Esa Jokivuolle – Kimmo Virolainen – Oskari Vähämaa

Macro-model-based stress testing of Basel II capital requirements

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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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Abstract

Basel II framework requires banks to conduct stress tests on their potential future minimum capital requirements and consider 'at least the effect of mild recession scenarios'. We propose a stress testing framework for minimum capital requirements in which banks' corporate credit risks are modeled with macroeconomic variables. We can thus define scenarios such as a mild recession and consider the resulting credit risk developments and consequent changes in minimum capital requirements. We also emphasize the importance of stress testing future minimum capital requirements jointly with credit losses. Our illustrative results based on Finnish data underline the importance of such joint modeling. We also find that stress tests based on scenarios envisaged by regulators are not likely to imply binding capital constraints on banks.

Keywords: Basel II, capital requirements, credit risk, loan losses, stress tests

JEL classification numbers: C15, G21, G28, G33

Basel II vakavaraisuusvaatimusten stressitestaus makrotaloudellisen luottoriskimallin avulla

Suomen Pankin keskustelualoitteita 17/2008

Esa Jokivuolle – Kimmo Virolainen – Oskari Vähämaa
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Basel II sääntely saattaa edellyttää, että pankit selvittävät stressitestein, kuinka niiden vakavaraisuusvaatimukset voisivat kasvaa tulevaisuudessa. Pankkien tulisi tarkastella stressitestissä vähintään lievän taantuman vaikutuksia. Tässä tutkimuksessa ehdotetaan vakavaraisuusvaatimuksille stressitestikehikkoa, jossa pankkien yritysluottojen luottoriskiä mallinnetaan makrotaloudellisilla muuttujilla. Tällä tavoin on mahdollista tarkastella lievän taantuman kaltaisten skenaarioiden vaikutusta luottoriskeihin ja vakavaraisuusvaatimusten muutoksiin. Tutkimuksessa korostetaan myös, että on tärkeää tarkastella stressitestein vakavaraisuusvaatimusten potentiaalista muutosta yhtä aikaa potentiaalisten luottotappioiden kanssa. Tulokset Suomen aineistolla havainnollistavat tällaisen yhteistarkastelun merkitystä. Tulosten perusteella voidaan lisäksi olettaa, että pankkien tyypilliset pääomapuskurit riittävät kattamaan lisäpääoman tarpeen, joka aiheutuisi lievän taantuman kaltaisissa skenaarioissa.

Avainsanat: Basel II, vakavaraisuusvaatimukset, luottoriski, luottotappiot, stressitesti

JEL-luokittelu: C15, G21, G28, G33

Contents

1 Introduction

The new international framework for banks' capital regulation, known as Basel II, poses a challenge to both banks and their supervisors. The new rules on capital adequacy are meant to better align banks' capital requirements with their true risks. This well-motivated aim may have some side-effects which will require careful monitoring and scrutiny. In particular, capital requirements that are tied to banks' actively measured risks will be more volatile than the previous constant capital requirements. They may also reinforce the business cycle because banks' asset risks, such as credit risks measured with internal credit ratings, tend to move in accordance with the business cycle. Such procyclicality may arise if banks are forced to cut back their lending as a result of deteriorating ratings and thus increasing minimum capital requirements in downturns.

The Basel II framework addresses these concerns by stating that banks are expected to hold capital in excess of the minimum requirements. Capital buffers can partly absorb unexpected increases in future minimum capital requirements in a downturn and may hence attenuate the procyclical effect.[1] The FSA (2005, 2006) has argued that even if macroeconomic effects of the new capital requirements remain inconclusive, the precautionary capital buffers are in any case important for banks in avoiding violations of minimum capital requirements in downturns when new external equity capital may be hard to come by.

To measure the size of sufficient extra capital buffers, Basel II framework requires banks to carry out stress tests on their potential future minimum capital requirements. Under the first pillar of Basel II it is stated that banks using the internal ratings based approach (IRBA) 'should…consider at least the effect of mild recession scenarios'. An example of a mild recession, given by Basel II, is two consecutive quarters of zero growth. Another example is provided by FSA (2005) which suggests considering a downturn which happens on average once in 25 years. The specific form of stress tests is left to banks to decide, subject to supervisory review.[2]

In this paper we propose a stress testing framework for minimum capital requirements, similar to the structure outlined by Sorge and Virolainen (2006) and Virolainen (2004), in which banks' corporate credit risks are modeled with central macroeconomic variables such as the GDP growth. The useful feature of our approach is that we can naturally define scenarios such as the mild recession and consider credit risk development and the resulting change in the minimum capital

[1] Eg Heid (2007) and Repullo and Suarez (2007) study the theoretical relationship between banks' precautionary capital buffers and procyclicality of the Basel II capital requirements. Buffers seem to help but may not suffice to prevent a credit crunch in a recession.
[2] An account of the stress testing requirements under Basel II is provided in Jokivuolle and Peura (2007).

requirements in connection with such scenarios. Consistent with Peura and Jokivuolle (2004), we further emphasize that it is important to stress test future minimum capital requirements jointly with credit losses, especially for longer stress test horizons. Both credit losses and future changes in capital requirements pose a potential burden on banks' capital, and they may be highly correlated with one another.

