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The Choice of Interest Rate Models and Its Effect on Bank Capital Requirements Regulation and Financial Stability

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Abstract

According to the Basel regulation banks may use internal risk models to measure interest rate risk and calculate regulatory capital requirements. Under its pillar II the Basel framework grants leeway to banks in their choice of these models. We therefore focus on how well interest rate models describe real interest rate movements empirically and which impact the model choice has on the economic value of bank equity during the financial crisis. Furthermore, we address the question how different choices of interest rate models affect the overall financial stability. To this end we estimate eight different interest rate models for three different currencies (USD, EUR, CHF) using the Generalized Method of Moments (GMM). Then we approximate the balance sheet of a typical Swiss bank during the financial crisis and run Monte Carlo simulations of the balance sheet using the estimated interest rate models. Our results show that the required economic value of equity for a bank varies considerably with the different choices of interest rate models. However, the interest rate models which are empirically best fitting do not imply aggregate financial stability. Thus, banks' choices of interest rate models to calculate regulatory capital requirements may have a crucial impact on overall financial stability.

Keywords: banks, government policy and regulation, interest rates, determination, term structure and effects

1. Introduction

Recently, new standards on minimum capital requirements for market risk were established within the regulatory framework of Basel III by the Basel Committee on Banking Supervision (BCBS, 2016a). Furthermore, the Basel Committee puts special focus on the management of interest rate risk in the banking book, as it considers interest rate risk to be a material source of risk especially during times when interest rates worldwide normalize from historically low levels ten years after the financial crisis. When interest rates rise again from these low levels, even small relative changes in rates may have high absolute outcomes in terms of the economic value of bank equity. This is why inter alia the U.S. Federal Deposit Insurance Corporation (FDIC) highlights the importance of interest rate risk management (FDIC, 2009). Meanwhile also on an international scale greater guidance is given by the Basel Committee on banks' interest rate risk management. In particular, the Basel Committee now focuses on how banks develop interest rate shock and stress scenarios. But even in its revised principles on interest rate risk management, the Basel Committee still leaves leeway to banks regarding the use of internal models to calculate interest rate risk (BCBS, 2016b) (Note 1). Thus the question arises, which results the different choices of internally developed interest rate models may bear on regulatory capital and overall financial stability. To answer this question we consider a typical Swiss bank and its leeway of choice to report interest rate risk on the basis of internally developed models during the financial crisis. To be consistent, we use the then prevailing rules of Basel II. Hereafter, banks had to report to supervisors results of internal interest rate risk models expressed in terms of the economic value of equity relative to regulatory capital. To facilitate the monitoring of interest rate risk across the financial system, banks had to calculate a standardized interest rate shock. Supervisors gave particular attention to the sufficiency of capital of 'outlier banks', whose sum of Tier 1 and Tier 2 capital declined by more than 20% as a result of a hypothetical 200 basis points interest rate shock (BCBS, 2007).

This article assesses differences in capital requirements related to the different choices of interest rate models during the financial crisis. We review eight interest rate models and calibrate them for three different currencies

(USD, CHF, EUR). Following a simulation methodology as suggested in Estrella (2004) and Koopmann, Lucas, and Klaassen (2005), we run Monte Carlo simulations of a typical Swiss bank's balance sheet to analyze bank-specific and systemic risks associated with the choice of different interest rate models.

2. Literature Review

Research suggests that there is no generally accepted model to determine interest rate risk (Kuritzkers & Schuermann, 2007). Consequently, the Basel Committee allows to measure interest rate risk with different approaches (BCBS, 2016b). One approach is to understand interest rate risk as earnings at risk. Another approach is to measure interest rate risk by changes in economic value of bank equity (Note 2). In general the Basel Committee defines interest rate risk in the banking book as current or prospective risk to the bank's capital and earnings arising from adverse movements in interest rates that affect the bank's banking book positions. The source of interest rate risk is hence a change in the present value and timing of future cash flows and therefore a change in the value of a bank's underlying assets and liabilities. Moreover, changes in interest rates affect a bank's earnings, i.e. its net interest income.

