, and allow for lower insurance prices: 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 price floor $p^{reg}(dr^{aim})$ that the regulator needs to impose to achieve the same safety level in terms of price regulation. The intuition behind this is that risk-based capital requirements enable the insurer to choose the most efficient combination of equity endowment and premium income (see Lemma 1), and a part of the ensuing efficiency gain will be transferred to policyholders. Not only policyholders, but also shareholders prefer risk-based capital requirements over price regulation, as the price floor leads away from the SHV-maximizing equity-premium combination provided by Lemma 1. Intuitively, the price floor allows for higher profits per insurance contract, but it cuts demand, thus decreasing shareholder value.

If the regulator employs both capital requirements and pricing constraints, price floors can be ineffective with regard to insurer safety levels, even though they are binding and make insurance more expensive. Suppose the regulator restricts the default ratio to the level dr^{aim}

by means of a risk-based capital requirement. Then, each price floor in the interval $\left(p^*\left(dr^{aim}\right), p^{reg}\left(dr^{aim}\right)\right)$ is binding and increases the price of insurance, but does not induce the insurer to seek a default ratio below dr^{aim}. In fact, the insurer will countervail the higher premium by choosing less initial equity endowment per contract in order to maintain the default ratio dr^{aim}. Thus, the price floor reduces the insurer's potential to shift risks from policyholders to shareholders, and risk is instead spread among policyholders. Policyholders are worse off with this kind of price floor, since it only makes insurance more expensive; at the same time, the price floor causes a loss of value for the shareholders since it dissuades the insurer from the SHV-maximizing strategy. However, once the price floor lies above $p^{reg}\left(dr^{aim}\right)$, it overrules the capital requirement, and effectively enhances safety.

Let us take a look at the distance $p^{reg}\left(dr^{aim}\right) - p^*\left(dr^{aim}\right)$, and its influencing factors. This distance measures the efficiency advantage and yields the maximum cost at which implementing risk-based capital requirements is still preferable to price regulation.[14] Furthermore, the larger the price distance, the more likely are binding, but ineffective, price floors.

Using Equations (5) and (7), we can rewrite the length of this interval as

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

The expression can be easily solved 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. Furthermore, there is a larger interval in which price floors are binding, but do not affect safety.

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

If default sensitivity of demand becomes large ($y_{dr}\uparrow$), price floors require lower profit mark-ups to be effective, and thus the interval becomes shorter.[15] Likewise, as the insurer's self-interest in solvency increases, capital requirements become less efficient.

5 Numerical Examples

5.1 Model Parameters and Results

We now use a numerical example to more graphically illustrate our results and to examine the influence of parameter changes. For the asset-liability model, we employ the following parameterization:[16] $\mu = 250\$$, $\sigma_A = 5\%$, $\sigma_L = 20\%$, $\rho_{AL} = 0\%$, and $r_f = 0\%$. For the insurance demand function, we 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., 2010):

$$y(p,dr) = n \cdot \exp(-f_p \cdot p - f_d \cdot dr), \tag{9}$$

where n adjusts 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 $\frac{y}{-y_{dr}} = \frac{1}{f_d}$, and thus all equations describing the insurer's best response functions are closed-form solutions (see Equations (5), (7), and (8)). For the carrying charge τ and the parameters of the demand function, we apply different values and examine their influence. In the base scenario, $\tau = 10\%$, $f_p = 7.2\%$, and $f_d = 40$.[17]

According to Proposition 2, in the case of no regulation, these parameters lead to a default ratio $dr^* = 1.0\%$ and $p^* = 269.54$ (Fig. 1, Point C). The insurer's reaction to capital and

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[15] At 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.

[16] 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. 309). As the measures in the subsequent analysis build on risk-neutral valuation, we can omit the drift rates under empirical probabilities.

