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## Risk-adjusted measures of value creation in financial institutions

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Alistair Milne – Mario Onorato

**Risk-adjusted measures of value  
creation in financial institutions**




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## Risk-adjusted measures of value creation in financial institutions

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Bank of Finland.

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# Risk-adjusted measures of value creation in financial institutions

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## Abstract

Measuring value creation by comparing the RAROC of an exposure (the return on risk capital) with a single institution-wide hurdle rate is inconsistent with the standard theory of financial valuation. We use asset pricing theory to determine the appropriate hurdle rate for such a RAROC performance measure. We find that this hurdle rate varies with the skewness of asset returns. Thus the RAROC hurdle rate should differ substantially between equity which has a right skew and debt which has a pronounced left skew and also between different qualities of debt exposure. We discuss implications for financial institution risk management and supervision.

Keywords: asset pricing, banking, capital allocation, capital budgeting, capital management, corporate finance, downside risk, economic capital, performance measurement, RAROC, risk management, value creation, hurdle rate, value at risk

JEL classification numbers: G22, G31

# Riskisopeutettujen tuottojen käyttö rahoituslaitosten arvonluonnin mittaamisessa

Suomen Pankin keskustelualoitteita 25/2009

Alistair Milne – Mario Onorato  
Rahapolitiikka- ja tutkimusosasto

## Tiivistelmä

Rahoituslaitoksen arvonluontia mitataan usein vertaamalla investointiposition riskisopeutettua tuottoa yhteen instituution tason kynnystuottoon. Tällainen menettely ei kuitenkaan ole sopusoinnussa rahoitusvarallisuuden arvostusta selittävien tavanomaisten teorioiden kanssa. Tässä tutkimuksessa hyödynnetään varallisuuden hinnoitteluteoriaa, jotta saadaan määritetyksi järkevä kynnystuotto, johon riskikorjattuihin tuottoihin perustuvaa tulosta voidaan puolestaan verrata. Kynnystuoton osoitetaan tarkasteluissa riippuvan varallisuuden tuottojakauman vinoudesta. Tästä puolestaan seuraa, että oman pääoman riskikorjatun tuoton kynnys poikkeaa merkittävästi velkapääoman kynnystuotosta, koska oman pääoman tuottojakauma on vino oikealle ja velkapääoman tuottojakauma vino vasemmalle. Tuloksen merkitystä arvioidaan rahoituslaitosten riskienhallinnan ja rahoitusvalvonnan kannalta.

Avainsanat: varallisuuden hinnoittelu, pankkitoiminta, investointisuunnitelma, investointien rahoitussuunnitelma, varallisuuden hallinta, yritysrahoitus, arvioitua heikomman kehityksen riski, taloudellinen pääoma, tuloksen mittaaminen, riskienhallinta, arvonluonti, kynnystuotto, VaR

JEL-luokittelu: G22, G31

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# 1 Introduction

Most of the world's large and internationally active financial institutions now use their risk-management systems for assessing risk-return tradeoffs. This practice is described as 'economic capital management' or 'capital allocation'.<sup>1</sup> The most widely used capital allocation based value measure is RAROC, the ratio of expected revenues on a particular exposure to its contribution to institution-wide risk capital.<sup>2</sup> The numerator is expected returns over some time horizon (usually one year) net of all operational and funding costs. The denominator – risk capital – is an exposure-specific measure of tail risk quantified using a combination of models, including VaR for market risk, Credit-VaR models for credit risk and other models of extreme losses from operational risk.

RAROC is nowadays actively promoted both by the consultancy industry and by regulators, for a wide range of applications, in commercial and investment banking, asset management and insurance. In order for financial institutions to be able to use their own internal models as part of the more advanced calculations of regulatory capital in pillar 1 of the Basel II accord, these models must pass a 'use test' ie they must be actively used by the bank for managing its own portfolio, not just constructed specifically for regulatory compliance. The new Solvency II regulations for European insurance companies, which introduce similar approaches to capital regulation as Basel II for banks, provide similar encouragement for capital allocation. As a number of consultancy studies document RAROC has become the most widely applied tool of financial valuation around the world, used by financial services firms for supporting decisions on portfolio allocations, business mix, product pricing, and employee remuneration.<sup>3</sup>

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<sup>1</sup> The major consultancy companies are a good source of information on how financial institutions apply these methods, see for example KPMG (2004) and PWC-EIU (2005) on their use in business management and Ernst and Young (2005) on their role in investor disclosure. For a recent published collection of practitioner writing see Dav (ed) (2006).

<sup>2</sup> Matten (2000, pp 146–166) describes RAROC alongside several related performance measures. The various acronyms (RAROC, RORAC, RARORAC, etc.) are not applied by practitioners in an entirely consistent manner. While RAROC is the most common acronym for the most commonly used measure, the one that we discuss in this paper, this same measure is frequently referred to by other names and acronyms, and the term RAROC is also applied to other related performance measures.

<sup>3</sup> Smithson (2002), page 266, reports that 78% of the respondents to his 2002 Rutter Associates survey of credit portfolio managers, used RAROC to evaluate the performance of their portfolio of credit assets. PWC-EIU (2005), covering more than 200 medium sized and large banks and insurance companies worldwide, finds that more than half now conduct such capital allocation and most use the resulting return measures for various purposes, including business decision making, product pricing, and the determination of bonuses. They write that 'economic capital is fast gaining critical mass within the industry'. A more recent 2006 update of this survey shows even greater adoption. Asset managers also make widespread use of RAROC as a performance measure when acting on behalf of both retail and institutional investors.

One reason for the widespread appeal of RAROC for making risk-return decisions is that happens to be consistent with the most tractable version of standard financial theory routinely taught in most MBA finance classes. Under the standard but rather implausible class room assumption that all returns are normally distributed, then the RAROC denominator – value at risk – measures the contribution of every exposure to aggregate portfolio risk. Return relative to aggregate portfolio risk can then be optimized by setting a single portfolio wide RAROC hurdle. These same assumptions also allow the standard capital asset pricing model (CAPM) to be derived in an especially straightforward way that even those with little previous exposure to financial theory can follow.

This is however a very special case. Our analysis is based instead on the well developed standard theory of financial valuation that does not make any assumptions about return distributions. This theory, beginning with the contributions of Markovitz and of Arrow, teaches us that if investors are rational, risk-averse, and can exchange exposures freely with each other without significant trading costs, then they will all agree on a present value for any tradable financial asset (if not then there are unexploited gains from trade). This present value should then depend only on the returns of the financial asset conditional on each possible outcome for aggregate economy wide output or market return.<sup>4</sup> This ‘pricing kernel’, the negative relationship between investor’s valuation of asset returns and aggregate output or market return, can then be used to obtain present values for any financial asset. This pricing kernel is not unlike the standard CAPM (one general theoretical formulation is the ‘consumption-CAPM’ and even the standard CAPM corresponds to the special cases where all investors have quadratic preferences or all returns are normal). But as we shall demonstrate, using the pricing kernel, if there are differences in the shape of return distributions then return relative to aggregate portfolio risk is *not* optimized by setting a single portfolio wide RAROC hurdle.<sup>5</sup>

The standard theory is far from perfect. It has not proved especially helpful to understanding asset price volatilities. Financial markets are incomplete and investors subject to trading constraints, so there will be some uninsured exposures to different states with the same aggregate payoffs and differences between investors in their valuation of these payoffs. But using RAROC with a single institution hurdle rate does not help correct financial valuation for any of these problems.

Our paper goes further, showing that these valuation distortions from using RAROC with a single hurdle rate for all types of exposure can be quantitatively extremely large. Consider for example a comparison between a debt and an equity

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<sup>4</sup> This is because risk averse investors can fully insure each with other for outcomes across states with the same level of aggregate output or market return.

<sup>5</sup> Formal proofs of the theoretical results presented in this paper are found in Milne and Onorato (2009).

portfolio. In this case there are substantial differences in RAROC hurdles between equity and debt exposures, and between debt of different ratings. This is because of the different skewness of their respective return distributions. Returns on equities are right skewed, implying that the volatility of returns is large relative to the risk capital. Defaultable debt, in contrast, is left skewed and has a low volatility of returns relative to risk capital. As a result the RAROC hurdle appropriate for a debt portfolio is very much lower than that for an equity portfolio, with the least risky investment grade debt having the lowest RAROC hurdles of all.