Due to the variety of interest rate risk measurement approaches different results exist on the question, whether banks reserve the appropriate amount to cover these risks. For example Esposito, Nobili, and Ropele (2015) find that Italian banks' interest rate risk exposure was noncritical over the period 2008 to 2012 by using a simplified measurement methodology for interest rate risk introduced by the Bank of Italy (2006). By contrast, Memmel, Seymen, and Teichert (2017) find for a set of German banks during the period 2005 to 2014, that bank managers tend to increase interest rate risk when operating income falls below a certain threshold. The authors thereby underscore that a prolonged low interest rate environment is counterproductive from a financial stability perspective. In this context Chaudron (2016) finds that Dutch banks, who received government help during the financial crisis, took on greater interest rate risk. Posner (2014) argues that bank regulators failed to give banks an adequate incentive to increase capital during the financial crisis. He explains that not using cost-benefit analysis to determine capital requirements may have contributed to the financial crisis.

Therefore, Alessandri and Drehmann (2010) as well as Kretzschmar, McNeil, and Kirchner (2010) suggest integrated models to calculate capital adequacy for banks. The authors argue that correlations between the different risk types, such as credit risk and interest rate risk, play a crucial role in calculating appropriate capital reserves. Cerrone, Cocozza, Curcio, and Gianfrancesco (2017) develop an internal measurement system for interest rate risk. On the basis of a sample of Italian banks the authors show that the current Basel regulation on interest rate risk needs to be improved from a financial stability perspective. Miller, Olson, and Yeager (2015) develop a forecasting model for bank failures and find out that Tier 1 leverage ratio is the most accurate distress signal for large bank holding companies.

Our contribution to the literature is twofold. We first highlight problems from a bank management perspective in choosing the right interest rate model. Then we discuss from a financial stability perspective, that the freedom of choice between different interest rate models to calculate regulatory bank capital requirements may negatively impact the overall financial system stability.

3. Methodology

Our research methodology comprises three steps. In the first step we set up a balance sheet of a typical Swiss bank with actual economic and currency exposures during the financial crisis. In the second step we calibrate stochastic processes for interest rates and stock returns. The interest rate models are estimated and benchmarked according to Chan, Karolyi, Longstaff, and Sanders (1992) for Swiss Francs (CHF), U.S. Dollars (USD) and Euros (EUR). To calibrate the models we use the Generalized Method of Moments (GMM). Stock returns follow a standard Geometric Brownian Motion, for which the parameters will be estimated. The third and final step of our methodology consists of a Monte Carlo simulation of assets and liabilities of the bank. The simulations highlight the consequences of the choice of different interest rate models on the economic value of equity capital of the bank. The simulations are run for three interest rate term structures, namely a normal, a flat and an inverse term structure.

3.1 Structure of the Bank Balance Sheet

In order to define a representative balance sheet of a Swiss bank, we use data from the central bank, the Swiss National Bank. Assets: 70% are loans, approximated as bonds with a constant duration of 2 years and 30% are stocks (SNB, 2007b). Liabilities: Between 12% and 15% are equity and between 88% and 85% are short-term liabilities with a duration of 1 year (SNB, 2007a, 2007c) (Note 3).

Credit risk, market and operational risks are incorporated by calculating average exposures to these risk categories of representative public and private sector banks in Switzerland with regard to their balance sheet totals (SNB, 2007a) (Note 4). In addition, as the annual report of Credit Suisse (CS, 2008) indicates, large Swiss banks had the following currency exposures during the financial crisis: 41% in Swiss Francs, 34% in US Dollars, 25% in Euros. To find out how different magnitudes of equity impact financial stability, we perform two simulation runs with an initial equity of 12% and an initial equity of 15%. This leads to the following representative balance sheets (Note 5):

Balance Sheet					
Assets			**Liabilities**		
Bonds		*70*	*Short-term liabilities*		*85*
CHF	*41%*		CHF	*41%*	
USD	*34%*		USD	*34%*	
EUR	*25%*		EUR	*25%*	
Stocks		*30*	*Equity*		*15*
CHF	*41%*				
USD	*34%*				
EUR	*25%*				
Total		*100*	*Total*		*100*

Balance Sheet					
Assets			**Liabilities**		
Bonds		*70*	*Short-term liabilities*		*88*
CHF	*41%*		CHF	*41%*	
USD	*34%*		USD	*34%*	
EUR	*25%*		EUR	*25%*	
Stocks		*30*	*Equity*		*12*
CHF	*41%*				
USD	*34%*				
EUR	*25%*				
Total		*100*	*Total*		*100*