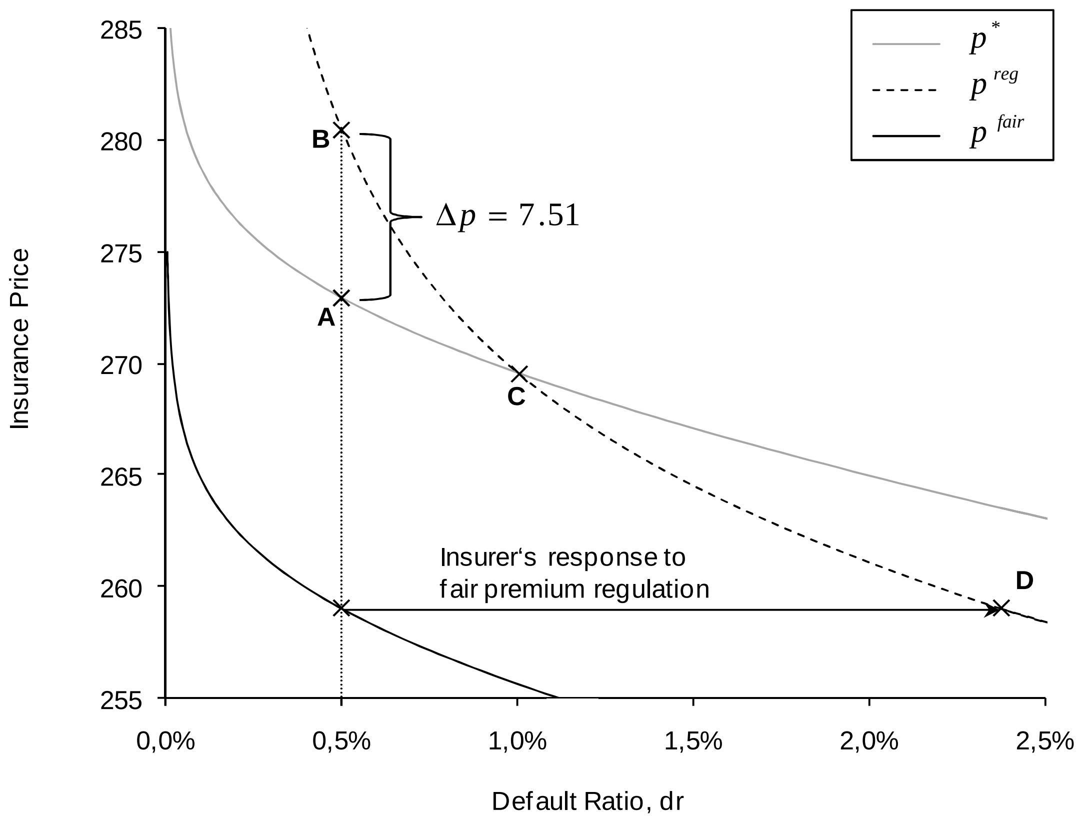
[17] Under the insurer's SHV-maximizing equity-price combination, this parameter set implies that the price elasticity of demand is equal to 19.41, and the default elasticity is equal to 0.4, both of which are similar to the empirically estimated parameters in Yow and Sherris (2008, p. 318).

price regulation is illustrated in Figure 1. The dashed line describes the insurer's SHV-maximizing price corresponding to a given default ratio (see Equation (5)). If the regulator restricts the default ratio by means of risk-based capital requirements to $dr^{reg} = 0.5\%$, the insurer will set the price at 272.91 (Fig. 1, Point A). The solid gray line gives the price floor necessary to induce the insurer to set the default ratio to *dr* (see Equation (7)). To achieve a default ratio of 0.5%, the regulator needs to require a price floor of 280.42 (Fig. 1, Point B).

The numerical example reflects the theoretical results from Section 4:

- To achieve the default ratio 0.5%, risk-based capital requirements have an efficiency advantage over the price floor, resulting in a premium reduction of $\Delta p = p^{reg}(0.5\%) - p^{*}(0.5\%) = 7.51$.
- If the regulator restricts the default ratio to 0.5% by means of capital requirements, each price floor in the interval [272.91, 280.42] is binding, but does not induce a higher safety level.
- If the regulator restricts the price to the fair premium corresponding to the default ratio 0.5%, $p^{fair}(0.5\%) = 259.02$, and does not enforce capital requirements, the insurer will increase the default ratio to 2.37% (Fig. 1, Point D).

Figure 1. Insurance prices depending on default ratios under different forms of regulation (base scenario).



5.2 Threshold for Investment in a Risk-Based Regulatory Scheme

In the base scenario, the 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 homogenous. 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. Let us take a look at the influences of the surrounding parameters regarding the price distance between capital and price regulation that justifies the threshold for the regulator's investments in risk-based insurance regulation. Figure 2 illustrates that an increase of the default sensitivity of demand from $f_d = 40$ to $f_d = 50$ causes the threshold to shrink to 3.2 per contract (1.3% of insurance liabilities). This is because consumer default sensitivity provides the insurer with a stronger incentive for risk management (dr^* decreases) and the regulator only needs to set the price floor at 276.1 to achieve the default ratio 0.5%. 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 2. Insurance prices depending on default ratios under different forms of regulation (default sensitivity of demand changing from $f_d = 40$ to $f_d = 50$).