Our model extends the Sorge and Virolainen's (2006) framework considering the Basle II requirements in the forefront. Sorge and Virolainen model industry-specific corporate default rates (henceforth PD; ie probability of default) as logistic functions of various macro variables. The macro variables are in turn modeled as AR(2) processes with mutually correlated error terms. They then run a Monte Carlo simulation on the error terms of their system of equations to generate paths of quarterly industry-PDs for the chosen stress test horizon. Having data on 3,000 Finnish companies, grouped in their respective industries, they use the simulated industry-PDs to construct a binary draw on every non-defaulted company in every quarter to determine whether a given company defaults in that simulation round or not. A defaulted company generates a credit loss which is assumed to be a constant proportion (ie, assuming constant loss-given-default; LGD) of its total debt. As a result, Sorge and Virolainen produce the probability distribution of the aggregate corporate credit loss over the chosen horizon.

Using Finnish data, our paper extends this framework further by using simulated industry-PDs at the end of horizon in order to calculate the change in the credit portfolio's IRBA capital requirement relative to the portfolio's initial time-zero capital requirements.[3] This change is then added to the portfolio's credit loss in each simulation round to produce their joint probability distribution. In addition to this value-at-risk approach, we also consider predetermined scenarios in our macro model. In doing so, we can stress test capital need in scenarios of mild recessions, such as the two consecutive zero-growth quarters suggested in the Basel II framework. Overall, Finland provides an interesting case to estimate and implement macro model based stress tests for credit losses and capital requirements because our sample period includes the years of the particularly severe banking crisis Finland experienced in the early 1990s.

Our procedure in calculating the IRBA capital requirement involves an obvious short cut. In a full-fledged procedure we would first model the migration of a bank's internal ratings as a function of macro variables, and use internal rating specific default probabilities to calculate the minimum capital requirements. Here we by-pass ratings and use directly (industry-specific) PDs. Developing the full-fledged model is ultimately a question of data availability. In this respect, our approach can primarily be seen as an illustration of how bank level macro model

[3] The capital requirement applies to non-defaulted credits; defaulted credits consume bank capital via the credit loss they incur.

based stress tests could be done with sufficient (in-house) data resources. Nonetheless, for the aggregate Finnish corporate credit portfolio our simplified approach should give a fair view of the magnitude of potential changes in IRBA capital requirements plus simultaneous credit losses. This is because individual banks' internal rating scales and respective rating-specific PDs vary across banks, so that calculating capital requirements directly from industry-PDs might well work as an approximation in the aggregate bank portfolio. Our quantitative results may thus provide some useful guidance to financial authorities and others concerned with the macro-prudential view of the banking industry.

Our results demonstrate the importance of jointly modeling and measuring the need for a precautionary capital buffer arising from potential future credit losses and changes in the minimum capital requirement. The change in the minimum capital requirement alone necessitates a buffer which at the 99% confidence level is 2.26% of total credit assets. In a joint model which incorporates credit losses, the buffer is 3.83% of total credit assets. The results also suggest that buffers implied by the specific deterministic scenarios envisaged by the regulators are much smaller than what banks themselves would probably prefer to hold.

The paper is structured as follows. The next section first motivates with the help of a simple model the joint stress testing of credit losses and capital requirements and then presents the empirical model. Section 3 presents the simulation and scenario based stress test results. Section 4 concludes.

2 Modeling framework

2.1 Capital buffers

We start by defining the object of our stress tests; ie the sum of portfolio credit losses and change in minimum capital requirements. For this purpose, we use a simplified version of the model in Peura and Jokivuolle (2004), originally presented in Jokivuolle and Peura (2001). We use aggregate corporate sector data in our empirical analysis; it is simplest to think of a representative bank ('the bank', henceforth) as the subject of stress testing, which proxy for the entire banking sector. Importantly, we consider the bank's corporate credit portfolio.

The bank's task is to implement a stress test as part of its Basel II IRBA requirements. The objective is to assess how much capital in excess of the current minimum capital requirement the bank needs to meet potential future minimum requirements at least in a mild recession. It is assumed that the bank has no access to external capital over the stress testing horizon. Let C denote the bank's actual capital and let C^{min} denote its minimum capital requirement. Periodic credit losses are denoted by l. Time runs from $t = 0, \ldots, T$ where T is the stress testing horizon.

If the bank is to meet its minimum capital requirement at T, the following condition must hold

$$C_0 - (L_T - E(L_T)) \geq C_T^{min} \tag{2.1}$$

where $L_T - E(L_T) \equiv \sum_{t=1}^{T} l_t$. In other words, the current amount of actual capital net of cumulative unexpected credit losses up to T must be no less than the minimum capital requirement at horizon T. Note that we consider only the unexpected credit losses by subtracting the expected credit losses from the total credit losses. This is consistent with the rather standard assumption that banks incorporate the expected credit loss into loan margins.[4] If we rearrange and subtract the current minimum capital requirement from both sides, we obtain the condition in the following form

$$C_0 - C_0^{min} \geq \left(C_T^{min} - C_0^{min}\right) + L_T - E(L_T) = \Delta C_{0,T}^{min} + L_T - E(L_T) \tag{2.2}$$

This says that the current capital buffer, ie the difference between the bank's actual capital and the minimum capital requirement, must be greater than or equal to the future change in the minimum capital requirement plus the cumulative unexpected credit losses.

As Peura and Jokivuolle (2004) argue, the bank may have its own additional criteria for reserving precautionary capital on top of its current minimum capital requirement. Peura and Jokivuolle suggest a value-at-risk based criterion; the bank would prefer some statistical confidence level that it meets condition (2.2). Following their approach, from condition (2.2) we obtain the following probabilistic condition

$$P\left[C_0 - C_0^{min} \geq \Delta C_{0,T}^{min} + L_T - E(L_T)\right] = \alpha \tag{2.3}$$

Condition (2.3) implies that the bank would choose to hold an initial capital buffer such that with probability α it would meet the minimum capital requirement at horizon T. Once we generate the joint probability distribution of change in capital requirement and credit losses, the necessary initial capital buffer is obtained as the α percentile of that distribution. This procedure is analogous to using value-at-risk to determine a bank's economic capital.

