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fails to reach its objective

Peter Zweifel, Dieter Pfaff, and Jochen Kühn

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Contact Details

Peter Zweifel

University of Zurich

Department of Economics

peter.zweifel@econ.uzh.ch

(corresponding author)

Dieter Pfaff

University of Zurich

Department of Business Administration

Plattenstrasse 14, CH-8032 Zurich, Switzerland

dieter.pfaff@business.uzh.ch

Tel.: +41 44 634 29 71

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Peter Zweifel, Economics Dept., University of Zurich (Switzerland),
Hottingerstr. 10, CH-8032 Zürich, phone ++41 44 634 3720, Fax ++41 44 634 4987,
peter.zweifel@econ.uzh.ch (corresponding author)
Dieter Pfaff, Economics Dept., University of Zurich (Switzerland), Plattenstr. 14, CH–8032 Zürich, dieter.pfaff@business.uzh.ch
Jochen Kühn, Volkenbachstr. 4, D-79798 Jestetten (Germany), mail@jochen-kuehn.de

Abstract

This paper contains a critique of solvency regulation such as imposed on banks by *Basel I* and *II*. Banks' investment divisions seek to maximize the expected rate of return on risk-adjusted capital (*RORAC*). For them, higher solvency S lowers the cost of refinancing but ties costly capital. Sequential decision making by banks is tracked over three periods. In period 1, exogenous changes in expected returns $d\overline{\mu}$ and in volatility $d\overline{\sigma}$ occur, causing optimal adjustments $dS*/d\overline{\mu}$ and $dS*/d\overline{\sigma}$ in period 2. In period 3, the actual adjustment $dS*$ creates an endogenous trade-off with slope $d\hat{\mu}/d\hat{\sigma}$. Both *Basel I* and *II* are shown to modify this slope, inducing top management to opt for a higher value of σ in several situations. Therefore, both types of solvency regulation can run counter their stated objective, which may also be true of *Basel III*.

JEL codes: G15, G21, G28, L51

Key words: regulation, banks, solvency, *Basel I*, *Basel II*, *Basel III*

1. Introduction

Return on risk-adjusted capital (*RORAC*) has increasingly become the benchmark for assessing the performance and governance of banks' investment divisions. For them, a higher solvency level has the benefit of lowering the cost of refinancing; on the other hand, it ties costly
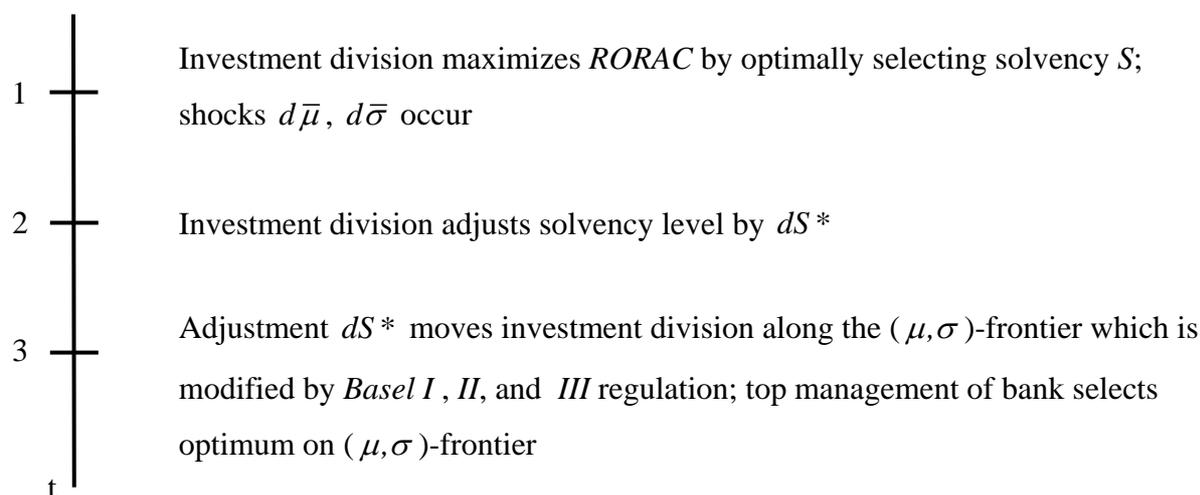
capital. At the same time, public regulators are concerned about solvency to ensure the continuity of a bank's operations. This paper deals with the conflict between the optimization of solvency by the bank itself and exogenously imposed solvency levels, taking *Basel I* and *Basel II* as the example. It depicts a bank in the process of its sequential decision making. In a first period, exogenous shocks ($d\overline{\mu}, d\overline{\sigma}$) impinge on the bank's investment division. A typical cause could be investments made in the previous period that turn out to have a lower rate of return or a higher volatility than expected. In the second period, the division adjusts its solvency level by $dS*/d\overline{\mu}$ and $dS*/d\overline{\sigma}$, respectively in the aim of attaining again its efficient amount of capital prior to rebalancing its portfolio. In the third period, it proposes to top management to rebalance in response to the changed solvency level through endogenous adjustments $d\hat{\mu}/dS*$ and $d\hat{\sigma}/dS*$. This defines the slope of an internal efficiency frontier on which top management chooses the optimum, taking into account its degree of risk aversion.

This efficiency frontier is modified by solvency regulation such as *Basel I* and *II*. It will be argued that *Basel I* neglects that both the cost of refinancing and its relationship with solvency depend on exogenous $\overline{\mu}$ and $\overline{\sigma}$. As to *Basel II*, it addresses solvency directly but still fails to take into account the fact that for a bank that initially just met this standard, the amount of risk capital needed to improve solvency changes when $\overline{\mu}$ falls or $\overline{\sigma}$ increases. It will be shown that both *Basel I* and *II* modify the slope of the efficiency frontier $d\hat{\mu}/d\hat{\sigma}$ as perceived by regulated banks. While one might expect that these regulations reduce the slope of the frontier (thus inducing top management to opt for lower μ and lower σ), it turns out that the opposite can be the case. Indeed, through their neglect of parameters of importance to banks themselves, both *Basel I* and *II* may have the unexpected consequence of causing at least some banks in several constellations to opt for a higher value of σ (i.e. higher volatility of the rate of return on their assets) than without it, causing regulation to miss its target. This risk is likely to increase again in the case of impending *Basel III* regulation, without however attaining the original level of *Basel I*.