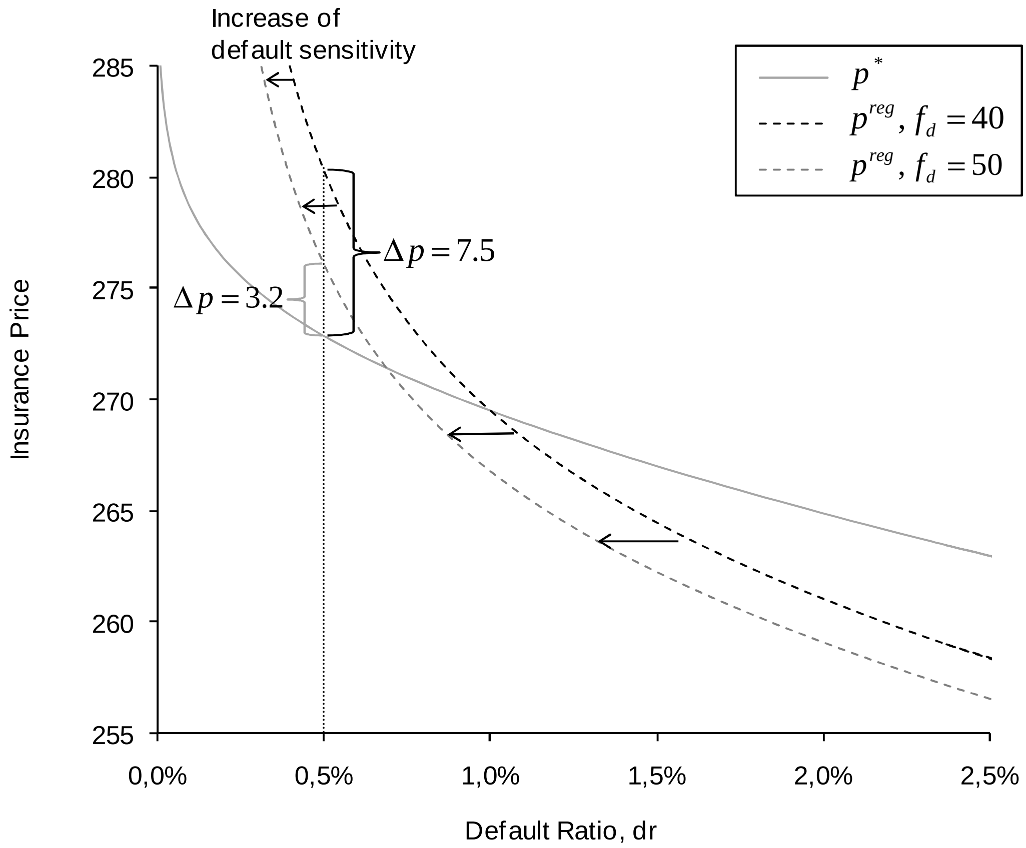
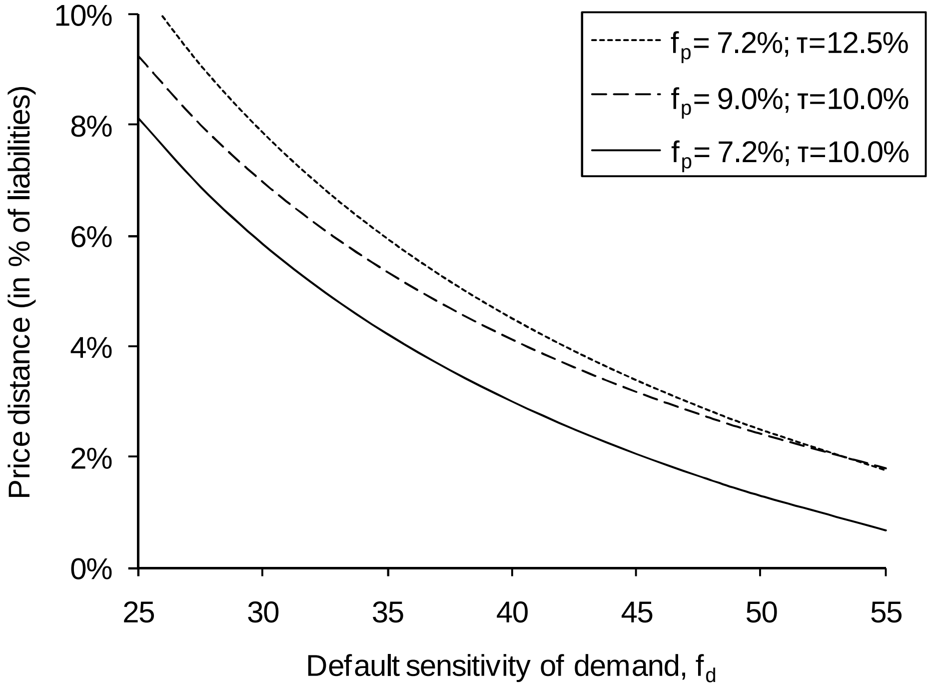