In the next subsection, we present the model following Sorge and Virolainen's (2006) empirical macro based structure for industry-specific PDs

[4] Alternatively, the bank's loan margin income from non-defaulted credits could be modeled more explicitly as eg in Peura and Jokivuolle (2004).

which are then used to generate credit losses and future changes of minimum capital requirements.

2.2 Macro model of industry-PDs

Sorge and Virolainen (2006) apply Wilson's (1997a, 1997b) model to analyse industry-specific default rates which are linked to macroeconomic factors. Here we reproduce Sorge and Virolainen's model which is then used to simulate credit losses and changes in minimum capital requirements in section 3. The reader is advised to consult Sorge and Virolainen's (2006) original work for further details.

The average default rate for industry j is modelled by the logistic functional form as

$$p_{j,t} = \frac{1}{1+\exp(y_{j,t})} \tag{2.4}$$

in which $p_{j,t}$ is the probability of default for a firm in industry j at time t, and $y_{j,t}$ is the industry-specific macroeconomic index, whose parameters must be estimated. A higher value for $y_{j,t}$ implies a better state of the economy with a lower default probability $p_{j,t}$, and vice versa. Note that $y_{j,t}$ is given by the logit transformation

$$L(p_{j,t}) = ln\left(\frac{1-p_{j,t}}{p_{j,t}}\right) = y_{j,t}$$

The industry-specific macroeconomic index is assumed to be determined by a number of exogenous macroeconomic factors, ie

$$y_{j,t} = \beta_{j,0} + \beta_{j,1}x_{1,t} + \beta_{j,2}x_{2,t} + \cdots + \beta_{j,n}x_{j,n} + \upsilon_{j,t} \tag{2.5}$$

in which β_j is a set of regression coefficients to be estimated for the jth industry, $x_{i,t}(i = 1,2, \ldots, n)$ is the set of explanatory macroeconomic factors, and $\upsilon_{j,t}$ is an independent and identically normally distributed random error. Equations (2.4) and (2.5) form a multifactor model of industry-specific average default rates. The systematic risk component is captured by the macroeconomic variables $x_{i,t}$ and an industry-specific shock is captured by the error term $\upsilon_{j,t}$. In estimations the explanatory macroeconomic variables may differ between industries.

Next, development of the individual macroeconomic variables are modelled as a set of univariate AR(2) processes

$$x_{i,t} = k_{i,0} + k_{i,1}x_{i,t-1} + k_{i,2}x_{i,t-2} + \varepsilon_{i,t} \tag{2.6}$$

where k_i is a set of regression coefficients to be estimated for the ith macroeconomic factor, and $\varepsilon_{i,t}$ is an independent and identically normally distributed random error.

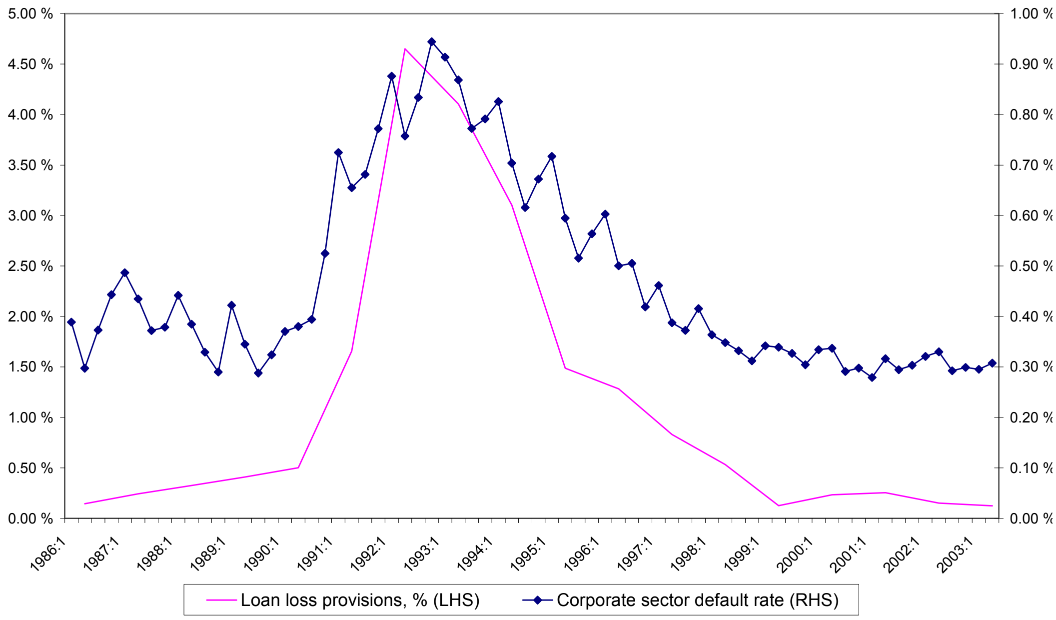
In sum, equations (2.4)–(2.6) define a system of equations governing the joint evolution of the industry-specific default rates and associated macroeconomic factors with a $(j+i) \times 1$ vector of error terms, E, and a $(j+i) \times (j+i)$ variance-covariance matrix of errors, $\sum$

$$E = \binom{\upsilon}{\varepsilon} \sim N(0, \Sigma), \qquad \Sigma = \begin{bmatrix} \Sigma_{\upsilon} & \Sigma_{\upsilon,\varepsilon} \\ \Sigma_{\varepsilon,\upsilon} & \Sigma_{\varepsilon} \end{bmatrix}$$

In our simulations, we also use the same estimated model as Sorge and Virolainen. It is based on quarterly Finnish data on corporate sector defaults by main industries and on key macroeconomic factors over the time period from 1986:1 to 2003:2. Default data come from six main industries: 1) agriculture (AGR), 2) manufacturing (MAN), 3) construction (CON), 4) trade, hotels and restaurants (TRD), 5) transport and communication (TRNS), and 6) other industries (OTH).