This paper is structured as follows. Section 2 contains a review of the pertinent literature to conclude that solvency regulation indeed may serve to avoid negative externalities. In Section 3, a higher level of solvency is found to have two effects for a bank's investment decision aiming to maximize *RORAC*. On the one hand, it serves to lower its cost of refinancing; on

the other, it ties capital that would have other, more productive uses. This optimum is disturbed by exogenous shocks in return $d\bar{\mu}$ and volatility $d\bar{\sigma}$, respectively (see period 1 of Figure 1). In period 2, the investment division adjusts the bank's solvency level to these shocks. These adjustments are derived in Section 4. However, there can be only one adjustment $dS*$, which moves the bank along an endogenous efficiency frontier in the third period. The slope $d\hat{\mu}/d\hat{\sigma}$ of this frontier is derived in Section 5. Top management is presented with this tradeoff and makes its choice taking account of its degree of risk aversion. The regulations imposed by *Basel I, II,* and *III* are introduced as parameter restrictions in Section 6 to show how $d\bar{\mu}/d\bar{\sigma}$ is modified, causing the top management of regulated banks to opt for a higher value of σ than absent this regulation in a number of situations. A summary and conclusions follow in Section 7.

Figure 1: Timeline of the model

1 — Investment division maximizes *RORAC* by optimally selecting solvency S; shocks $d\bar{\mu}$, $d\bar{\sigma}$ occur

2 — Investment division adjusts solvency level by $dS*$

3 — Adjustment $dS*$ moves investment division along the (μ,σ)-frontier which is modified by *Basel I*, *II*, and *III* regulation; top management of bank selects optimum on (μ,σ)-frontier

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2. Literature review

The solvency regulation of banks has traditionally been justified by the external costs of insolvency, especially in the guise of a bank run (Diamond and Dybvig, 1983). This view was challenged by the proponents of the Capital Asset Pricing Model, who emphasized that for well-diversified investors, the solvency of a bank does not constitute a reasonable objective. They are concerned with expected profitability, adjusted for the degree to which the bank's

profitability systematically varies with the capital market (the Beta of the Capital Asset Pricing Model). By way of contrast, for little-diversified investors (among them, ordinary consumers holding deposits with the bank), the bank's overall risk is relevant, which importantly includes the risk of insolvency [Goldberg and Hudgins (1996), Park and Peristiani (1998), Jordan (2000), Goldberg and Hudgins (2002)]. Option Pricing Theory shows that due to their limited liability, shareholders of the bank in fact have a put option that is written by the other stakeholders (notably creditors) of the bank [Merton (1974), Jensen and Meckling (1976), Merton (1977)].

When a solvency risk materializes, internal and external costs need to be distinguished. Internal costs are borne by the bank's shareholders, who see the value of their shares drop to zero unless the bank is in business again. However, in view of the loss of reputation, this re-entry would meet with high barriers to entry [Smith and Stulz (1985), pp. 395-396, Stulz (1996), pp. 9-12]. In addition, insolvency has external costs (i.e. costs not borne by the insolvent bank). First, the insolvency may trigger a bank run [Diamond and Dybvig (1983), Jacklin and Bhattacharya (1988), Bauer and Ryser (2004)]. Depositors who are late to withdraw their funds stand to lose part of their assets. Some of these depositors may be banks themselves; therefore, the insolvent bank may drive other financial institutions into bankruptcy, causing substantial external costs [Lang and Stulz (1992), Furfine (2003)]. Second, investors in the capital market at large often are affected as well. A bank that becomes insolvent causes owners and creditors of banks in general to re-evaluate the estimated risk of insolvency. In response to the revised estimate, they demand a higher rate of interest from their banks, driving up the cost of refinancing. There is a substantial body of empirical research substantiating this claim [Flannery and Sorescu (1996), Park and Peristiani (1998), Covitz et al. (2004)].

This research suggests that a solvency level that is deemed optimal by the individual bank is too low from a societal perspective because insolvency causes substantial external costs. However, it may be worthwhile to emphasize that this conclusion does not suffice to justify public regulation to ensure solvency. One would have to first examine whether the expected benefit of the intervention exceed its expected cost. An important component of this cost is caused by behavioral adjustments that are not intended. The present contribution belongs to this tradition of research, which dates back at least to Koehn and Santomero (1980). Characterizing a bank by its utility function and assuming it to optimize a portfolio containing both

assets and liabilities, they find that imposing a simple equity-to-assets ratio constraint is ineffective on average. Relatively safe banks become safer, while risky ones increase their risk position to make up for decreased leverage. In Kim and Santomero (1988), emphasis is on the choice of appropriate risk weights in the determination of what has since become 'Risk-Adjusted Capital'. Here, the cost of regulation derives from non-optimal risk weights.

In Rochet (1992), banks choose their asset portfolio taking into account limited liability, which may cause them to become risk-lovers. This makes imposing minimum capital requirements necessary to prevent them from choosing very inefficient portfolios. However, the effectiveness of this regulation is not guaranteed at all. John, Saunders, and Senbet (2000) show that U.S. capital-based regulation introduced in 1991 may fail to prevent bank managers from shifting risk to outside financiers unless features of their compensation plans are taken into account along with the opportunity set of asset investments. More recently, Repullo (2004) explicitly has dealt with *Basel II* in the context of an imperfectly competitive market. He derives conditions for two Nash equilibria to obtain, one in which banks invest in riskless and another where they invest risky assets. While capital requirements on risky assets do enlarge the parameter space of the 'prudent' equilibrium, depositors bear the burden of regulation in the guise of lower interest rates. That is also the reason why in Repullo (2004) capital requirements are in general effective in preventing excessive risk-taking by banks. Furthermore, it is shown that *Basel II* permits a reduction in the overall amount of capital required by regulation compared to *Basel I*. However, pointing to bank-specific problems of governance, Mülbert (2009) argues that prudential regulation of the *Basel I* and *Basel II* type may even induce rather than prevent banking crises.

The present contribution differs from the earlier literature in two ways. First, it clearly distinguishes between the earlier *Basel I* and the more refined *Basel II* regulation, showing that the more recent variant may have unintended consequences only for a subset of banks rather than all of them. However, *Basel III* is found to likely increase this subset again. In this respect, this work elaborates on and refines the contributions by Kim and Santomero (1988) as well as Rochet (1992). The second distinguishing feature of this paper is its emphasis on dynamics in the following way. Whereas earlier contributions analyzed optima or [in the case of Repullo (2004)] equilibria, here the bank's path of adjustment from one optimum to the next is analyzed. Adjustment to exogenous shocks will be shown to be conditioned by solvency regula-

tion of the *Basel I* to *III* type. In return, welfare implications will not be spelled out; rather, the fact that banks may be induced to act against the stated intentions of the regulator will be highlighted.