The implication is that if RAROC is to be used as a valuation tool then it requires exposure-specific hurdle rates, adjusted to correct for differences in skewness and higher moments of the return distribution. Exposures with relatively large left-hand tails should be subject to relatively lower RAROC hurdles. This is true even when investors value marginal returns especially highly when aggregate output is relatively low.

The paper is arranged as follows. Section 2 provides some further motivation and discusses some related contributions to the literature. Section 3 is a review of the relationship between valuation theory and the RAROC value metric, drawing on the contributions of Crouhy et al (1999) and Milne and Onorato (2009). Here we apply the ‘pricing kernel’, the valuation metric of standard asset pricing theory, to investigate the determinants of zero net present value RAROC hurdle rates. Section 3.1 sets out our notation and assumptions. Section 3.2 briefly summarizes the relevant asset pricing theory. Section 3.3 discusses the conditions under which different exposures can be compared using a single zero-NPV RAROC hurdle rate and how these hurdle rates are affected by skewness of exposures. Section 4 explores the quantitative implications of the results of Section 3, presenting calculations of zero-NPV RAROC hurdle rates showing these differ substantially between different exposures, under a range of assumptions about portfolio parameters, the RAROC threshold and investor preferences. Section 5 is a short conclusion.

## 2 Motivation and literature review

The use of capital modeling for the twin applications of default protection and for business management is widely promoted.<sup>6</sup> It is nevertheless somewhat surprising that financial institutions have developed their own distinct capital based performance measures, rather than using standard net present value tools used for

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<sup>6</sup> See for example Zaik et al (1996) who note that models of risk capital are used for both for finding the proportion of equity to assets that minimizes the cost of funding and for risk-return assessment.

example in project appraisal by non-financial companies. The most obvious reason is the importance of credit standing to financial institutions.<sup>7</sup> A further reason for the use of capital based performance measures – not much emphasized in the research literature – is that capital allocation can be relatively easily extended to the important non-funded off-balance sheet exposures of financial institutions, where for example the familiar method of internal rate of return cannot. This is why it is convenient to use capital, rather than funding, for setting limits on the positions taken by both business lines and individual employees.

If credit standing matters then a financial institution should make valuations relative to its own portfolio as well as to the market as a whole. There are two key academic articles exploring this point. Froot, Scharfstein and Stein (1993) point out that, faced with an increasing cost of raising external funds financial institutions will behave in a risk-averse fashion towards risks that are diversifiable at a market level. Specifically, a business unit's contribution to aggregate earnings volatility will be an important factor in the capital allocation and capital structure decisions and also in the decision to hedge earnings risk. Capital structure, hedging and capital budgeting are therefore inextricably linked together. Froot and Stein (1998) demonstrate that in a two period model with linearly increasing costs of recapitalization that the hurdle rate for investments can be calculated from a two factor pricing model. Adopting their notation this can be written as the covariance of the return with the market  $R_m$  and with the risks of the existing portfolio  $R_p$ , so the required return is given by  $\mu_i = \gamma \text{cov}(\mu_i, R_m) + \lambda \text{cov}(\mu_i, R_p)$  where  $\gamma$  is the market unit price of risk for the (market) priced factor  $R_m$  and  $\lambda$  is the unit cost for volatility of the portfolio ie they have a key practical message. Balance sheet and systematic risk must be separately priced. While not the focus of their analysis, their work suggests that incorporating systematic risk within a single measure such as RAROC is misguided because, even if as they assume returns are multivariate normally distributed,  $R_p$  is not the same as  $R_m$ .

Our analysis complements that of Froot and Stein (1998). We show that if returns are *not* multivariate normally distributed then, *even if* there are no costs of recapitalization, a single hurdle RAROC cannot be used to price risk. Moreover if there are costs of recapitalization or other constraints on raising equity, then a two factor pricing model similar to that suggested by Froot and Stein (1998) can be useful.

Another related branch of literature is that on coherent measures of risk, initiated by Artzner et al (1999). They demonstrate that the RAROC Value at Risk denominator (VaR) fails to satisfy their axiom of sub-additivity. This implies that

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<sup>7</sup> Merton and Perold (1993) emphasize this point, arguing that performance measurement in financial institutions is different from industrial companies because their customers are their largest liability holders and as a consequence, a high credit rating is generally essential to maintain their business activities, eg as dealers or customers in OTC markets, to underwrite securities or to compete effectively in the corporate banking and deposit markets.

it is possible, when combining portfolios, that the overall VaR of the combined portfolio can be greater than the sum of the individual VaRs. This potential absence of diversification benefits has been interpreted to mean that VaR is an unsatisfactory risk measure and that alternative measures which do not violate the axiom of sub-additivity, eg expected tail shortfall, should be preferred instead. Our analysis leads to a slightly different interpretation of the Artzner et al (1999) results. We provide a further reason, in addition to the violation of sub-additivity, for thinking that VaR is a poor measure of risk for assessing risk-return trade-offs. So in this sense our work reinforces that of Artzner et al. But our work also implies that VaR remains an acceptable risk measure for assessing the probability of default (in this application there is no compelling reason to impose the axiom of sub-additivity) and therefore may play a role in a two-factor pricing model such as that suggested by Froot and Stein (1998).

Another paper close to our own is Crouhy et al (1999). They note that that RAROC does not measure NPV, when NPV is measured according the CAPM and there is a single RAROC hurdle rate. However they restrict their analysis to the comparison of arithmetic and log-normally distributed returns and do so without reference to underlying asset pricing theory. We provide a fuller discussion of the underlying economic intuition and extend the quantitative comparisons to defaultable debt, revealing much larger differences in RAROC hurdles than they report.<sup>8</sup> Our work and that of Crouhy et al (1999) can usefully be contrasted with the analysis of RAROC and economic capital provided by Jokivuolle (2006), who also assumes CAPM valuation but under the alternative assumption that returns are multivariate normally distributed.

### 3 RAROC and financial valuation

This section discusses the relationship between RAROC and the standard theory of financial valuation.

#### 3.1 Notation and assumptions

A financial institution considers an investment in an exposure indexed by  $i$  held for a single period with an initial funding cost of  $L_i(0)$ .<sup>9</sup> The exposure can be one of many different kinds, including a loan, a trading position, an off balance sheet commitment, or an insurance contract. It can be a portfolio of assets as well as a

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<sup>8</sup> Milne and Onorato (2009) provide a more formal discussion of the underlying theory.

<sup>9</sup> Throughout this section we distinguish the timing of cash flows and payoffs, using (0) to indicate the beginning of the period and (1) the end of the period.

single asset.  $L_i(0)$  can be positive or negative (for example writing an option creates a positive cash flow at the time of the contract, in which case  $L_i(0)$  is negative). At the end of the period this exposure realises a payoff of  $R_i(1) + A_i(1)$  with an expected value of  $R_i(1)$  ie  $A_i(1)$  measures the distribution of end-period payoffs about their mean value with  $E[A_i(1)] = 0$ .

In order to discuss balance sheet diversification we must also pay attention to the distribution of returns on the remainder of the institution's portfolio. Payoffs on the remainder of the portfolio are denoted by  $\bar{R}_i(1) + \bar{A}_i(1)$ , and on the total portfolio including  $A_i$  by  $R(1) + A(1) = \bar{R}_i(1) + R_i(1) + \bar{A}_i(1) + A_i(1)$ . The upper case for the expected payoffs  $R_i(0)$ ,  $\bar{R}_i(0)$ , and  $R(0)$  indicates that these are all absolute nominal monetary payoffs, not rates of return which we will distinguish using lower case eg  $r$ .

The distribution of total portfolio payoffs are described by the cumulative density function (CDF) denoted by a double HH to indicate this is a multivariate distribution  $HH(X_i, \bar{X}_i) = p(A_i(1) \leq X_i, \bar{A}_i(1) \leq \bar{X}_i)$ . From HH we can derive various single variable distributions which are of interest for risk measurement purposes:

1. the total portfolio CDF denoted as  $H(X) = p(A(1) = A_i(1) + \bar{A}_i(1) \leq X)$ ;
2. the stand alone CDF denoted as  $H_i(X_i) = p(A_i(1) \leq X_i)$ ; and
3. the total portfolio CDF without the investment  $i$  denoted as  $\bar{H}_i(\bar{X}_i) = p(\bar{A}_i(1) \leq \bar{X}_i)$ .