Due to the severe banking crisis in the early 1990s, Finland provides an interesting case to implement macro model based stress tests for credit losses and capital requirements. Figure 2.1 illustrates this history and the strong relationship between aggregate corporate sector default rates and banks' loan losses.

Figure 2.1 **Corporate sector default rate (quarterly) and banks' loan loss provisioning (annual, percentage of loan stock)**



Source: Sorge and Virolainen (2006)

In determining corporate default rates in this type of model, the literature (see, Sorge and Virolainen, 2006) recommends the crucial involvement of measures of profitability (or its determinants), indebtedness and interest rates. The key explanatory macro variables in such models are the gross domestic product, the nominal annual interest rate and the corporate indebtedness. A dummy variable is used to control for the change in the bankruptcy law which came into force in 1993:1 as well as for other contemporaneous structural changes in the Finnish economy (see, Sorge and Virolainen, 2006, for more details). In order to account for the correlation structure between the error terms Sorge and Virolainen use SUR methodology to estimate the system of industry-PD equations in (2.5). Table 2.1 reproduces their estimation results which we are also going to use. The GDP variable and the industry-specific measures of corporate indebtedness have the expected sign and are statistically significant in all equations. The coefficient on the interest rate is also consistent for the latter period starting 1993:1. Overall, the Sorge and Virolainen (2006) provides a plausible model for the industry-specific default rates. Finally, Sorge and Virolainen's estimation results for the AR(2) processes of the macro factors in equation (2.6) are reproduced in table 2.2.

Table 2.1 **SUR estimates for the static model; sample period 1986Q1–2003Q2, no. of observations 70**

	y_{AGR}	y_{MAN}	y_{CON}	y_{TRD}	y_{TRNS}	y_{OTH}
Constant	7.747	5.997	5.670	6.566	6.300	6.245
	(17.5)	(73.9)	(118.3)	(50.7)	(32.7)	(82.5)
D_{9303}				-0.736		
				(-5.29)		
GDP	2.743	4.427	2.125	3.554	1.529	5.004
	(3.27)	(12.1)	(4.20)	(9.29)	(2.53)	(13.9)
$D_{9303}\times$GDP				1.531		1.309
				(2.91)		(2.91)
R		-3.027	-1.748		10.07	-3.072
		(-2.69)	(-2.49)		(3.59)	(-8.71)
$D_{9303}\times$R					-12.81	
					(-2.58)	
$DEBT_j$	-0.895	-0.665	-0.513	-1.041	-2.521	-0.874
	(-2.83)	(-4.58)	(-4.82)	(-11.3)	(-4.22)	(-6.80)
$D_{9303}\times DEBT_j$				0.5548	2.004	
				(4.61)	(2.30)	
Adj. R^2	0.132	0.864	0.828	0.929	0.559	0.898
SEE	0.429	0.169	0.140	0.114	0.233	0.123
DW	1.878	1.676	1.697	1.832	2.306	1.606

Note: $DEBT_j$ variable is industry-specific. t-statistics in parentheses.
Source: Sorge and Virolainen (2006)

Table 2.2 **Estimates for the AR(2) macro factor models**

	C	x_{t-1}	x_{t-2}	Adj. R^2	SEE	DW
GDP	0.0005	1.203	-0.227	0.957	0.013	2.10
	(0.32)	(9.96)	(-1.88)			
R	0.001	1.372	-0.400	0.964	0.008	1.86
	(0.53)	(12.1)	(-3.46)			
$DEBT_{AGR}$	0.315	0.802	-0.02	0.611	0.095	1.99
	(2.80)	(6.46)	(-0.18)			
$DEBT_{MAN}$	0.006	1.288	-0.299	0.982	0.042	2.14
	(0.32)	(10.9)	(-2.53)			
$DEBT_{CON}$	0.011	1.213	-0.234	0.962	0.067	1.99
	(0.58)	(10.1)	(-1.94)			
$DEBT_{TRD}$	0.003	1.444	-0.451	0.988	0.041	2.31
	(0.17)	(13.0)	(-4.03)			
$DEBT_{TRNS}$	0.012	1.232	-0.261	0.953	0.024	2.05
	(1.00)	(10.4)	(-2.19)			
$DEBT_{OTH}$	0.029	1.105	-0.156	0.960	0.020	2.03
	(2.48)	(9.04)	(-1.32)			

Source: Virolainen (2004)

3 Simulation and stress testing results

In this section we present first the results of simulating the joint distribution of the bank's potential future credit losses and the change in minimum capital requirements. Second, we also present the results of stress testing credit losses and the IRBA capital requirement with deterministic scenarios. If not noted otherwise, we measure both credit losses and changes in the minimum capital requirements as the ratio to the initial size of the bank's corporate loan portfolio. Following Sorge and Virolainen (2006), our simulation over a given time horizon T is carried out in the following way. For each step of the simulation a $(j+i)\times 1$ vector of standard normal random variables $Z_{t+1}{\sim}N(0,1)$ is drawn. This is transformed into a vector of correlated innovations in the macroeconomic factors and the industry-specific (logit transformed) default rates by using the Cholesky decomposition.[5] Using the simulated realisations of the error terms and initial values for the macroeconomic factors as of 2003:2, ie the end of the estimation period, the corresponding simulated values for $x_{i,t+1}$ and, subsequently, for $y_{j,t+1}$ and ultimately for $p_{j,t+1}$, the industry-PDs, are derived using the system of equations (2.4)–(2.6). The procedure is repeated until the chosen horizon and the desired number of simulated paths (50,000) of default probabilities is reached. It is worth re-emphasising that the simulation takes into account correlations between the macroeconomic factors and any industry-specific shocks.