3. Optimal solvency in a model of a bank's investment division

Let a bank's investment division maximize the expected rate of return on risk-adjusted capital (*RORAC*) through its choice of solvency *S*. It is assumed to act in a risk-neutral manner. This assumption can be justified by noting that allowing risk aversion to affect decisions of employees of the investment division would result in inconsistencies. Employee A (who is strongly risk averse) might turn down a client seeking to obtain funding for a project while employee B (who has more of a risk appetite) of the same bank would accept it. Top management needs to avoid such inconsistencies. Therefore, the expectation operator is dropped as long as the investment division is being analyzed; risk aversion will enter in period 3 when the bank's top management selects its preferred position on the (μ, σ)-efficiency frontier generated by the bank's investment division. A higher level of solvency *S* enables the bank (and hence the division) to obtain funds at a lower rate of interest paid on deposits r_D.

There is no need to define solvency in a formal way; however, it may be thought in terms of the likelihood of a shortfall (Leibowitz et al., 1992) or in terms of value-at-risk (*VaR*) or expected value-at-risk (*EVaR*) concepts [see Artzner et al. (2000) for a critique]. Whenever *VaR* or *EVar* increases, solvency can be said to decrease. Also note that economics is replete with latent (i.e. not directly observed) variables ever since Cassels' (1918) purchasing power parity, Keynes' (1936) 'state of confidence', Friedman's (1957) 'permanent income', and Barro's (1977) 'unanticipated money growth'. For the argument below, it is sufficient for the level of solvency to be a decision variable both for the bank and the regulatory authority. For the bank, one has

$$r_D = r_D(\cdot, S), \quad \text{with } \frac{\partial}{\partial S} r_D(\cdot, S) < 0 \text{ and } \frac{\partial^2}{\partial S^2} r_D(\cdot, S) > 0; \tag{1}$$

the arguments other than *S* are discussed in Section 4 below. The amount of risk-adjusted capital $C > 0$ increases with the solvency level *S* aimed at by the bank,

$C = C(\cdot, S)$ with

$$\frac{\partial}{\partial S} C(\cdot, S) > 0, \ \frac{\partial^2 C}{\partial S^2} > 0. \tag{2}$$

Note that equations (1) to (2) suffice to describe the effects a change in the solvency level has on the bank.

Risk capital C is invested at some hurdle rate (lower than μ that can be achieved on deposits D), which for simplicity is set equal to some risk-free interest rate r_f. The financial crisis of 2007 has shown that such a rate does not really exist; accordingly, there is no security market line complementing the efficiency frontier depicted in Figure 2 (see Section 5 below). The risk-free rate used to be associated with the rate of return on government bonds, which in the case of Greece, Italy, Portugal, and Spain have proved to be anything but risk-free. Operating costs and taxes are disregarded as well, while regulations affecting equity capital are taken up in Section 6. On the basis of these simplifications, $RORAC$ can be expressed as follows,

$$RORAC = \frac{\left(\mu - r_D(\cdot, S)\right)D + r_f C(\cdot, S)}{C(\cdot, S)} = \frac{\left(\mu - r_D(\cdot, S)\right)D}{C(\cdot, S)} + r_f. \tag{3}$$

Assuming the volume of the business portfolio and hence D to be constant for simplicity, the maximization of $RORAC$ leads to the following first-order condition for optimal solvency,

$$-\frac{\partial r_D[S*]}{\partial S} - \frac{\mu - r_D[\cdot, S*]}{C[\cdot, S*]} \cdot \frac{\partial C[\cdot, S*]}{\partial S} = 0, \tag{4}$$

with the bracket notation pointing to the fact that the endogenous determinant S has to be evaluated at its optimal level. Equation (4) can be interpreted as follows. It is optimal for the investment division of a bank to weigh the favorable marginal effect of increased solvency on the cost of refinancing (first term of the equation, called marginal return of solvency in terms of risk cost) against its marginal downside effect (second term, called the marginal cost of solvency). The marginal cost of solvency consists of two interacting components. First, solvency ties costly capital C. Secondly however, this cost is particularly high when the rate of

return achievable μ exceeds by far the bank's refinancing cost r_D. Note because of $\partial r_D / \partial S < 0$, it must be true that $\mu > r_D$ for an interior solution.

Equation (4) indicates that the optimal adjustment to an exogenous change will not be given once and for all but importantly depends on parameters not yet specified, in particular the risk-return profile inherited from the past. Before substantiating this claim, it is worthwhile to note that regulation fixing a solvency level to be adhered to by all at all times does not only entail disadvantages. One advantage is simplicity, although the bank's investment division may be hard put to operationalize 'level of solvency' in all circumstances. Second, a fixed prescribed solvency level in fact makes the cost of (re)financing independent of investment decisions, permitting separation of the bank's lending and borrowing policies, which again re-sults in an important simplification of management tasks. On the downside, uniform regula-tion creates a similarity in the decision-making situation of regulated firms, which usually re-sults in a type of implicit collusion limiting competition.

4. Adjustment of solvency to exogenous shocks

Still during the first period, exogenous shocks impinging on rates of return ($d\bar{\mu}$) and volatil-ity of returns ($d\bar{\sigma}$) occur (see Figure 1). To derive the optimal adjustments of the solvency level, the following assumptions are introduced.

As shown in Appendix A, qualitative optimal adjustment of the solvency level S^* to a shock $d\bar{\mu} > 0$ in expected returns is given by

$$\text{sgn}\left[\frac{dS^*}{d\bar{\mu}}\right] = \text{sgn}\left[\frac{\partial^2 R}{\partial S \partial \bar{\mu}}\right] = \text{sgn}\left[-\underbrace{\frac{\partial^2 r_D}{\partial S \partial \bar{\mu}}}_{(-)} + \underbrace{\frac{1}{\mu - r_D}}_{(+)}\left(1 - \underbrace{\frac{\partial r_D}{\partial \bar{\mu}}}_{(+)}\right)\underbrace{\frac{\partial r_D}{\partial S}}_{(-)} - \frac{1}{C}\cdot\underbrace{\frac{\partial C}{\partial \bar{\mu}}}_{(-)}\cdot\underbrace{\frac{\partial r_D}{\partial S}}_{(-)} - \underbrace{\frac{\mu - r_D}{C}}_{(+)}\cdot\underbrace{\frac{\partial^2 C}{\partial S \partial \bar{\mu}}}_{(-)}\right];$$

(5)

the terms are signed using assumptions A2 to A9. Therefore, one obtains

$$\frac{dS^*}{d\bar{\mu}}\begin{cases} < 0 \;\; if \;\; \mu - r_D \to 0; \\ > 0 \;\; if \;\; \mu - r_D \gg 0. \end{cases}$$

(6)

Table 1: Assumptions of the model

A1: $\mu = \bar{\mu} + \hat{\mu};$

$\sigma = \bar{\sigma} + \hat{\sigma}.$

Returns and volatility (μ, σ) are additive in an exogenous $(\bar{\mu}, \bar{\sigma})$ component determined on the capital market and an endogenous one

A2: $\partial C / \partial \bar{\mu} < 0.$

The higher returns on the capital market, the less risk capital is needed to attain a given solvency level. A positive shock on returns makes positive net values of the bank more likely, therefore reducing the need for risk capital.