All these distributions have zero expectations, since they describe payoffs relative to their expected values. Otherwise we place no restrictions on these distributions.

Risk capital is measured using the quantiles of the CDF at a chosen probability threshold  $p^*$ . Thus the total portfolio risk capital is given by  $-HH^{-1}(p^*)$  while the stand alone risk capital for investment  $i$  is given by  $-H_i^{-1}(p^*)$ .<sup>10</sup> Typically, since  $p^*$  is small,  $H^{-1}(p^*)$  is negative and much greater in absolute magnitude than expected net return, so risk capital is positive. We can also allow for diversification at portfolio level by measuring risk capital as  $\bar{H}_i^{-1}(p^*) - H^{-1}(p^*)$ . We define return on risk capital or RAROC for exposure  $i$  in two ways, either as a standalone measure,  $r_i^{rc}$

$$r_i^{rc} = \frac{R_i(1) - r_f L_i(0)}{-H_i^{-1}(p^*)} \quad (3.1)$$

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<sup>10</sup> Note that under this definition risk capital is a VaR type quantile risk measure associated with period 1 return distribution and therefore differs from equity capital which is a period 0 source of funding.

or as a portfolio measure

$$r_i^{\text{prc}} = \frac{R_i(1) - r_f L_i(0)}{\bar{H}_i^{-1}(p^*) - H^{-1}(p^*)} \quad (3.2)$$

The difference between the two is that in the second portfolio measure the numerator is the ‘marginal’ contribution to institution wide portfolio risk ie the difference between aggregate portfolio VaR with and without exposure i.

In the remainder of the paper we will consider only the stand alone measure. This is not because the portfolio measure is unimportant for risk management decisions, but because as discussed in the following sub-section the standard theory of financial valuation depends only on the market pricing kernel. Thus, a point often forgotten by practitioners, in order to measure value created for investors the benefits of diversification need to be assessed at the level of the aggregate economy and largely depend on the contribution to aggregate investor portfolio risk exposure not to firm portfolio risk exposure.

## 3.2 Asset pricing theory and market valuation

We denote the time  $t = 0$  market value of exposure i by  $\hat{A}_i(0)$ .<sup>11</sup> In this subsection we outline the standard asset pricing theory that we use to model this market value  $\hat{A}_i(0)$ .<sup>12</sup> Under the assumption that all risks are tradable in liquid markets the market value of exposure i can be expressed as<sup>13</sup>

$$\hat{A}_i(0) = E[z(R_i(1) + A_i(1))] = E[z]R_i(1) + E[zA_i(1)] \quad (3.3)$$

where  $z$  is a pricing (or stochastic discount) factor. The market rate of return on asset i is defined as

$$r_i = \frac{R_i(1)}{\hat{A}_i(0)} \quad (3.4)$$

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<sup>11</sup> We use a ‘hat’ to distinguish market measures (eg  $\hat{A}_i$ ) from the corresponding accounting measure (the accounting valuation of the exposure measured at cost would be  $A_i = L_i$ ). We use the same ‘hat’ for the zero-NPV RAROC, since this is the return on capital achieved by an exposure with a market value  $\hat{A}_i(0)$  that equals its accounting value measured on a cost of acquisition basis  $L_i(0)$ .

<sup>12</sup> This theory is described in many textbooks. Our presentation follows that in part I of Cochrane (2005).

<sup>13</sup> This is Cochrane (2005), equation 1.4, with our slightly amended notation.



Note that in the case of a risk free asset  $\hat{A}_i(0) = E[z]R_i(1)$ , implying that  $E[z] = \hat{A}_i(0) / R_i(1) = (1 + r_f)^{-1}$ .<sup>14</sup>

We will further assume that markets are complete.<sup>15</sup>  $z$  is then unique and represents the marginal valuations by investors of all possible asset returns.<sup>16</sup> The content of this theory comes from the fact that  $z$  is the same for all assets. This theory supports a number of widely standard results about asset pricing. Investors do not need to be compensated for risks that can be diversified through trading of risky investment instruments. Compensation is required only for risks that are correlated with the investor valuation of returns (those that co-vary with  $z$ ). Portfolio or exposure-specific characteristics will not affect valuations.

This theory can be represented in many equivalent ways. We will use the following ‘security line representation’ expressing the correlation of returns between  $\frac{A_i(1)}{\hat{A}_i(0)}$  and  $z$  in terms of  $\rho_{iz}$ , and the standard deviation of  $\frac{A_i(1)}{\hat{A}_i(0)}$  in terms of  $\sigma_i$

$$r_i = r_f - \rho_{iz} \sigma_i \sigma_z \quad (3.5)$$

This shows that excess returns  $(r_i - r_f)$  are linear function of both correlation of returns with  $z$  and of the standard deviation of returns. The  $z$  are not directly observed. They are a set of relative valuations inferred from the prices of investment assets. However given further assumptions about either investor preferences, or the determinants and distribution of investor returns,  $z$  can be modeled using observable economic or market factors, yielding a number of standard asset pricing equations, including the standard CAPM.

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<sup>14</sup> A different expression applies in the situation where there are no risk free assets and hence no risk-free interest rate  $r$ .

<sup>15</sup> Our main results still obtain under the weaker assumption that all assets are traded in liquid markets (absence of arbitrage opportunities). Suppose first that we are considering the RAROC hurdle for an asset that is ‘spanned’ by all existing traded assets. In this case, while there is no unique stochastic discount factor  $z$ , market prices are still uniquely determined and our propositions continue to hold. If the financial asset is not so spanned then no unique RAROC hurdle exists and so RAROC certainly cannot be used for performance measurement. In this case there is instead a minimum hurdle below which an exposure is definitely value destroying for all investors.

<sup>16</sup> The ratio of  $z^a$  and  $z^b$  for two different outcomes  $A_i^a$  and  $A_i^b$  represents the willingness of investors to exchange a small increase in return in the event of outcome  $A_i^a$  for a small decrease in return in the event of outcome  $A_i^b$ .

### 3.3 Defining the right hurdle rate: the zero-NPV RAROC

This sub-section defines the appropriate hurdle rate when using RAROC  $r_i^{rc}$  (return on risk capital) as a performance measure to measure value creation. As explained in section 3.1, RAROC can be written

$$r_i^{rc} = \frac{R_i(1) - r_f L_i(0)}{-H_i^{-1}(p^*)} \quad (3.6)$$

We first obtain the zero-NPV RAROC hurdle rate. Net present value or NPV is the difference between the market value of an exposure  $\hat{A}_i(0)$  and its cost of acquisition  $L_i(0)$  and can therefore be written as<sup>17</sup>

$$NPV = \hat{A}_i(0) - L_i(0) \quad (3.7)$$

This is a net present value because it is the present discounted value of future returns less the current cost of acquisition of the exposure. Exposures are value creating and should be acquired if and only if  $NPV > 0$ . The stand alone return on risk capital on a zero-NPV exposure (one where  $\hat{A}_i(0) = L_i(0)$ ) can then be written as the following ratio

$$\hat{r}_i^{rc} = \frac{R_i(1) - r_f \hat{A}_i(0)}{-H_i^{-1}(p^*)} \quad (3.8)$$

Equation (3.8) is the zero-NPV RAROC hurdle rate. An alternative and equivalent decision criteria to  $NPV > 0$  is to accept all exposures for which  $r_i^{rc} > \hat{r}_i^{rc}$  ie  $\hat{r}_i^{rc}$  is the required rate of return on risk capital or zero-NPV RAROC hurdle rate.

We now examine the determinants of this zero-NPV RAROC hurdle rate, showing that an increase in skewness increases risk capital relative to required returns and so reduces  $\hat{r}_i^{rc}$ . By substituting equation (3.4) and (3.5) into (3.8) we can rewrite this zero-NPV hurdle rate as

$$\hat{r}_i^{rc} = \frac{\hat{A}_i(0) \rho_{i,z} \sigma_i \sigma_z}{-H_i^{-1}(p^*)} \quad (3.9)$$

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<sup>17</sup> This is the NPV formula in a single-period setting. Multi-period NPV formulations are obtained from the valuation of an asset traded at period 0 offering period t future expected payoffs  $R_i(t) + A_i(t)$  where  $R_i(t)$  is the known expected return and  $A_i(t)$  is the distribution around that return for  $t = 1, 2, \dots, T$ .