As the final step of the simulation, the simulated industry-PDs in each quarter are used to determine individual corporate credits' default/non-default in the respective industries from a binary random draw. This is based on the assumption that conditional on the macroeconomic factors, the defaults of individual debtors are independent events. Recall that in this study we do not model PDs at individual corporate debtor level but use the industry-PD as the representative PD for each debtor in that industry.

As discussed in section 2.1 we need cumulative credit losses over the horizon and the change in the minimum capital requirement from the start to the horizon. Regarding the loss part, a credit loss at obligor level is materialized at the first time an obligor defaults; ie, we need to control for the possibility of subsequent multiple defaults in our simulation procedure. For those obligors who reach the horizon non-defaulted, the new capital requirement is calculated. The IRBA formula requires as an input the PD estimate for one year ahead. Consistent with this we generate the $t+4$ cumulative forecasts of the industry PDs both at period zero and at period T in order to calculate the respective capital requirements.

The 3,000 largest debt exposures in a comprehensive sample of Finnish corporate borrowers constitute our portfolio, covering almost 94% of total loans in

[5] The Cholesky decomposition of the variance-covariance matrix of the error terms Σ is defined as A, so that $\Sigma = AA'$.

the original sample. However, a cap of 3% of the total portfolio is applied on any individual exposure; reflecting regulatory limits on banks' large exposures. Throughout the simulations the loss given default (LGD) parameter is fixed at 50%. Although this deviates from the 45% LGD assumption used in the calculation of the IRBA minimum capital requirements,[6] the 50% LGD assumption is maintained to facilitate comparison of our results with those of Sorge and Virolainen (2006). For the same reason of facilitating comparisons with Sorge and Virolainen we have chosen to use the same starting period for our simulations as they do; that is, the second quarter of 2003. Of the two horizons used in Sorge and Virolainen, we opt for the longer 3-year horizon. Although stress testing standards regarding the horizon are left somewhat open in the Basel II document, say, a one-year horizon may be too short to account for the fact that it can be time-consuming to unwind risks of a relatively illiquid credit portfolio or to raise new external capital particularly during an economic downturn. Indeed, the subprime crisis has demonstrated that liquidity can quickly dry up in the market for credit risk transfer.

3.1 Distribution of credit losses and change in capital requirements

Table 3.1 summarizes the central results concerning the simulated distributions of credit losses, change in minimum capital requirements, and their sum. The entire distributions are displayed, respectively, in figures 2.1a–c. We first note that the expected and unexpected loss results replicate the corresponding results of Sorge and Virolainen (2006). The 3-year expected credit loss and the 99% unexpected loss, 1.83% and 2.91%, are indeed quite close to theirs (1.81% and 2.95%). The small difference is attributable to the error induced by using a finite number of simulation rounds.

Table 3.1 **Simulation based results**

	Mean	Difference between 99th-percentile and mean	Capital buffer	Shape of distribution
Loss	1.83	2.91		skewed
ΔCapital	0.67	1.59	2.26	symmetric
Loss+ΔCapital	2.49	3.16	3.83*	symmetric

* Sum of the difference between 99th-percentile and mean plus the mean of ΔCapital.

[6] See Basel Committee for Banking Supervision (2006). In addition to the 45% LGD assumtion we use 50 million euro turnover and 2.5 year loan maturity assumptions in the IRBA formula, each of which represents the benchmark case envisaged by the Basel Committee.

Figure 3.1a **Distribution of the aggregate credit loss ('Loss') as percentage of the initial loan portfolio value**