A3: $\partial C / \partial \bar{\sigma} > 0.$

The higher volatility on the capital market, the more risk capital is needed to attain a given solvency level. Positive net values of the bank are less likely, and this must be counteracted by more risk capital.

A4: $0 < \dfrac{\partial r_D}{\partial \bar{\mu}} < 1.$

The rate of interest paid on deposits reacts to an exogenous increase of returns less than proportionally. Otherwise, the condition $\hat{\mu} > r_D$ for an interior optimum [see eq. (4) again] would sooner or later be violated.

A5: $\dfrac{\partial r_D}{\partial \bar{\sigma}} > 0.$

With increased volatility in the market, the bank must offer better conditions to depositors as well.

A6: $\dfrac{\partial^2 r_D}{\partial S \partial \bar{\mu}} < 0.$

According to A4, the bank must increase its interest rate on deposits when market conditions become more favorable. However, it can afford to adjust to a lesser degree if its solvency level is high.

A7: $\dfrac{\partial^2 r_D}{\partial S \partial \bar{\sigma}} <$

$\dfrac{\partial^2 r_D}{\partial S \partial \bar{\mu}} < 0.$

According to A5, the bank must follow the market with its interest paid on deposits. However, it can again afford to adjust to a lesser degree if its solvency level is high. The inequality derives from the fact that by A4, $\partial r_D / \partial \bar{\mu}$ is bounded, while $\partial r_D / \partial \bar{\sigma}$ is not.

A8: $\dfrac{\partial^2 C}{\partial S \partial \bar{\mu}} < 0.$

A higher solvency level calls for more risk capital but to a lesser degree if higher market returns prevail, making positive net values of the bank more likely.

A9: $\dfrac{\partial^2 C}{\partial S \partial \bar{\sigma}} > 0$.
A higher solvency level calls for more risk capital, especially when market volatility is high, making positive net values less likely.

These results are intuitive. If the margin $\mu - r_D$ is extremely small [note that the pertinent multiplier $(1 - \partial r_D / \partial \bar{\mu})$ is bounded by (0,1)], the investment division's incentive to preserve costly capital becomes of overriding importance, causing it to reduce its solvency level in response to an exogenous increase in expected returns. However, when the margin becomes larger, less capital is needed to attain a given solvency level. This permits to actually increase the solvency level. Thus, $dS * / d\bar{\mu} > 0$ is considered the normal response.

Now consider a shock $d\bar{\sigma} > 0$ (again, details are given in Appendix A),

$$\mathrm{sgn}\left[\frac{dS^*}{d\bar{\sigma}}\right] = \mathrm{sgn}\left[\frac{\partial^2 R}{\partial S \partial \bar{\sigma}}\right] = \mathrm{sgn}\left[-\underset{(-)}{\frac{\partial^2 r_D}{\partial S \partial \bar{\sigma}}} - \frac{1}{\mu - r_D}\cdot \underset{(+)}{\frac{\partial r_D}{\partial \bar{\sigma}}}\cdot \underset{(-)}{\frac{\partial r_D}{\partial S}} - \frac{1}{C}\cdot \underset{(+)}{\frac{dC}{d\bar{\sigma}}}\cdot \underset{(-)}{\frac{\partial r_D}{\partial S}} - \underset{(+)}{\frac{\mu - r_D}{C}}\cdot \underset{(+)}{\frac{\partial^2 C}{\partial S \partial \bar{\sigma}}}\right].$$

(7)

Using assumptions A2 to A9 once more, one obtains

$$\frac{dS^*}{d\bar{\sigma}} \begin{cases} > 0 & \text{if } \mu - r_D \text{ small;} \\ < 0 & \text{if } \mu - r_D \to \infty. \end{cases}$$

(8)

Again, the results are intuitive. An exogenous increase in volatility of returns makes refinancing more costly; to counteract this effect, it is appropriate to increase the solvency level if the margin is small. Note that 'small' does not imply 'close to zero' in this case because the relevant term contains $\partial r_D / \partial \bar{\sigma}$ and $\partial r_D / \partial S$, which are both first-order. Therefore, $dS * / d\bar{\sigma} > 0$ can be regarded as the normal response. Yet, in the presence of very high margins, the opportunity cost of increased solvency becomes excessive, motivating a decrease in solvency.

5. Determination of the endogenous efficiency frontier

In the third period, the bank inherits a net adjustment of solvency dS^* from the second period that is the result of responses to the shocks $(d\bar{\mu}, d\bar{\sigma})$ that occurred in the first period. The bank's investment division now proceeds to adjust the endogenous components $\hat{\mu}$ and $\hat{\sigma}$. Optimal adjustments are described by eqs. (5) and (7), respectively, with dS^* now assuming the role of an exogenous shock. By reshuffling the bank's assets, the investment division therefore effects changes $d\hat{\mu}$ and $d\hat{\sigma}$, creating an endogenous efficiency frontier with slope $d\hat{\mu}/d\hat{\sigma}$, on which top management will proceed to choose the optimum (see Section 6.1). This slope can be obtained by dividing (7) by (5), yielding