Table 1. Threshold for investment in risk-based capital regulation ($dr^{aim} = 0.5\%$, $f_p = 7.2\%$, $\tau = 10\%$).

Default sensitivity	f_d	30	35	40	45	50
Insurer strategy in absence of regulation						
▪ Default ratio	dr^*	1.8%	1.3%	1.0%	0.8%	0.7%
▪ Insurance premium	$p^*(dr^*)$	265.6	268.0	269.5	270.6	271.5
Insurance premium if default ratio restricted to 0.5%						
▪ Capital regulation	$p^*(0.5\%)$	272.9	272.9	272.9	272.9	272.9
▪ Price regulation	$p^{reg}(0.5\%)$	287.5	283.5	280.4	278.0	276.1
Efficiency advantage of capital regulation over price regulation						
▪ Price distance (absolute)	$p^{reg}(0.5\%) - p^*(0.5\%)$	14.6	10.6	7.5	5.1	3.2
▪ Price distance (in % of liabilities)	$\frac{p^{reg}(0.5\%) - p^*(0.5\%)}{\mu}$	5.9%	4.2%	3.0%	2.1%	1.3%

Figure 3 compares these results to scenarios with higher price sensitivity of demand ($f_p = 9.0\%$ 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. Also 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. Therefore, the regulator must increase the price floor to counteract this incentive, particularly if demand is only weakly default sensitive. In the latter case, the threshold for investment in risk-based insurance regulation is 7.9% (for $f_d = 30$).

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



6 Discussion

The model framework shows how price regulation affects safety level decisions by insurance companies, albeit in a simplified setting. An interesting extension of our approach would be to incorporate additional risk management instruments in the model. Besides collecting premiums and raising equity funds, insurers typically manage risk by purchasing reinsurance, adjusting the duration between the asset and liability cash flows, and optimizing diversification of the insurance portfolio. The latter aspect could be incorporated into the present approach by allowing for multiple insurance lines. We expect that doing so will only strengthen our results, since it provides the insurer with even better opportunities of ensuring safety efficiently if default risk is regulated directly by means of risk-based capital requirements. Hence, price floors will become even less favorable. Our setting could also be generalized by comparing risk-based capital standards with other regulatory restrictions, such as investment guidelines or underwriting restrictions. Similar to our findings in regard to price floors, we expect that risk-based capital standards will be more efficient than these other regulatory interventions because risk-based capital standards impose fewer restrictions on the insurer's risk management mix and allow it to choose the most efficient way of ensuring its safety.

The paper also 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 the German endowment and private pension insurance industry, where the Ministry of Finance annually sets a maximum discount rate for calculating actuarial provisions. This restriction effectively serves as an upper boundary for the guaranteed interest rate or, conversely, as a minimum premium for each Dollar of guaranteed life insurance benefit (price floor). Once the EU framework for insurance regulation, Solvency II, comes into force, German life insurers will be subject to risk-based capital requirements and will also face restrictions regarding the guaranteed interest rates required by the German Ministry of Finance, which are, in principle, the equivalent of a price floor for the guaranteed insurance benefits. According to our results, this interest rate restriction will be either ineffective with regard to life insurers' safety levels, or will override, and thus make redundant, the Solvency II capital requirements. In either case, the result will be a less than welfare optimal. It would be interesting to discover whether or not the interest rate constraint is effective and, if so, how the situation could be improved. These questions can be answered by extending and calibrating our model to a life insurance context.