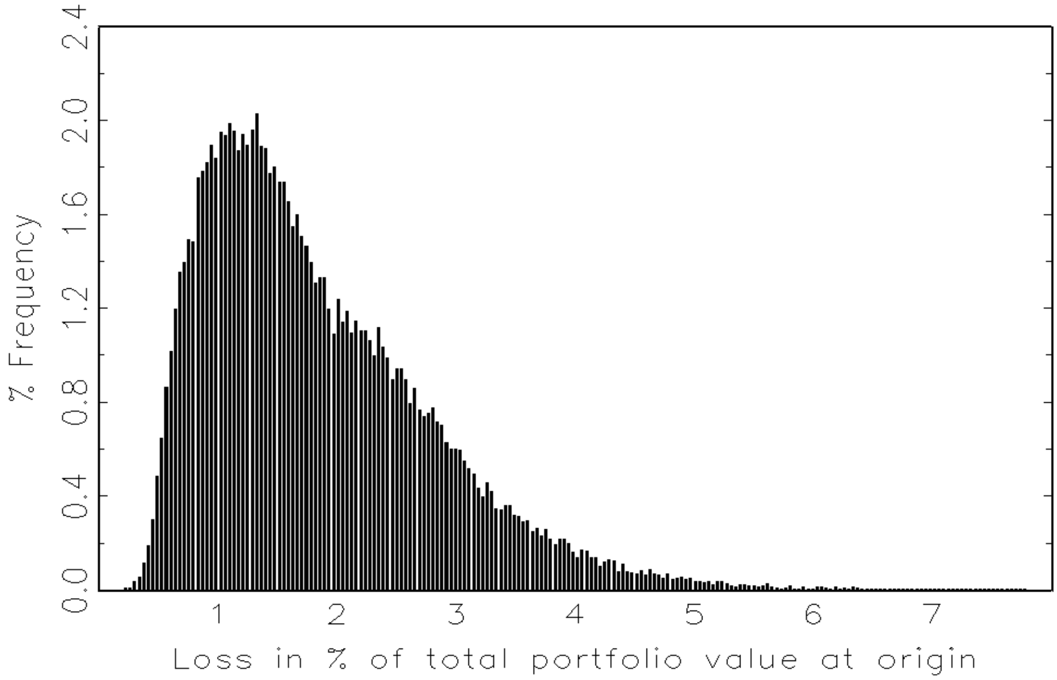


Figure 3.1b **Distribution of the change in the capital requirement ('ΔCapital') as percentage of the initial loan portfolio value**

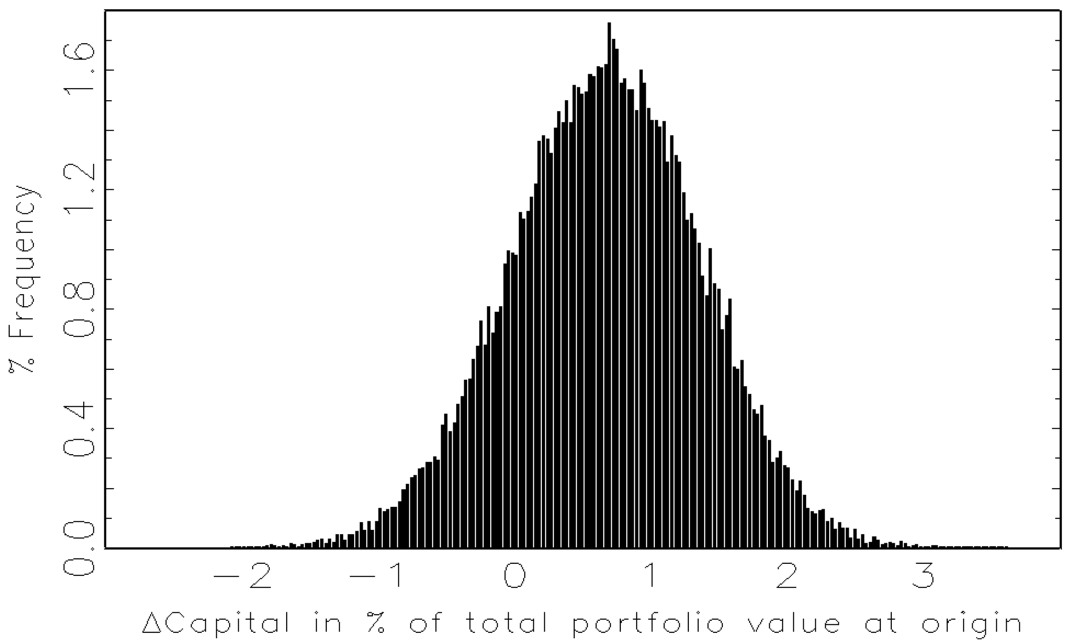
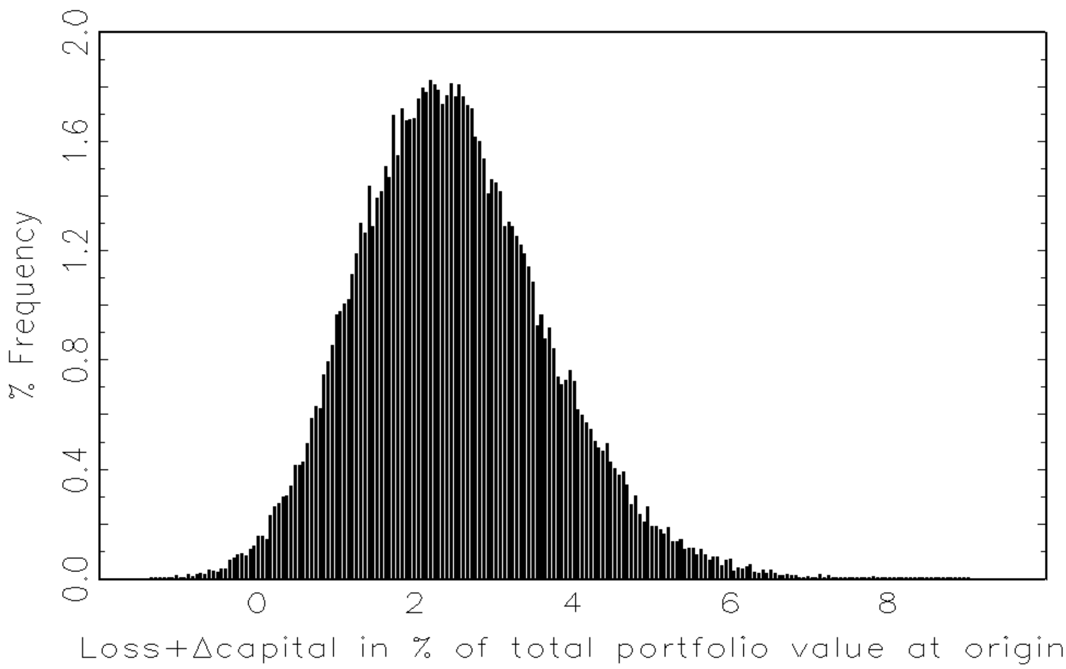