$$
\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{S^*} = \frac{-\overset{(-)}{\frac{\partial^2 r_D}{\partial S \partial \bar{\sigma}}} - \overset{(+)}{\frac{1}{\mu - r_D}} \cdot \overset{(+)}{\frac{\partial r_D}{\partial \bar{\sigma}}} \cdot \overset{(-)}{\frac{\partial r_D}{\partial S}} - \frac{1}{C} \cdot \overset{(+)}{\frac{\partial C}{\partial \bar{\sigma}}} \cdot \overset{(-)}{\frac{\partial r_D}{\partial S}} - \overset{(+)}{\frac{\mu - r_D}{C}} \cdot \overset{(+)}{\frac{\partial^2 C}{\partial S \partial \bar{\sigma}}}}{\underset{(-)}{-\frac{\partial^2 r_D}{\partial S \partial \bar{\mu}}} + \underset{(+)}{\frac{1}{\mu - r_D}}\left(\underset{(+)}{1 - \frac{\partial r_D}{\partial \bar{\mu}}}\right)\underset{(-)}{\frac{\partial r_D}{\partial S}} - \frac{1}{C} \cdot \underset{(-)}{\frac{\partial C}{\partial \bar{\mu}}} \cdot \underset{(-)}{\frac{\partial r_D}{\partial S}} - \underset{(+)}{\frac{\mu - r_D}{C}} \cdot \underset{(-)}{\frac{\partial^2 C}{\partial S \partial \bar{\mu}}}}. \tag{9}
$$

The sign of eq. (9) is negative both if $(\mu - r_D) \to 0$ and if $(\mu - r_D) \to \infty$ in view of eqs. (6) and (8). In Figure 2, these extreme cases are shown for completeness. However, with $dS^*/d\bar{\mu} > 0$ and $dS^*/d\bar{\sigma}$ constituting the normal responses [see the discussion below eqs. (6) and (8)], the slope of the endogenous efficiency frontier is positive for intermediate values of $(\mu - r_D)$ and hence μ by assumptions A1 and A4. Moreover, a negatively sloped internally perceived efficiency frontier in (μ, σ)-space would contradict daily experience on capital markets $(d\mu/d\sigma > 0)$. A crucial result is that the slope defined in eq. (9) depends not only on observable parameters such as (μ, r_D) and first-order effects the regulator likely is aware of such as $(\partial C/\partial \bar{\mu}, \partial C/\partial \bar{\sigma}, \partial r_D/\partial S)$ but also terms such as $\partial^2 C/\partial S \partial \bar{\mu}$ and $\partial^2 C/\partial S \partial \bar{\sigma}$ which indicate that the relationship between required risk capital and solvency depends on conditions on the capital market (see assumptions A8 and A9 again).
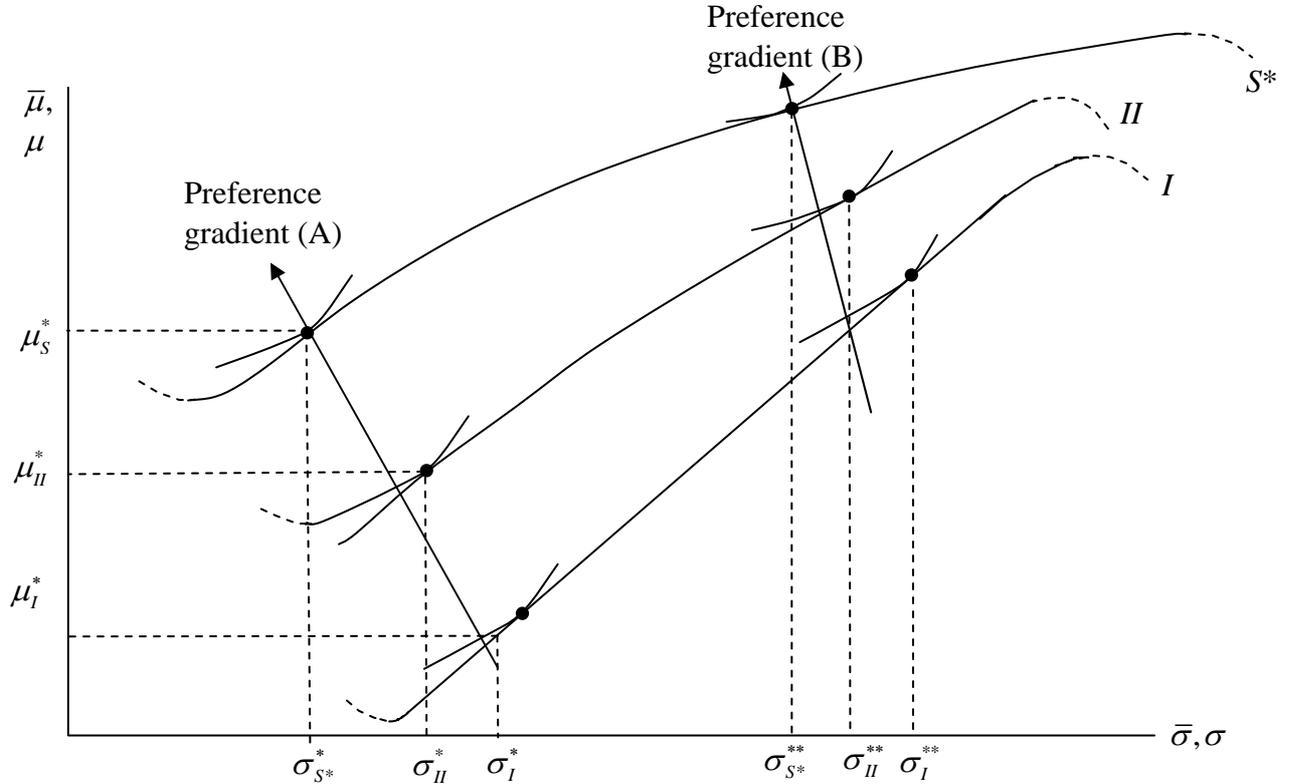
Figure 2: Endogenous efficiency frontiers in (μ,σ)-space

Figure 2 shows three endogenous efficiency frontiers. Note that μ and $\bar{\mu}$ as well as σ and $\bar{\sigma}$ are depicted on the same axis, reflecting the assumption that e.g. a low first-period value of $\bar{\bar{\sigma}}$ tends to translate into a low third-period σ. The first frontier (labeled S^*) holds prior to the influence of regulation. The two other frontiers (labeled *I* and *II*, respectively) are modified by *Basel I* and *Basel II* regulation in ways to be discussed in Section 6 below.

Conclusion 1: Due to its responses to shocks in expected rate of return and volatility in the process of sequential adjustment, the investment division of the bank induces an endogenous efficient frontier, whose slope also depends on the changing relationship between risk capital and solvency.