This shows that it is legitimate to use RAROC with single institution-wide hurdle rate for all exposures  $i = 1, 2, \dots, I$  only if the required return premium for each exposure (the numerator of equation (3.9) is proportional to the risk capital (the denominator of this equation). The conditions for this to be true are demanding. In particular an increase skewness raises the VaR denominator  $H_i^{-1}(p^*)$  by more than it increases  $\hat{A}_i(0)\rho_{i,z}\sigma_i$  and so lowers the zero-NPV hurdle rate.

A sufficient condition for the return on standalone risk capital to be the same for all exposures is that for any given  $i$  the distribution of  $i$  can be expressed as a mean-preserving spread of a single underlying asset return distribution  $A^+(1)$  ie that the skewness and higher moments of all distributions are the same.<sup>18</sup> In this case  $\rho_{i,z}$  and is the same for all assets and  $H(A^i(1))$  is proportional to  $\sigma_i$  so  $\hat{r}_i^{rc}$  is the same for all assets. An example where this is the case is when all asset returns obey a multivariate normal distribution. This is not a necessary condition because it is just possible that differences in  $\rho_i$  between assets are exactly offset by differences in the ratio of  $H(A^i(1))$  to  $\sigma_i$ ; but this is an implausible situation. It is clear that zero-NPV RAROC hurdles can vary considerably, depending upon the shape of the return distribution.

## 4 Calculations of zero-NPV RAROC hurdles

This section presents some illustrative calculations of the RAROC hurdle rate, the return on risk capital that must be achieved by an NPV positive investment either in equities or in debt portfolios of varying credit qualities and discusses the practical implications of our analysis. Variations in these hurdle rates from one exposure to another are not just a theoretical issue. Our calculations suggest that the differences in these hurdle rates are large enough to be of considerable practical concern and that using a single institution-wide RAROC measure leads to substantial misvaluation of investment opportunities.

In order to conduct these calculations we making some specific but plausible assumptions about the distribution of returns on different assets (equity and various qualities of debt) at the end of a fixed holding period.<sup>19</sup> These assumptions determine both the distribution of asset returns and, most importantly, the relationship between these returns and aggregate market returns.

We then apply the standard asset pricing tools described in the previous section to calculate the expected market return on each investment. We do this by value each portfolio (its ‘present value’) and calculating its correlation with the

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<sup>18</sup> For a formal proof of this statement see Milne and Onorato (2009).

<sup>19</sup> It would be possible to extend to the case of multiple periods of investment and consumption, rather than a single holding period, but this is not necessary to our argument.

‘pricing kernel’. Most of our calculations assume quadratic investor preferences so the pricing kernel is then that of the standard CAPM, a negative linear function of the market return, but we also consider the case of constant relative risk aversion, with the pricing kernel is proportional to the marginal utility of a representative investor.

Finally we compute the amount of risk capital that has to be held against each asset in order to maintain the probability of default to a given threshold ie we calculate its value at risk. Combining these results allows us to compute the RAROC hurdle rate on each investment (this is the ratio of the required expected market return, less the cost of financing the purchase of the asset, to risk capital).

Our calculations make the following assumptions:

- The investment horizon and also maturity of debt securities are one year (having these time periods the same means that there is no interest rate risk.)
- For Tables 4.1–4.3 we assume that all investors have quadratic preferences, the required returns on both equity and debt are calculated using the capital asset pricing model. For our baseline illustrations we assume  $r_f = 5\%$  and  $r_m = 11\%$  and  $\sigma_m = 10\%$ .
- Our use of the CAPM is different from that in the usual MBA level textbooks, because returns are not normally distributed. The end period value of the equity portfolio is instead log-normally distributed given by:  $R_i(1) + A_i(1) = \exp(q + sZ)\hat{A}_i(0)$  where  $q$  and  $s$  are the log (or instantaneous) rate of return and standard deviation and  $\hat{A}_i(0)$  is the period 0 market value of the equity portfolio.  $Z$  is the underlying portfolio risk factor with a standard normal distribution.
- The market portfolio is assumed to be that offered by the equity portfolio (the equity portfolio is fully diversified). Hence for the equity portfolio  $\sigma_i = \sigma_m$  and  $r_i = r_m$  and we can use these relationships to obtain expressions for both  $q$  and  $s$  in terms of  $\sigma_m$  and  $r_m$  (see appendix for these and other technical details and supporting Mathematica notebook for calculations).
- Tables 4.4 and 4.5 assume a representative investor with constant relative risk aversion ie with expected utility given by  $\int [\exp(q + sZ)]^{1-\gamma} \phi(Z) / (1-\gamma) dZ$  hence placing a marginal valuation on returns for given  $Z$  of  $[\exp(q + sZ)]^{-\gamma}$ . Here  $\gamma$  is the investors’ coefficient of relative risk aversion and this can itself be calculated from observable market rates of return.
- The returns on portfolios of defaultable debt are determined by the same aggregate factor  $Z$  as the equity portfolio, according to the single aggregate factor asymptotic Vasicek model (the standard model of credit portfolio returns used for the IRB calculations in the Basel II accord, see appendix for formal details). In our baseline LGD is the loss given default that we assume equal to 0.4; PD is the default probability, as reported in the third column of

Table 4.1, for the various debt classes; and  $\omega = 0.4$  is the correlation of underlying asset values within the portfolio ( $\omega^{0.5}$  is the correlation of each asset with the market factor); and  $Z$  is the same aggregate risk factor that determines the returns on the equity portfolio.

- While our assumptions ensure analytical solutions for required return on equity, we have to use numerical integration to calculate the required returns on debt.

We compare the equity portfolio with six different qualities of defaultable debt, ranging from  $A^-$  to CCC. The annual default probabilities PD are taken from the Fitch Ratings Global Corporate Finance Average Cumulative Default Rates 1990–2007. Table 4.1 presents the resulting calculations of the zero-NPV RAROC hurdle rates.

Table 4.1 **Baseline CAPM Calculations of RAROC Hurdle Rates**

Exposure	Rating	Default probability %	standard deviation %	Correlati on with market	required return %	Risk capital %	RAROC hurdle % (8) = ((6)– $r_f$ )/(7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Equity			10.00	1.00	11.00	29.80	20.14
Debt	$A^-$	0.10	0.22	0.37	5.05	4.90	0.95
Debt	BBB	0.26	0.45	0.44	5.11	8.74	1.29
Debt	$BB^+$	0.69	0.90	0.53	5.27	14.62	1.86
Debt	BB	1.24	1.36	0.59	5.46	19.05	2.40
Debt	$B^+$	1.44	1.52	0.61	5.52	20.27	2.57
Debt	CCC	21.91	9.54	0.92	9.38	35.73	12.25

Notes: The risk free rate of interest is  $r_f = 5\%$ . In the case of the equity portfolio column (4), (5) and (6) are all determined by the assumption that equity returns match those on the market as a whole, with a market return of  $r_m = 11\%$  and standard deviation of  $\sigma_m = 10\%$ . In the case of debt Column (3) is an assumed parameter and the standard deviation and market return shown in columns (4) and (5) are calculated from the assumed Vasicek return distribution with asset correlation  $R = 0.4$  and  $LGD = 0.4$ . Column (6) is the required return calculated according to the CAPM from (4) and (5) using  $r_f + \rho_{i,m}\sigma_i^*(r_m - r_f)/\sigma_m$ . Risk capital in column (7) is calculated as the difference between the mean expected return and the 99.97% left hand tail of the assumed return distribution. Columns (3), (4), (6) and (7) are all percentages of the beginning of period market value of the exposure.

The standard deviation, and correlation and required return on the equity portfolio (columns (4), (5) and (6)) are determined by our assumption that equity portfolio returns correspond exactly to those for the market portfolio as a whole. The corresponding standard deviation and correlation with the market for the debt portfolios are calculated from equation (11) using numerical integration. Column (6) is the CAPM required return. The risk capital in column (7) is  $-H_i^{-1}(p^*)$  calculated using the default probability threshold  $p^* = 99.97\%$ . This threshold is a common industry choice for credit and value at risk calculations at a one year

horizon. Finally the RAROC hurdle is the required risk premium (the required return less the risk free rate) as a percentage of risk capital.