Figure 3.1c **Distribution of the sum of the credit loss and the change in the capital requirement ('Loss+ΔCapital') as percentage of the initial loan portfolio value**



Results regarding the distribution of the change in the minimum capital requirement are displayed on the row titled 'ΔCapital'. We argue that instead of the unexpected change alone one should focus on the sum of the expected and the unexpected change which totals 2.26 at the 99% level. The argument is the following. As was already discussed in section 2.1, it is normally perceived that banks incorporate the expected credit loss into their loan margins and therefore one should focus on the unexpected credit losses in determining capital buffers. However, it is not clear that banks similarly incorporate into loan prices the expected change in the capital requirement, particularly if the expected change is effectively based on a macro forecast of changes in PDs as in our framework. Therefore we believe the sum of the expected and the unexpected change is the relevant measure to look at. Note that the expected change in the capital requirement may well be negative if the economy would be in a cyclical downturn (below trend) at the start of the simulation. The positive expected change, 0.67, that we obtain indicates that the economy was in a cyclical upturn (above trend) in the second quarter of 2003. In other words, our macro econometric model predicts a higher credit risk at the end of the next three year period than in 2003 and as a result a higher capital requirement than in 2003.

Comparing the expected plus unexpected change in the capital requirement with the unexpected credit loss we conclude that they are roughly of the same order of magnitude; 2.26 and 2.91., respectively. The fact that the unexpected loss is somewhat higher only re-emphasizes the need to jointly measure unexpected credit losses when designing stress tests for change in capital requirements as part of the IRBA requirements. The row 'Loss+ΔCapital' in table 3.1 finally displays results concerning the joint distribution. As argued above, the relevant measure to consider is the 99% VaR figure of the joint distribution, 3.16, to which the expected change in the capital requirement, 0.67, is added, totalling 3.83. This should be contrasted with 2.26, the expected plus unexpected change in the capital requirement. In other words, the joint effect of unexpected loan losses and change in the capital requirement implies a 1.57 percentage point higher capital need than the change in the capital requirement alone. On the other hand, 3.83 is considerably lower than the sum of 2.26 and 2.91, which indicates that it is important to model the true correlation between credit losses and capital requirements in order not to overstate their joint impact on the bank's capital need.[7] The results regarding the relative contributions of credit losses and the change in capital requirements to the bank's capital need are broadly in line with the corresponding results reported in Peura and Jokivuolle (2003), which were obtained from a model based on the CreditMetrics methodology.

Finally, we would like to make a note on the symmetry of the distribution of change in capital requirement. Symmetry may be a bit surprising because one could think that, like credit losses, capital requirements would increase in a convex manner as macro economic development deteriorates. Two things, however, contribute to the symmetry (see Peura and Jokivuolle, 2003). First, the IRBA minimum capital requirement is globally a concave function of the PD (for an illustration, see eg Jokivuolle, 2006). So, when adverse shocks to the macro variables increase the industry PDs, the resulting increase in capital requirements is relatively weaker. Secondly, defaulted credits no longer appear in the capital requirement because they are written off as credit losses. Interestingly, additional results which are not reported here suggest that the skewness of the credit loss distribution is mainly caused by the concentration of large exposures in the portfolio. Namely, repeating the loss simulation for a hypothetical portfolio of evenly distributed credit exposures resulted in a virtually symmetric loss distribution. This suggests that the industry PDs are in actuality quite linear in the macro state of the model, which would also contribute to the symmetry of the distribution of change in capital requirements. Moreover, it seems that this type of macro model for loan losses may not be able to produce an inherently skewed loan loss distribution as the Merton model based credit portfolio models which

[7] In fact, the correlation is only 0.03, which results from the lumpiness of the credit portfolio. If a large individual exposure causes a credit loss, it simultaneously strongly reduces the capital requirement. In case of a hypothetical evently distributed credit portfolio, the correlation between losses and change in capital requirement is much higher; 0.65.

incorporate a structural model of the default mechanism at obligor level and correlated individual defaults.

3.2 Stress testing credit losses and IRBA capital requirements with deterministic scenarios

While section 3.1 represented a value-at-risk type of analysis, in this subsection we aim to implement deterministic scenario based stress tests which the Basel II framework and supervisory agencies have envisaged. We consider two scenarios: 1) zero GDP growth and 2) the worst in 25 GDP developments, based on the Finnish history after liberalisation of the capital markets. A given scenario is assumed to materialize during the first two quarters.[8] In order to facilitate comparison with the results of section 3.1, we maintain the three-year horizon and assume that after the first two quarters the macro variables deterministically revert back to their trends along their expected paths. As a result, we obtain two entirely predetermined macro developments and the resultant predetermined PD-paths for each industry over the 3-year horizon. Using the PDs, the cumulative credit loss, the change in the capital requirement, and their sum, are then calculated for both scenarios.[9] From our main measure of interest, the sum of the credit loss and the change in the capital requirement, we deduct the unconditional expected credit loss. This follows the logic discussed in section 3.1 that banks would incorporate the expected credit loss into their pricing of loans.