6. Effects of solvency regulation on the efficiency frontier

The objectives of solvency regulation differ from those of the bank, who by assumption seeks to be on the efficient (μ,σ)-frontier as given in (9) and depicted as $d\mu/d\sigma|_{S^*}$ in Figure 2. Solvency regulation is designed to avoid the external costs caused by insolvencies described

in Section 2. Its main instrument is capital requirements, based on the norms of the Basel Committee on Banking Supervision, an agency of the Bank for International Settlements.

6.1. Basel I

Basel I stipulates capital requirements as a function of risk-weighted assets and separately for off-balance sheet positions (Basel Committee on Banking Supervision, 1988). Its focus is on the relationship between solvency and capital. By defining four asset classes with fixed weights, *Basel I* imposes a fixed relationship between solvency capital *C* and solvency *S* (see the locus *B* of Figure 3 below). It therefore does not allow banks to react to changes in market conditions affecting the risk characteristic of assets. In terms of the model, this neglect amounts to the restrictions

$$\frac{\partial^2 C}{\partial S \partial \bar{\mu}} = 0, \quad \frac{\partial^2 C}{\partial S \partial \bar{\sigma}} = 0. \tag{10}$$

Inserting this in (9), one immediately sees that the numerator increases while the denominator increases. One therefore obtains for the slope of the efficiency frontier (subscript *I* denoting *Basel I*),

$$\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{I} => \left.\frac{d\bar{\mu}}{dS*}\right|_{S*} \tag{11}$$

The *Basel I* frontier therefore runs steeper than the original *S** frontier, approaching but never crossing it for high values of μ because regulation cannot increase the bank's feasible set.

One might argue that the bank can choose to act in accordance with parameters it knows to be of importance, contrary to the regulator's decision rule. This amounts to neglecting the restrictions stated in (10). However, as emphasized by Power (2004, ch.7), managers are responsibility-averse, leading them to use regulatory decision rules as a convenient justification of their own actions. For example, let there be a second-period upward adjustment in solvency indicating that the bank should move away from the origin on the efficiency frontier. With the flat endogenous efficiency frontier *S** auf Figure 1 in view, the investment division would propose to accept a substantial increase in volatility whereas based on the steeper efficiency

frontier induced by *Basel I*, the suggested increase is smaller. If the bank's top management were to move along *S**, it could be criticized by the regulator for taking on an excessive amount of risk. This threat causes a responsibility-averse management to adopt the restrictions of eq. (10) and view the steeper *Basel I* efficiency frontier as the relevant one.

For predicting optimal solutions, one needs two assumptions regarding the preferences of bank's top management. The first is the assumption of risk aversion on the part of top management. In principle, fully diversified owners would like management to accept a great deal of risk because this allows them to benefit from an increase in the value of their shares [which have properties of a call option, see e.g. Zweifel and Eisen (2012), ch. 4.3]. Managers however, being less than perfectly diversified with their human capital tied to the employing firm, have reason to be risk-averse. Given imperfect governance by (dispersed) ownership, management can follow its preferences at least to some extent (Shrieves and Dahl, 1992). Second, homotheticity of risk preferences is imposed in order to obtain sharper predictions. Under these assumptions, *Basel I* regulation induces the bank to be less conservative regardless of degree of risk aversion (type A or B in Figure 2; see the movements from σ^{*}_{S*} to σ^{*}_{I} and from σ^{**}_{S*} to σ^{**}_{I}, respectively).

Conclusion 2: Regulation of the *Basel I* type is predicted to induce banks to take a more risky position than they would on their own, thus having a counter-productive effect in terms of stated objectives.

Note that this prediction holds even if the regulation-induced downward shift of the efficiency frontier is minimal. The crucial point is that *Basel I* signals to banks that interaction parameters their investment divisions would take into account can be neglected, causing their perceived efficiency frontier to indicate that more return can be achieved on expectation for accepting a given increment in volatility. As an example, consider a bank heavily engaged in the financing of mortgages. When expected rates of return in the capital market increase $\left(d\bar{\mu} > 0\right)$, it can free risk capital (decreasing its effective solvency level somewhat and paying a higher rate of interest on deposits) in favor of an investment in a more risky asset without violating the *Basel I* norm.

6.2. *Basel II*

Basel II allows a choice of approach for the calculation of capital requirements, viz. the Standardized Approach and the Internal Ratings-Based Approach (Basel Committee on Banking Supervision, 2004). Whilst the first approach is based on *Basel I*, the second lets banks choose their probability of default, their percentage loss at default, and the maturity of their credits. Large institutions with average and below-average credit risks mostly prefer the Internal Ratings-Based approach to save on capital despite its higher cost of implementation. In terms of the model, *Basel II* permits these banks to take all elements of eq. (9) into account which amounts to a lifting of the restrictions of eq. (10) as long as the constraint regarding the solvency level is not binding.

Figure 3: Implications of *Basel II* regulation
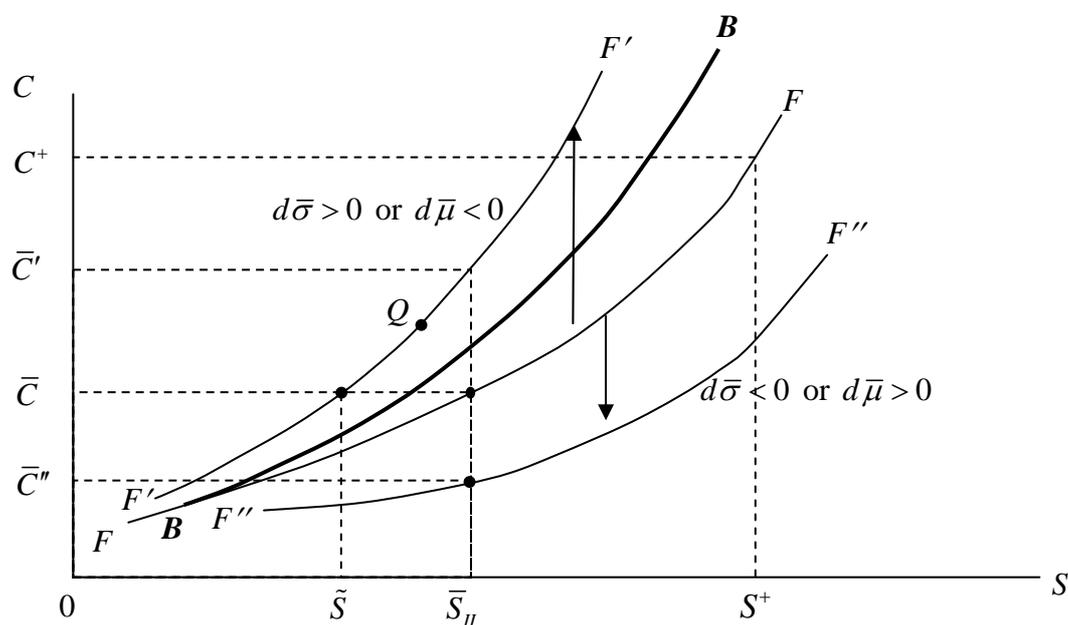
To show this, assume that the bank has opted for the more flexible Internal-Ratings-Based approach. Taken together, the rules promulgated by the Basel Committee on Banking Supervision (2004, especially para. 40 to 44) establish a relationship between a targeted solvency level and required risk capital. This relationship (which the bank cannot modify once it has selected its internal model) is depicted by the locus labeled *F* in Figure 3. It has increasing slope to reflect decreasing marginal returns to risk capital as stated in eq. (2). Locus *F* runs