Note that the standard deviation of returns on debt (column (4)) are much smaller, as a percentage of market value, than those on equity. Investment grade debt has especially low volatility of returns (recall this is short term one year debt so there is no interest rate risk over a one year holding horizon) and even the speculative grade ( $B^+$  and BB) has much less volatility than equity. Only the debt in immediate risk of default (CCC) has a volatility of returns close to that of equity.

Correlations of debt returns with the market (column (5)) are also somewhat smaller than for equity, especially for the higher grades of debt. This is a plausible feature of the Vasicek model that underlies these calculations, since there is a very non-linear relationship between aggregate market returns and default. Small deviations in market returns about their expected level have only a minor impact on default rates, but a large decline in market returns is associated with a proportionately bigger rise in default and credit losses. Therefore correlation is less than one to one, even when the same aggregate risk factor drives both market returns and corporate debt default.

The relatively low standard deviation of returns and correlation with the market mean that the required returns on debt (column (6)) are also comparatively low. They are of course still at a positive premium to the risk free rate of 5%, because returns all increase with the same underlying risk factor. But on one-year  $A^-$  debt the required return premium is only 5 basis points. The observed market risk premium on such debt is in practice likely to be higher than such a theoretical calculation because of liquidity and other market frictions; none the less it is quite appropriate that it should be far less than the risk premium on equity. Even for  $B^+$  debt the risk premium we calculate is only 46 basis points, again much lower than the assumed 6% on equity. Again this is one year debt so such a risk premium is not implausible. Only the distressed CCC debt, on the verge of default, has a risk premium similar to that of equity.

The key finding of this table then appears in column (7). The zero-NPV RAROC hurdle represents the level of RAROC on a marginal investment opportunity. Any investment earning a superior RAROC than that shown in column (7) creates value for the investor. This zero-NPV RAROC hurdle varies hugely and is very much lower for most categories of debt than for equity. The RAROC hurdle for debt rated  $B^+$  or above is between one eighth and one twentieth of that for equity exposures. This is a very large difference indeed. Even for the distressed CCC debt, which is in many ways similar to equity, the zero-NPV RAROC hurdle is somewhat smaller than on equity, a consequence of the large amount of required risk capital.

Why this large difference in required returns on risk capital? As discussed above in relation to equation (3.9) the RAROC hurdle depends on the *skewness* of

return distributions. The RAROC hurdle for debt is much lower than that for equity, because of the right-skew of our assumed log-normal returns on equity and the left-skew of our assumed Vasicek credit portfolio returns on debt. These are standard models of the returns on equity and debt. They can be criticized as not providing the best possible fit to data. But still, even if other models are preferred, those will still share same skewness properties of these distributions, with a pronounced left-skew on debt returns and a more modest right skew on equity and thus yield RAROC hurdles for debt much lower than on equity.

It follows that when making a leveraged investment in debt, investors should be willing to accept a much lower return on capital than when investing in a leveraged equity portfolio. This is because, while they must hold a relatively large amount of capital that must be held against debt exposures as protection against comparatively rare extreme events (in Table 4.1 this is assumed to be equivalent to a loss of capital one in every three-thousand years), this is comparatively safe capital. In all but the very worst years debt investments will almost all be fully repaid and so the return on capital, in most years, is very predictable. In contrast when making a leveraged investment in equity, relative to the amount of capital needed as protection against the same extreme events, the return is relatively uncertain, even a modestly bad outcome can result in losses.

Debt, even below investment grade, is normally fairly safe (the standard deviation of column (6) and the required risk capital of column (7) are considerably smaller when compared those on an equity portfolio with the same market value); but when losses do occur they are comparatively large. As a result it is necessary to hold a relatively large amount of risk capital for these debt exposures, in comparison to the required excess of return over and above the safe rate of interest. And therefore the return on risk-capital is very much smaller than on equity.

Table 4.1 illustrate that RAROC hurdles for debt portfolios can be quantitatively very much smaller than for equity investments. This reported difference has been obtained for very specific choices of investor utility and market return parameters. Tables 4.2–4.4 explore the most material variations of this baseline specification.

Table 4.2

**Alternative calculations, varying risk-capital  
default threshold**

Exposure	Rating	PD	baseline: p* = 99.97%		p* = 99.8%		p* = 98%		p* = 90%	
			Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %
Equity			29.80	20.14	25.65	23.39	21.31	28.15	15.65	38.35
Debt	A <sup>-</sup>	0.10	4.90	0.95	2.08	2.24	0.39	11.87	0.03	178.02
Debt	BBB	0.26	8.74	1.29	4.28	2.63	1.02	11.07	0.11	102.22
Debt	BB <sup>+</sup>	0.69	14.62	1.86	8.30	3.27	2.52	10.80	0.40	67.21
Debt	BB	1.24	19.05	2.40	11.85	3.85	4.18	10.92	0.83	54.79
Debt	B <sup>+</sup>	1.44	20.27	2.57	12.90	4.03	4.74	10.99	1.00	52.25
Debt	CCC	21.91	35.73	12.25	33.20	13.18	25.48	17.17	14.34	30.51

Note: Calculations the same as for columns (7) and (8) of Table 1.

Table 4.2, compares the baseline calculations of Table 4.1 (repeated in the fourth and fifth columns) with three other sets of calculations, each with a successively less extreme default threshold for the calculation of risk capital. Thus we move from one in three thousand years (the Table 4.1 baseline  $p = 99.97$ ) to one in five hundred years ( $p = 99.8\%$ ), one in fifty years ( $p = 98\%$ ) and one in ten years ( $p = 90\%$ ). Some financial institutions using capital allocation for assessing risk-return decisions have chosen  $p = 95\%$  or  $p = 90\%$  rather than the extreme of  $p = 99.97$  (there is considerable variation amongst firms in how capital allocation is actually put into practice). This means they have to use one default threshold when assessing their capital needs for protection against extreme outcomes and a different default threshold for assessing risk-return decisions and pricing loan and derivative products. But it has the advantage, illustrated in Table 4.2, of bringing the different RAROC hurdle rates more closely into line with each other. It is then easier to justify using a single hurdle rate for return on capital across an institution.

This correction does not eliminate the inconsistency between RAROC and standard valuation theory. As Table 4.2 illustrates, while the differences in RAROC hurdle rates at  $p = 99.8\%$  and  $p = 98\%$  are reduced, when compared with Table 4.1, they are far from eliminated. And when  $p = 99\%$  a new problem emerges. Now the RAROC hurdle rates for debt are very much higher than those on equity. The reason for this that the returns on debt, with their pronounced left-hand skew, have correspondingly small but positive returns for the large majority of outcomes for the aggregate factor  $Z$ . As a result, as the probability threshold for measuring risk capital is reduced, the level of risk capital falls much more quickly for debt than for equity and eventually declines to zero even when  $Z$  is still negative (thus resulting in an unbounded threshold for return on capital). At some intermediate probability threshold, the RAROC hurdle rate may work out approximately the same for equity and for different categories of debt. But there is no means of determining this appropriate probability threshold without having



some independent measure of required returns, such as the one based on asset pricing theory applied in this paper.

Table 4.3 **Alternative calculations, varying Vasicek asset correlation**

Exposure	Rating	PD	$\omega = 0.6$		Baseline: $\omega = 0.4$		$\omega = 0.2$		$\omega = 0.1$	
			Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %	Risk capital %	RAROC hurdle %
Equity			29.80	20.14	29.80	20.14	29.80	20.14	29.80	20.14
Debt	A <sup>-</sup>	0.10	10.35	0.54	4.90	0.95	1.68	2.02	0.68	3.57
Debt	BBB	0.26	17.35	0.78	8.74	1.29	3.24	2.52	1.40	4.19
Debt	BB <sup>+</sup>	0.69	25.97	1.26	14.62	1.86	6.03	3.25	2.80	5.03
Debt	BB	1.24	31.02	1.78	19.05	2.40	8.52	3.86	4.16	5.66
Debt	B <sup>+</sup>	1.44	32.20	1.95	20.27	2.57	9.27	4.04	4.60	5.84
Debt	CCC	21.91	37.70	14.14	35.73	12.25	27.63	11.27	19.22	11.51

Note: Calculations the same as for columns (7) and (8) of Table 4.1.