7 Conclusion

This article compares insurers' best responses to risk-based capital requirements and insurance pricing constraints. Regulatory price floors above the unregulated premium increase insurer safety levels, and thus work as a form of solvency regulation. The reason is that price floors aid the insurer in ensuring safety while holding less equity per contract, resulting in more profit per contract, and thus, the insurer will attempt to attract more customers by choosing less default risk. Risk-based capital standards turn out to be a more efficient way of ensuring solvency. Given that regulation is achieved by means of risk-based capital requirements, insurers will choose the most efficient equity-premium combination that ensures the desired safety level, and therefore will offer insurance at lower prices. This makes insurance attractive to a larger number of customers, causing that consumer surplus as well as shareholder value are higher with risk-based regulation than with price floors.

Risk-based capital standards are not without certain disadvantages, however. In particular, it is easier for regulators to monitor compliance with price floors or investment guidelines than to make sure that insurers' risk portfolios actually meet the required safety level. In designing a welfare-enhancing insurance regulation scheme, the benefits of risk-based capital standards must be weighed against their disadvantages. By making these benefits measureable, our approach provides an essential design tool.

Furthermore, the article detects a serious pitfall of price ceilings at the "fair" premium. Even though the "fair" premium takes insurer default risk into account and provides shareholders with an adequate rate of return, it induces the insurer to reduce its safety level, unless demand is perfectly sensitive with regard to default risk. We thereby provide a straightforward explanation of the empirical analysis of Klein et al. (2002), who observed that insurers that are subject to price regulation hold lower capital levels than insurers in unregulated markets. Price ceilings, that may result from regulatory rate suppression or the presence of subsidized, therefore increase the necessity of regulatory control of insurer default risk.

Appendix

A.1 Derivation of Equation (2)

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

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

where the second equation follows from the definition of A_0 and L_0. Solving Equation (A.1) for *K* reveals the corresponding initial equity endowment:

$$K=\frac{1}{1-\tau}y\cdot\left(s(dr,\sigma)\cdot\mu-p\right). \tag{A.2}$$

Inserting this equation and the definition $dr=\frac{\Psi\max\{L_1-A_1;0\}}{L_0}$ into Equation (1) implies:

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

A.2 Proof of Lemma 1

Equations (4) and (5) can be derived by solving $\frac{\partial}{\partial p}SHV(dr^{reg},p)=0$ for *p*, and inserting the result $p^*(dr^{reg})$ into Equation (A.2).

A.3 Proof of Proposition 1

Proposition 1 follows directly from inserting $p^{fair}(dr^{aim})$ into Equation (6):

$$\left.\frac{\mathrm{d}\,SHV(dr,p^{reg})}{\mathrm{d}\,dr}\right|_{(dr^{aim},p^{fair}(dr^{aim}))}=y\cdot\mu\cdot\left(1-\frac{\tau}{1-\tau}\cdot\underbrace{\frac{\partial s}{\partial dr}}_{<0}\right)>0.$$

A.4 Proof of Proposition 2

The FOC for the strategy in the absence of constraints, Equation (8), can be rewritten as

$$\frac{\partial dr}{\partial s} = -\frac{\tau y_p \mu}{y_{dr} - (1-\tau) y_p \mu}. \tag{A.3}$$

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), we can rewrite the LHS of Equation (A.3) as

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

Inserting the last term into Equation (A.3) implies

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

A.5 Proof of Proposition 3

We can rewrite $p^{reg}\left(dr^{reg}\right) - p^{*}\left(dr^{reg}\right) = \mu \cdot \left(1 - \tau \cdot \left(1 + \frac{\partial s}{\partial dr}\right)\right) \cdot \frac{y}{-y_{dr}} - \frac{y}{-y_p}$. At the limit $dr^{reg} \to 0$, we have:

$$\lim_{dr^{reg}\to 0}\left[p^{reg}\left(dr^{reg}\right)-p^{*}\left(dr^{reg}\right)\right]=\lim_{dr^{reg}\to 0}\left[\mu\cdot\left(1-\tau\cdot\left(1+\underbrace{\frac{\partial s}{\partial dr}}_{=-\infty}\right)\right)\cdot\frac{y}{\underbrace{-y_{dr}}_{<\infty}}-\frac{y}{\underbrace{-y_{p}}_{<\infty}}\right]=\infty\ .$$

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

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