below locus *B* of *Basel I*, reflecting that *Basel II* permits banks to save on risk capital. The other difference is that *Basel II* imposes a minimum degree of solvency, which is denoted by $\bar{S}_{II}$.

Now let a shock $d\bar{\sigma} > 0$ occur (volatility of returns has increased). In keeping with assumption A9, this corresponds to a steepening of the locus, resulting in F' from the bank's point of view. It indicates that a given capital $\bar{C}$ would now only suffice to guarantee a solvency level $\tilde{S} < \bar{S}_{II}$. Therefore, in order to keep to the *Basel II* norm, a bank that just satisfied it initially would have to come up with the full additional amount of capital $(\bar{C}' - \bar{C})$. Absent *Basel II*, the bank would opt for a point such as Q that entails a somewhat lower solvency level (compared to $\bar{S}_{II}$) in return for a substantial saving of costly risk capital.

A bank with excess solvency, symbolized by the combination (S^+, C^+), would not have to react to the shock $d\bar{\sigma} > 0$. The same conditional responses are predicted for a shock $d\bar{\mu} < 0$, i.e. a drop in the mean return on investments.

Conversely, consider a shock $d\bar{\sigma} < 0$, i.e. capital markets have become less volatile. For the bank, this causes the locus F of Figure 2 to become flatter, such as F''. Now $\bar{C}'' < \bar{C}$ suffices to reach the prescribed solvency level, and the 'marginal' bank that was at $\bar{S}_{II}$ initially can reduce capital by as much as $(\bar{C} - \bar{C}'')$. This of course holds true of $d\bar{\mu} > 0$ as well.

In sum, one has the following set of conditional predictions (in absolute value) for *Basel II*, focusing on the critical changes $d\bar{\mu} < 0$ and $d\bar{\sigma} > 0$,

$$0_I < \left| \frac{\partial^2 C}{\partial S \partial \mu} \right|_{II} < \left. \frac{\partial^2 C}{\partial S \partial \mu} \right|_{S*} \quad \text{if} \quad d\bar{\mu} < 0 \text{ and } S = \bar{S}_{II}.$$

$$0_I < \left| \frac{\partial^2 C}{\partial S \partial \sigma} \right|_{II} < \left. \frac{\partial^2 C}{\partial S \partial \sigma} \right|_{S*} \quad \text{if} \quad d\bar{\sigma} > 0 \text{ and } S = \bar{S}_{II}; \tag{12}$$

Here, 0_I symbolizes the zero restriction imposed by *Basel I* [see eq. (10) again]. Applied to eq. (9) and in view of assumptions A8 and A9, these restrictions again cause the numerator to increase and the numerator, to decrease. One therefore obtains,

$$\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{II} > \left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{S*} \quad \text{if} \quad d\bar{\sigma} > 0 \text{ or } d\bar{\mu} < 0 \text{ and } S = \bar{S}_{II}. \tag{13}$$

Figure 2 illustrates once more. *Basel II* being less stringent (at least by intent), the frontier runs higher than that of *Basel I* but still lower than absent regulation. To make up for reduced expected returns, even a strongly risk-averse top management (preferences of type A) is predicted to opt for a more risky allocation $\left(\sigma_{II}^* > \sigma_{S*}^*\right)$ provided the bank just satisfied the *Basel II* norm initially. This condition presumably holds as a rule for those banks with a less risk-averse management (preferences of type B), again resulting in an investment policy that entails a higher volatility of returns than without regulation. In comparison with *Basel I*, these counter-productive effects are less pronounced, since *Basel II* causes a smaller downward shift of the efficiency frontier (see Figure 2 again).

In sum, *Basel I* and *Basel II* are predicted to have similar effects in one respect. Both may induce banks to opt for a more rather than less risky exposure than if they were optimizing free of the respective restraints. However, the two regulations differ in another respect. *Basel I* causes a 'deformation' of the (μ, σ)-frontier for all banks. By way of contrast, the 'deformation effect' of *Basel II* is limited to the subset of banks who just satisfied the norm initially.

Conclusion 3: At least for banks just compliant initially with the solvency norm, *Basel II* may still cause banks to pursue a riskier investment policy than absent regulation, but less risky than under *Basel I*.

6.3. *Basel III*

The details of implementation of *Basel III* regulation are not known yet at the time of writing. However, its objective clearly is to prescribe a higher level of solvency, to be attained by more solvency capital of which a greater part is to be equity [Bank for International Settlements (2011); Basel Committee on Banking Supervision (2011)]. In terms of Figure 3, the mandated solvency level shifts toward S^+ or even beyond. The consequence of this shift is that

the set of banks that does not have to react to a shock $d\bar{\sigma} > 0$ shrinks while the set of banks that have to come up with the full additional amount of capital to meet *Basel III* requirements increases (see the discussion in Section 6.2 again). Therefore, the steepening of the efficiency frontier predicted in (13) applies to a larger subset of banks, at least during a (lengthy) time of transition that sees banks struggling to increase their equity and reserves. Moreover, the fact that an increased share of solvency capital must be equity means an increase in regulatory stringency, causing the endogenous efficiency frontier pertaining to *Basel III* to be shifted back down towards that of *Basel I* (see Figure 2 again). Conclusion 3 therefore is predicted to hold more generally, implying that more banks may in fact be induced to pursue a riskier investment policy than in the absence of regulation.