Table 4.3 instead varies asset correlation, the key parameter of the Vasicek model of debt portfolio returns. The baseline figure of  $\omega = 0.4$  is a fairly typical of the values imposed in Basel II IRB risk calculations for corporate lending.<sup>20</sup> But by increasing this correlation to  $\omega = 0.6$  we can investigate the impact of increasing the sensitivity of loan default to aggregate risk; and by reducing this correlation we can obtain values more typical of retail lending of 0.2 or below.

Equity returns are unaffected by the asset correlation parameter determining debt default, so the entire equity row of Table 4.3 simply replicates the risk-capital and RAROC hurdle rates from Table 4.1. Changing asset correlation has however a substantial impact on the risk capital that has to be set aside as protection on a leveraged investment in debt. Thus with  $\omega = 0.6$  the required risk capital (column (4)) is more than double that of the Table 4.1 baseline (column (6)), while with  $\omega = 0.2$  required risk capital (column (8)) falls to less than half that of the baseline. Increasing asset correlation also increases the correlation of debt returns with market returns, but this impact is relatively small. As a result the RAROC hurdle rate works out at close to the inverse of the required risk capital. Again this is consistent with equation (3.9) above. A higher asset correlation magnifies the left-hand skew of the Vasicek distribution of returns on debt and the more pronounced the left-hand skew the lower the required return on risk capital (the RAROC hurdle rate).

Other parameter changes are of less interest than those reported in Tables 4.2 and 4.3. Changing the risk-free rate of interest ( $r_f$ ), the expected market return ( $r_m$ ) alters the CAPM required return per unit of portfolio standard deviation (recall

<sup>20</sup> The Basel II IRB does not impose a single value for asset correlation. Instead it states ‘risk curves’ that specify how asset correlation varies along with probability of default and firm size. But these risk curves average out at close to 0.4 for corporate exposures and around 0.15 for retail lending.

this depends on  $(r_m - r_f)/\sigma_m$ ); but this has the same impact on the returns required on both debt and on equity and so raises or lowers the RAROC hurdles by about the same amount. Their relative values are unaffected. The effect of altering  $\sigma_m$  is more complicated, a higher level of  $\sigma_m$  not only reduces the CAPM required returns per unit of portfolio standard deviation, it also alters the standard deviation and level of risk capital in equity portfolios and these changes increase the RAROC hurdle for equity relative to that on debt. But this impact is quantitatively small. Increasing LGD increases risk capital and required returns on debt but does not affect the RAROC hurdle.

The assumption of quadratic investor preferences underlying Tables 4.1–4.3 conflicts with one of the basic rationales for measuring risk capital, the desire to avoid extreme losses. This suggests that alternative specifications of investor preferences, assuming relatively greater aversion to extreme losses, could reduce the gap between the RAROC hurdle rates for debt and for equity. Table 4.4 shows recalculations of the RAROC hurdle rates, assuming that instead of quadratic investor preferences there is a representative investor with constant relative risk aversion. In this case it is necessary to constrain investor preferences, for consistency with observable data and for the sake of comparability with Table 4.1. It turns out (see the technical appendix) that the coefficient of relative risk aversion ( $\gamma$ ) of the representative investor can be easily calculated from the imposed values for risk-free rate of interest ( $r_f$ ), the expected market return ( $r_m$ ) and the volatility of market returns ( $\sigma_m$ ) and this in turn allows calculations of the RAROC hurdle rates.

Required returns now depend on the covariance of investment returns with the marginal utility of the representative investor. Columns (4) and (5) report baseline results which can be directly compared with Table 4.1, making as they do exactly the same assumptions about the risk-free rate of interest ( $r_f$ ), the expected market return ( $r_m$ ) and the volatility of market returns ( $\sigma_m$ ). Risk capital and expected returns on equity exactly as in Table 4.1 (recall that we assume that the equity portfolio is the same as the market portfolio). Expected returns on debt portfolios are now however higher than in Table 4.1 and the market values of debt portfolios correspondingly lower. As a result of the assumption of a representative investor with constant relative risk aversion, the RAROC hurdle for A<sup>-</sup> debt slightly more than doubles from 0.95 to 2.09. The impact becomes somewhat smaller as debt ratings decline. For the equity like CCC debt there is only a small increase. Despite this, the RAROC hurdle for all debt portfolios (except CCC) remains substantially below the hurdle rate for equity portfolios.

Table 4.4

### Representative Investor with Constant Relative Risk Aversion

Relative risk aversion: Exposure Rating PD			Baseline: $r_f = 5\%$ , $r_m = 11\%$ , $\sigma_m = 10\%$		$r_m = 14\%$		$\sigma_m = 5\%$	
			$\gamma = 7.23$		$\gamma = 15.70$		$\gamma = 45.00$	
			Expected return	RAROC hurdle	Expected return	RAROC hurdle	Expected return	RAROC hurdle
Equity			11.00	20.14	14.00	30.09	11.00	37.53
Debt	A <sup>-</sup>	0.10	5.10	2.09	5.22	4.54	5.40	8.23
Debt	BBB	0.26	5.23	2.60	5.47	5.40	5.82	9.36
Debt	BB <sup>+</sup>	0.69	5.50	3.44	6.00	6.78	6.65	11.17
Debt	BB	1.24	5.80	4.18	6.53	7.97	7.47	12.73
Debt	B <sup>+</sup>	1.44	5.90	4.41	6.71	8.34	7.73	13.19
Debt	CCC	21.91	10.29	14.67	13.43	22.75	16.39	29.97

Notes: Risk capital for both debt and equity is computed as in Table 4.1. As in Table 4.1, equity returns are assumed equal to market returns, so that the expected return on equity equals  $r_m$ , yielding the RAROC hurdle for equity. The required return on debt depends on the coefficient of relative risk aversion of the representative investor. This is calculated from  $r_f$ ,  $r_m$  and  $\sigma_m$  (see appendix for details) and allows a calculation of the covariance between debt returns and the marginal utility of consumption of the aggregate investors, in turn yielding the required return on debt.

With a representative investor with constant relative risk aversion it is no longer the case that changes in the expected market return ( $r_m$ ) or the volatility of market returns ( $\sigma_m$ ) have a similar impact on the RAROC hurdles for both debt and equity, leaving their relative values largely unchanged. The reason, illustrated in columns (6)–(9) of Table 4.4, is that raising  $r_m$  or lowering  $\sigma_m$  substantially increases the coefficient of relative risk aversion of the representative investor ( $\gamma$ ). This increases the valuation placed by the representative investor on returns when aggregate output and consumption are comparatively low and marginal utility is high, in turn increases the required return on debt and raises the RAROC hurdle for debt relative to that for equity. Nevertheless, even when the coefficient of relative risk aversion rises to the very high level of 45, the RAROC hurdle on equity remains about four times those on almost all categories of debt.<sup>21</sup>

We complete this section with a brief discussion of some practical issues. What are the potential losses to shareholders if a financial institution mistakenly imposes a hurdle rate, appropriate for equity, on debt investments? Since equity capital cannot be easily increased to take advantage of investment opportunities, how can a financial institution sensibly ration its available equity capital amongst competing opportunities?

We address these questions using the further calculations reported in Table 4.5. This table investigates how shareholder value added, available when a bank make loans with a fundamental value (in our notation  $\hat{A}(0)$ ) greater than cost (in our notation  $L(0)$ ), affects risk capital and RAROC. The successive rows of Table 4.5 report risk capital and RAROC for increasingly profitable lending

<sup>21</sup> As demonstrated in the Mathematica notebook supporting this paper, reducing  $r_f$  also increases  $\gamma$  and thus increases the RAROC hurdles for debt relative to that for equity.

opportunities, with a cost (relative to fundamental value) ranging from 100% down to 95%. A loan in the first row – one that costs 100% of its the present discounted value of future cash flows – creates no value for shareholders. A loan represented on the second row, one that costs 99% of its fundamental value, creates a new value (or in the terminology of the CAPM an ‘alpha’) of 1% of the fundamental value for shareholders. By the bottom row we have reached highly profitable lending opportunities creating an ‘alpha’ of 5%.