Results of the stress tests are summarised in table 3.2. The zero growth scenario produces a rather mild outcome, indicating a capital need over the current minimum requirement of 0.79 percentage points. The worst in 25 scenario, on the other hand, produces a considerably bigger capital need of 1.52, which is not surprising given the Finnish history of a deep recession in the early 90s. Yet even this scenario is far below the 99% VaR of the entire distribution; 3.83. There are at least two obvious explanations for why the chosen deterministic stress scenarios can produce much smaller figures than the value-at-risk type analysis. First, the scenario which turned out to be the worse of the two, eg the 1 in 25

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[8] In the second scenario, we use the worst GDP development over any half-year period during 1986:1–2003:3 in Finland. In actuality, this means an even more conservative choice than a 1 in 25 scenario.

[9] Note that although the entire macro development and hence the PD paths are predetermined in these scenarios, idiosyncratic uncertainty remains as to what particular credits in the bank's portfolio default. In order to end up with only one number, not a distribution, for our scenario based capital buffer estimates, we take expectations with respect to the remaining idiosyncratic default uncertainty. In the current context this is perhaps most easily done by generating a sufficiently large number (50000 in our case) of default/non-default paths with the binary default simulator of Sorge and Virolainen (2006), and then using the simulated sample means of the cumulative credit loss, change in capital requirement, and their sum.

scenario, corresponds to a confidence level of 96% which is less conservative than the 99% used in our value-at-risk analysis. Secondly, the deterministic stress scenarios are restricted to the first two quarters (after which expected macro development resumes) whereas in our value-at-risk type simulations the macro development is allowed to evolve ‘freely’ over the entire 3-year horizon.

Table 3.2 **Stress tests based on deterministic scenarios**

Results expressed as percentage of total portfolio value at origin. 3-year horizon is used, in which expected developments of the macro variables resumes after the specific GDP scenario during the first two quarters.

	zero-growth scenario	1 in 25 scenario
Loss	1.85	2.22
ΔCapital	0.78	1.13
Loss+ΔCapital	2.62	3.35
Capital buffer (Loss+ΔCapital-EL_{loss}^{uc})*	0.79	1.52

* EL_{loss}^{uc} refers to the unconditional expected loss; eg the mean 1.83 from table 3.1.

Peura and Jokivuolle (2004) provide tentative calibration results that banks may well use a confidence level around the 99% to reserve precautionary capital on top of the minimum requirement. Therefore it seems quite possible that banks would prefer to hold much higher extra capital buffers than the above deterministic scenarios suggested by regulators would imply.[10]

4 Conclusions

Capital requirements set the minimum on the amount of capital a bank should hold; it is expected that at least in normal times banks hold buffers of capital that exceed the minimum requirement. Under Basel II, determining sufficient additional capital buffers has become an increasingly demanding risk management issue for banks. This is because the new minimum capital requirements, particularly the internal ratings based, potentially fluctuate much more than Basel I requirements (see also the discussion in Peura and Jokivuolle, 2004). This has also been recognized in the Basel II standards which require banks using the IRBA rules to conduct stress tests on how future minimum requirements could potentially increase. In particular, the Basel rules require banks to look at such an adverse scenario at least under the conditions of a mild

[10] Banks’ actual capital levels could also be determined by their economic capital considerations. See Berger et al (2008) for recent empirical results on the determinants of banks’ capital ratios.

recession, eg, with the economy exhibiting zero growth over two consecutive quarters.

In this paper we have explored how such a stress test could be accomplished. In order to consider specific macro economic scenarios, we have chosen to follow the macro based model for credit losses of Sorge and Virolainen (2006). We have made a preliminary attempt to incorporate the dynamics of minimum capital requirements in that framework. Following Peura and Jokivuolle (2004) we also emphasize that it is important to model and consider the joint dynamics of minimum capital requirements and credit losses because their correlation structure is non-trivial and because they have a joint impact on a bank's need for an additional capital buffer.

Our results clearly show that if credit losses are ignored and the change in the capital requirement is stress tested alone, banks' precautionary capital need, on top of the current minimum requirement, can be seriously underestimated. On the other hand, simply adding the unexpected credit loss from a separate stress test can considerably overestimate the capital need because then correlation between the two is not modeled and taken into account. We found the relevant size of the additional capital buffer to be about halfway between these extremes: according to our simulations and the 99^{th} percentile of the resulting distributions, change in capital requirement alone would necessitate a capital buffer of 2.26 per cent of total credit assets, a naive addition of unexpected credit losses would increase this buffer to 5.17 per cent, whereas the buffer resulting from a joint model of losses and future capital requirements would be 3.83 per cent.

The second set of results comprises stress tests based on specific deterministic macro scenarios envisaged by the regulators. Of the two scenarios considered, the worst in 25 GDP developments for two consecutive quarters implied a considerably higher capital need than the zero growth scenario, at least in the case of the Finnish data used in this study. However, compared to the capital buffer of 3.83 percent implied by the 99^{th} percentile of the entire simulated distribution within a value-at-risk approach, the worst in 25 scenario implied a capital buffer of only 1.54 percent. Thus, we conjecture that demands for capital buffers resulting from the stress scenarios envisaged by regulators are not likely to impose binding capital constraints on banks, given that we have implemented these scenarios in the manner that the regulator has meant.

Our results have been obtained by using average industry specific probabilities of default as the representative PD for each company in the respective industry in the Finnish aggregate corporate portfolio. Ratings and rating specific PDs for individual companies have not been used. Therefore our application and results may be informative as such for macro-prudential analysis but not necessarily for analysis of an individual bank unless the bank's portfolio composition is close to that of the aggregate portfolio. Some more work, and data, indeed, would be needed to adapt our framework to model the dynamics of a bank's internal ratings and thus of minimum capital requirements explicitly based on them.

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