7. Summary and conclusion

The basic hypothesis of this paper states that banks' investment divisions seek to attain a solvency level that balances the advantage of lower refinancing cost against the disadvantage of tying capital that would yield higher returns in other uses. However, this solvency level is too low from a societal point of view because it neglects the fact that insolvency causes substantial external costs. This analysis proceeds to assume that banks' investment divisions maximize the rate of return of risk-adjusted capital (*RORAC*), which implies that the marginal benefit of a higher level of solvency is the lower cost of refinancing while its marginal cost consists of the extra capital to be allocated and return forgone. These divisions learn the slope of their efficiency frontier in (μ,σ)-space in the course of three periods. In period 1, two shocks occur, viz. an exogenous change in expected returns $(d\bar{\mu})$ and in their volatility $(d\bar{\sigma})$. These shocks induce lagged adjustments $(dS*/d\bar{\mu}, dS*/d\bar{\sigma})$ during period 2. Net adjustment $dS*$ then triggers a reallocation of assets and liabilities and hence endogenous changes $d\bar{\mu}$ and $d\bar{\sigma}$ during period 3. This implies a perceived endogenous frontier in (μ,σ)-space prior to solvency regulation, with slope $d\hat{\mu}/d\hat{\sigma}\big|_{S*}$. This slope is not a constant but depends importantly on the fact that the relationship between risk capital and solvency is modified by exogenous changes in expected returns and volatility occurring in the capital market (Conclusion 1). The regulations imposed by *Basel I* are now shown to neglect this effect, causing a modification of the risk-return frontier as perceived by the regulated bank. This modification

induces top management to take a more risky position than it would absent regulation (Conclusion 2). The implications of *Basel II* are more complex. Still, banks initially just attaining the prescribed solvency level are again predicted to react to regulation by taking a more risky position than they would have otherwise (Conclusion 3). As to *Basel III*, its likely effect will be to increase the subset of banks responding in the same way, running counter the very objective of the regulators, who want banks take on less rather than more risk.

All of these predicted adjustments may be considered to amount to regulatory failures. .However, it would be inappropriate to conclude that *Basel I*, *II* or *III* or even solvency regulation in general should be revoked. First, the model analyzed in this paper might be too simplistic; banks possibly pursue other objectives than just maximizing *RORAC*. Second, *Basel II* already constitutes an improvement over *Basel I* in that its self-defeating effect is limited to the (usually small) subset of banks that initially had just been compliant with the prescribed solvency level. As to *Basel III*, the short-run increase in this problematic subset effect has to be weighed against the long-run increase in solvency levels generally achieved. And finally, assuming that solvency regulation does entail more benefit (in terms of external cost avoided) than cost (in terms of biasing banks' tradeoffs between μ and σ), one would have to find an alternative whose benefit-cost ratio beats that of the *Basel* type. However, the present work does call attention to likely shortcomings of current and planned future solvency regulation not only of banks, but of insurance as well [see Zweifel and Eisen (2012), ch. 8.4].

Appendix A

First, consider a shock $d\overline{\mu}$ disturbing the first-order condition (4). With R shorthand for *RORAC*, the comparative static equation reads,

$$\frac{\partial^2 R}{\partial S^2} dS* + \frac{\partial^2 R}{\partial S \partial \overline{\mu}} d\overline{\mu} = 0. \tag{A.1}$$

Since $\partial^2 R / \partial S^2 < 0$ in the neighborhood of a maximum, $\mathrm{sgn}\left[\partial^2 R / \partial S \partial \overline{\mu}\right]$ determines $\mathrm{sgn}\left[dS* / d\overline{\mu}\right]$. Differentiating eq. (4) w.r.t. $\overline{\mu}$, one has

$$\frac{\partial^2 R}{\partial S \partial \overline{\mu}} = -\frac{\partial^2 r_D}{\partial S \partial \overline{\mu}} - \left(\left(1 - \frac{\partial r_D}{\partial \overline{\mu}}\right) C - (\mu - r_D)\frac{\partial C}{\partial \overline{\mu}}\right)\frac{1}{C^2}\cdot\frac{\partial C}{\partial S} - \frac{\mu - r_D}{C}\cdot\frac{\partial^2 C}{\partial S \partial \overline{\mu}}. \tag{A.2}$$

Using (4) to obtain $\partial C / \partial S = -(\mu - r_D)^{-1}(\partial r_D / \partial S)\cdot C$, one has

$$\frac{\partial^2 R}{\partial S \partial \overline{\mu}} = -\frac{\partial^2 r_D}{\partial S \partial \overline{\mu}} + \left(1 - \frac{\partial r_D}{\partial \overline{\mu}}\right)\frac{1}{C}\cdot\frac{1}{\overline{\mu} - r_D}\cdot C\cdot\frac{\partial r_D}{\partial S} - (\mu - r_D)\frac{\partial C}{\partial \overline{\mu}}\cdot\frac{1}{C^2}\cdot\frac{1}{\mu - r_D}\cdot C\cdot\frac{\partial r_D}{\partial S} - \frac{\mu - r_D}{C}\cdot\frac{\partial^2 C}{\partial S \partial \overline{\mu}}.$$
$$. \tag{A.3}$$

This can be simplified to become eq. (5) of the text.

Now consider $d\overline{\sigma} > 0$. In full analogy to (A.1), one obtains from eq. (4),

$$\left[\frac{\partial^2 R}{\partial S \partial \overline{\sigma}}\right] = -\frac{\partial^2 r_D}{\partial S \partial \overline{\sigma}} - \left(-\frac{\partial r_D}{\partial \overline{\sigma}}\cdot C - (\mu - r_D)\cdot\frac{\partial C}{\partial \overline{\sigma}}\right)\cdot\frac{1}{C^2}\cdot\frac{\partial C}{\partial S} - \frac{\mu - r_D}{C}\cdot\frac{\partial^2 C}{\partial S \partial \overline{\sigma}}. \tag{A.4}$$

Using (4) again to substitute $\partial C / \partial S$, one has

$$\frac{\partial^2 R}{\partial S \partial \overline{\sigma}} = -\frac{\partial^2 r_D}{\partial S \partial \overline{\sigma}} - \frac{\partial r_D}{\partial \overline{\sigma}}\cdot\frac{1}{C}\cdot\frac{1}{\mu - r_D}\cdot C\cdot\frac{\partial r_D}{\partial S} - (\mu - r_D)\frac{\partial C}{\partial \overline{\sigma}}\cdot\frac{1}{C^2}\cdot\frac{1}{\mu - r_D}\cdot C\cdot\frac{\partial r_D}{\partial S} - \frac{\mu - r_D}{C}\cdot\frac{\partial^2 C}{\partial S \partial \overline{\sigma}}. \tag{A.5}$$

Slight rearrangement yields eq. (7) of the text.

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