Table 4.5 **Assessment of loan decisions**

Cost as % of fundamental value	BB debt, default probability 0.26% RAROC hurdle: 2.60			BBB debt default probability 1.24% RAROC hurdle: 4.18		
	Risk capital %	Achieved RAROC	Surplus RAROC	Risk capital %	Achieved RAROC	Surplus RAROC
100.0	8.75	2.60	0.00	19.12	4.18	0.00
99.00	7.70	15.59	12.99	18.07	9.71	5.54
98.00	6.65	32.69	30.08	17.02	15.93	11.75
97.00	5.60	56.19	53.59	15.97	22.97	18.79
96.00	4.55	90.54	87.94	14.92	31.00	26.82
95.00	3.50	145.52	142.92	13.87	40.24	36.06

Notes. Uses the baseline assumptions of Table 4.4, so  $p = 99.97\%$ , all loans are one year, and  $r_f = 5\%$ ,  $r_m = 11\%$ ,  $\sigma_m = 10\%$  together implying a coefficient of relative risk aversion  $\gamma = 7.23$ . The RAROC hurdle is that of Table 4.4, column 5.

The columns of Table 4.5 reports risk capital and RAROC hurdles for two categories of debt, selected from the earlier tables, for BB debt with an average annual default probability of 0.26% and for BBB debt with an annual average default probability of 1.24%. Risk capital and the RAROC hurdle rate are calculated using the assumptions of the baseline in Table 4.4, ie with a representative investor with constant relative risk aversion and with the baseline assumptions of Table 4.1 for the risk free rate of interest, and the expected level and volatility of market returns. Columns 2 and 5 report the level of risk capital, expressed as a proportion of fundamental value, for the two categories of debt. These fall as lending opportunities become more profitable. This is simply because the surplus available on these one year loans (the increasing interest margin) provides an additional margin of protection against default and so less capital is needed.

Columns 3 and 6 report the RAROC achieved from these different lending opportunities. For loans in the first row that do not create value, RAROC equals the RAROC hurdle from Table 4.4. The achieved RAROC then rises rapidly as fundamental value increases, because the RAROC denominator risk capital falls and the RAROC numerator, expected return less the cost of funding, rises. Columns 4 and 7 report the surplus RAROC, over and above the hurdle rate. The level of risk capital times the surplus RAROC equals the economic value added or

EVA created for shareholders and this in turns equals the difference between the fundamental value and the cost of the loan.

Suppose now that a bank operates its lending business with an institution wide RAROC hurdle of 20% (ie the RAROC hurdle for equity from the baseline of Table 4.4.) This bank will refuse one year BB loans with an profit margin (net of all costs including risk) of 1%, because the achieved RAROC (Table 4.5, column 3, line 2) is only just over 15%. In the case of BBB loans it will refuse opportunities with a profit margins as high as 2% (column 6). These lending opportunities are all valuable opportunities for shareholders that could easily be passed over by applying a single institution wide RAROC hurdle.

Suppose instead that the bank uses, as our analysis indicates it should, different RAROC hurdle rates for different categories of exposure, using the hurdle rates calculated from the baseline of Table 4.4. In this case it will wish to accept a much wider range of lending opportunities. But this creates a new problem: that of ensuring that it has sufficient capital to survive a situation when returns on lending and investments are poor. Suppose the bank wishes to reduce the probability of losing all its capital, and ending up in financial distress, to the 0.03% per annum, ie it makes the conservative choice of  $p = 99.97\%$  used in our baseline calculations. One way to proceed would be to persuade shareholders that it does indeed have many profitable lending opportunities of the kinds illustrated in Table 4.5. It could then raise sufficient capital to reduce the probability of financial distress to its desired level. But what if, as is likely, shareholders are not persuaded that these opportunities are real and will not provide the necessary capital. Then the bank must ration its capital across all available lending opportunities.

An effective way to do this is to set an institution wide target for surplus RAROC, the RAROC over and above the RAROC hurdle, as illustrated in Table 4.5, columns 4 and 7. This target level has then to be set at the positive level where the institution is employing all its available capital. If capital remains unused when the surplus RAROC equals zero, then there is an opportunity to return capital to shareholders.

What calculations of the kind shown in Table 4.5 achieve is a ranking of all investment opportunities. The bank should begin first with the opportunities offering the highest surplus RAROC and only then subsequently move onto those with the lower surplus RAROC. This yields to very different portfolio choices than when applying a single institution wide RAROC hurdle. Consider for example a surplus RAROC hurdle of 15%. A casual look at Table 4.5 might suggest that this leads to the same lending decisions as using a single institution wide RAROC hurdle rate of 20% ie the RAROC hurdle derived from equity investments, since once again the 1% profit margin BB and the 2% profit margin BBB lending opportunities are turned down. But this is not the case. Now, if the same surplus RAROC criteria is applied to equity investments as well as to debt

then these, in order to achieve a surplus RAROC of 15%, must provide an annual return on capital of 35% or more. So the likely consequence is a reduction of equity investments and a re-allocation of capital to lending (given that this bank has highly profitable lending opportunities).

Provided there is then capital to spare, released by a withdrawal from equity investments, then the surplus RAROC hurdle can be reduced, to say 10%, allowing the financial institution characterized by Table 4.5 to take up the additional 1% profit margin BB and 2% profit margin BBB lending opportunities. If further capital remains unallocated then the surplus RAROC hurdle can be reduce further, to 8% and 6% and so on. Formally we can rewrite equation (3.9) for the required hurdle rate as the following two factor relationship

$$\hat{r}_i^{\text{src}} = \frac{\hat{A}_i(0)\rho_{i,z}\sigma_i\sigma_z}{-H_i^{-1}(p^*)} + s \quad (4.1)$$

in which required return on risk capital are corrected separately both the systematic risk ( $\rho_{i,z}\sigma_i\sigma_z$ ) and also for balance sheet constraints ( $s$ ).

This approach also resolves one of the main practical problems when conducting capital allocation using a single institution wide hurdle rate. Even though RAROC is widely used, financial institutions have no process for establishing the level of the RAROC hurdle and set it at arbitrary levels. The process of rationing available capital to the highest surplus RAROC opportunities resolves this problem, because the surplus RAROC hurdle emerges naturally as the ‘shadow price’  $s$  for the limited available equity. This is not a market price, rather it is adjusted up and down to the level at which all capital is being utilised and supporting those investments yielding the highest possible surplus over the minimum required RAROC. If however this shadow price falls to zero, then equity should be returned to shareholders instead of used to support further, value destroying, investments.

## 5 Concluding remarks

This paper has examined the common industry measure return on risk capital ie RAROC and its use as a performance measure. In all realistic situations the hurdle rate for zero-value investments, the required return on risk capital, must be adjusted on an exposure-specific basis. Such an adjustment is needed in order to correct for differences in skewness and vary substantially from one exposure to another (as illustrated by the very different RAROC hurdles reported in Tables 4.1–4.4 for equity and different rating classes of debt).

The rationale for these results is both standard and once understood fairly obvious. In the frictionless setting of standard asset pricing theory, investors need compensation only for systematic risk (correlation of returns with the investor's marginal valuation of aggregate returns). All other risk can be diversified away. Exposures with relative large left-hand tails should therefore be subject to relatively low RAROC hurdles.

There is room for refinement of our quantitative results, using more detailed market and financial institution data and alternative return distributions. Such further analysis could alter the discrepancies between RAROC hurdle rates either up or down. We could use models of equity returns that have larger left hand tails and thus lower the RAROC discrepancies. At the same time the Vasicek debt portfolio model we use is far from perfect and the most obvious developments of that model, for example allowing for correlation between LGD and aggregate economic conditions, would increase the left hand tail of debt returns and increase the RAROC discrepancy. We could allow for less than complete correlation between the risk factor driving portfolio returns and the aggregate market and we could allow aggregate returns to incorporate returns on debt. Nonetheless, even without conducting further research it is clear that the discrepancies we report are not accidental. They are quantitatively large and caused by fundamental differences in the shape of return distributions.

Another topic that merits further research would be to correct these RAROC hurdles to allow for potential systemic interactions, such as those which have undermined financial institution balance sheets in the current global financial crisis. Systemic events, which are not captured by the simple Vasicek portfolio model applied here, induce exceptionally large left hand tails in return distributions and should therefore be taken into account in determining the level and return on capital in financial institutions.

The usual current practice in the industry, applying a single institution-wide RAROC hurdle, entirely ignores the substantial differences in zero-NPV RAROC hurdles reported here. As illustrated by Table 4.5, this can lead to potentially severe misallocation of capital ie to the failure to take up lending and investment opportunities that create substantial shareholder value.

Our analysis leads to a simple procedure for correcting this shortcoming, based on our equation (3.8). Risk managers should estimate the covariance between individual investment returns and aggregate market returns. This covariance, preferably adjusted as in Table 4.4 to allow for investor preferences that value marginal returns relatively highly when aggregate returns are poor, yields exposure specific RAROC hurdles. Using these, rather than a single institution wide hurdle rate, can help institutions do a much better job of identifying investment opportunities that create value for shareholders. If equity capital, as it usually will be, is in short supply then they can use a second risk measure, the surplus of RAROC above the exposure specific hurdle, to ration

equity capital amongst different value creating opportunities. In this way, as earlier recommended by Froot and Stein (1998), financial institutions are able to price separately for systematic risk and balance sheet constraints.

Our findings should be of interest not just to the shareholders and management of financial institutions but also to debt holders and to financial regulators, those ‘stakeholders’ with a particular interest in ensuring that there is a low risk of financial institution default or distress. Distinguishing between the pricing of systematic market wide risk and institution specific balance sheet constraints seems to be essential, if financial institutions are to appropriately manage their activities from the perspective of debt and deposit holders, and of broader financial system stability, as well as from the narrower perspective of shareholder value creation.

Using single institution-wide RAROC hurdle rates has exaggerated the shareholder benefits of leverage has encouraged banks and other financial institutions to repay too much capital to shareholders and acquire excessive debt. This has been one reason for the excess leverage that has contributed to the global financial crisis of the past two years. Using exposure-specific RAROC hurdle rates incorporating systematic risk, and pricing separately for balance sheet constraints, removes this unnecessary conflict. Debt holders and regulators prefer the bank to be safe from the risk of default, ie to make a relatively conservative choice of the threshold for the calculation of the risk capital in the RAROC denominator and hence operate the institution with relatively low leverage. A more conservative choice of threshold (a higher  $p^*$ ), while it increases the capital allocated to each exposure, also lowers the zero-NPV RAROC hurdle, the exposure specific return required to compensate shareholders for systematic risk. But the value creating exposures available to the bank are exactly the same, whether it is run aggressively with high leverage or conservatively with low leverage. Hence institutions run with higher capital do not necessarily end up creating less shareholder value.

The conflict between shareholders and debt holders is not entirely removed. Shareholders do not always trust financial institution management as stewards of their money. They are therefore reluctant to provide additional capital. The rapid increases in regulatory bank capital requirements, now expected in the wake of the global financial crisis, will stretch bank balance sheets and to force them to forgo some value creating but relatively low return on capital opportunities. But such balance sheet pressures makes a switch to exposure specific RAROC hurdles all the more worthwhile. As we discuss in the context of our Table 4.5, when a financial institution is subject to balance sheet constraints then the efficient allocation of capital requires that they apply not one but two performance thresholds, as in our final equation (3.9). The first – the exposure specific RAROC hurdle – is needed to capture market wide systematic risk while the second – a required surplus RAROC – is needed to reflect the impact of institution specific



balance sheet constraints. Only by distinguishing these two costs of risk can the value created by different investment exposures be accurately measured and capital efficiently allocated to its different uses.

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## Appendix

Technical details of the calculations reported in Tables 4.1–4.5.

- The Mathematica notebook supporting this paper contains derivations of all results in this Appendix and the calculations of all Tables.
- For Tables 4.1–4.3 where we assume that all investors have quadratic preferences, the required (zero NPV) return on portfolio  $i$  from equation 5 becomes  $r_i = r_f + \rho_{im}\sigma_i\sigma_m$  (since with quadratic preferences  $\rho_{iz} = -\rho_{im}$  and  $\sigma_z = \sigma_m$ ). Evaluating 5 for the case where the asset portfolio  $i$  is the market portfolio  $m$  and so  $\rho_{im} = \rho_{mm} = 1$ , yields  $r_m = r_f + \sigma_m\sigma_z$  and hence the standard CAPM relationship  $r_i = r_f + \rho_{im}\sigma_i(r_m - r_f)/\sigma_m = r_f + \beta_i(r_m - r_f)$ .
- The end period expected return and standard deviation of return of equity is computed from  $r_i = \int_{-\infty}^{+\infty} \exp(q + sZ)\phi(Z)dZ = \exp(q + \frac{1}{2}s^2)$  and  $\sigma_i = \sqrt{\int [\exp(q + sZ) - r_i]^2 \phi(Z)dZ} = \exp(2(s^2 + q))$ , where  $\phi(Z)$  is the standard normal density.
- The market portfolio is assumed to be that offered by the equity portfolio (the equity portfolio is fully diversified). Hence for the equity portfolio  $\sigma_i = \sigma_m$  and  $r_i = r_m$  and we can use these relationships to obtain expressions for both  $q$  and  $s$  in terms of  $\sigma_m$  and  $r_m$ . These are  $s^2 = \log[1 + \sigma_m^2/(1 + r_m)^2]$  and  $q = \log[(1 + r_m)] - \frac{1}{2}s^2$ .
- Tables 4.4 and 4.5 assume a representative investor with constant relative risk aversion ie with expected utility given by  $\int [\exp(q + sZ)]^{1-\gamma} \phi(Z)/(1-\gamma)dZ$  and who hence places a marginal valuation on returns in state of the world  $Z$  of  $[\exp(q + sZ)]^{-\gamma}$ . Here  $\gamma$  is the investors' coefficient of relative risk aversion. The pricing kernel, given by  $z = [\exp(q + sZ)]^{-\gamma} / [(1 + r_f) \exp(-\gamma q - \frac{1}{2}\gamma^2 s^2)]$ , is this marginal valuation rescaled so that  $E[z] = (1 + r_f)^{-1}$ . The covariance of equity returns with the pricing kernel is then given by  $\sigma_{mz} = -\exp((1-\gamma)q + (1-\gamma)^2 s^2)(\exp \gamma s^2 - 1)/(1 + r_f)$ . Using equation (3.5), this yields  $\gamma = \frac{1}{2} + q/s^2 - \log(\exp(q + \frac{1}{2}s^2) - (1 + r_f)(r_m - r_f))/s^2 \approx (1 + r_f)(r_m - r_f)/s^2$ . This expression is used to determine  $\gamma$  as a function of  $r_f$ ,  $r_m$  and  $\sigma_m$  for the calculations of Table 4.4.
- The returns on portfolios of risky (defaultable) debt are determined by the same aggregate factor  $Z$  as the equity portfolio according to the single aggregate factor asymptotic Vasicek model (the standard model of credit portfolio returns used for the IRB calculations in the Basel II accord), in which an individual obligor  $j$  defaults if  $a_j = \omega^{0.5}Z + \sqrt{1 - \omega}\epsilon_j < K$  where  $\epsilon_j$  is the specific risk of each individual counterparty. From this model, the

portfolio return, conditional on a particular outcome for the aggregate risk factor  $Z$ , is  $\theta(Z) = R_i(1) + A_i(1) = 1 - \text{LGD} * N((N^{-1}(\text{PD}) - \omega^{0.5}Z) / \sqrt{1 - \omega})$  and  $R_i(1) = 1 - \text{PD} \times \text{LGD}$ .  $\text{PD}$  is the default probability for the various debt classes; and  $\omega$  is the correlation of underlying asset values within the portfolio (so  $\omega^{0.5}$  is the correlation of each asset with the market factor).  $Z$  is the same aggregate risk factor determining equity portfolio returns.

- Tables 4.1–4.3 use numerical integration to calculate the CAPM pricing inputs for debt, the standard deviation of the debt portfolio and its correlation with the market portfolio. The formulas are:  $\sigma_i = \sqrt{\int [\theta(Z) - R_i(1)]^2 \phi(Z) dZ}$  and  $\rho_{im} = \int [\exp(q + sZ) - r][\theta(Z) - R_i(1)]\phi(Z) dZ / (\sigma_i \sigma_m)$ .
- Tables 4.4 and 4.5 use numerical integration to compute the covariance of debt returns with the pricing kernel  $\sigma_{iz} = \int [\exp(q + sZ) - r]^{-1/\gamma} [\theta(Z) - R_i(1)]\phi(Z) dZ$ , yielding required returns from equation (3.5).

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