Figure 1. Bank balance sheets with 12% equity and 15% equity

3.2 Design of the Monte Carlo Simulation Model

The economic value of equity of a bank is the result of interest rate movements. Future interest rate movements are described in different stochastic models. We analyze consequences of the choice of the stochastic model on the resulting economic value of equity capital of the bank. The methodology we use is a simulation of the assets and liabilities which are interest rate sensitive (Figure 1). The simulations are run for periods of 120 months. For these ten years, the economic values of equity are compared to the equity requirement of the Basel regulation. We set the balance sheet total equal to 100 monetary units and thus assume that bank management will not change the structure of the balance sheet during the simulation horizon. The balance sheet positions are determined at the beginning of the simulation in $t=0$ and change only on the basis of the stochastic processes involved in the simulation. The market value of equity at any given point in time t (120 months) is given as the difference between assets and liabilities:

$$MV_t(Equity) = MV_t(Assets) - MV_t(Liabilities) \tag{1}$$

The Basel regulation requires determining the minimum equity capital on the basis of two provisions:

a) Pillar 1: Credit, market and operational risks must be covered by the sum of risk-weighted assets for credit risk, as well as the exposures on market and operational risks:

$$Equity_{\min 1} = \left(\sum_{j=1}^{N} RW_j\right) \cdot 0.08 + RA(Market\ Risks) + RA(Operational\ Risks) \text{(Note 6)} \tag{2}$$

b) Pillar 2: Interest rate risks in the banking book are controlled by a provision which stipulates that equity capital must not be reduced by more than 20 percent after a standardized interest rate shock. A standardized interest rate shock is defined for G10 currencies by a 200 basis points parallel up- or downward shift of the yield curve or a change of the 1st or the 99th percentile of interest rate changes in the past five years on a one-year holding period (BCBS, 2007) .

Based on these two provisions we define the minimum equity capital requirement for interest rate risk in the banking book as a function of the respective market values (*MV*):

$$Equity_{\min 2} = MV(stocks) + MV(bonds) - \frac{0.2 \cdot MV(stocks) + MV(bonds(0.2 + \Delta MV(bonds))}{0.2 + \Delta MV(short\text{-}term\ liabilities)} \tag{3}$$

During the simulation runs, the minimum capital requirement for keeping the bank solvent is defined as the maximum value between the two capital requirement provisions, i.e. max ($Equity_{\min1}$; $Equity_{\min2}$). If the market value of equity $MV(equity_t)$ drops below the higher value of $Equity_{\min1}$ or $Equity_{\min2}$, the bank is considered to be insolvent, i.e. defaulted.

Now we consider three interest rate term structures, namely a normal, a flat and an inverse term structure. The normal term structure characterizes increasing interest rates for longer maturities. We prescind from modeling the three term structures in a general equilibrium setting (Note 7). Stock market returns are modeled by a standard Geometric Brownian motion of the form $dS_t/S_t = \mu d_t + \sigma dW_t$, where μ represents the drift, σ is the volatility of the stock, and dW_t is the increment of a Wiener process.

The simulations are based on the calibrations of stochastic interest rate processes. The calibrations are conducted for all three currency exposures (Figure 1). Each of the currency positions are included by 10,000 simulation runs for 120 months. The simulated balance sheet positions are connected by means of the Cholesky transformation. That is, the random number generation process accounts for the correlations between the bond, stock and short-term liability positions in the respective currency. Compounding effects are offset among the balance sheet positions. The market values of equity are calculated as residual factors according to (1). Then the resulting magnitudes of equity are compared to the Basel capital requirements as defined in (2) and (3). This again, is done in each of the 10,000 simulation runs. This enables us to analyze the equity demanded by the regulator for each scenario, as well as the actual equity situation of the bank under the 10,000 simulated scenarios.

3.3 Estimating Stochastic Interest Rate Models

Chan et al. (1992) estimate and compare eight continuous-time models of the short-term riskless rate using the Generalized Method of Moments (GMM). The authors find that the best models in describing the dynamics of (the short-term) interest rate are the ones, which reflect in their formulae that the true volatility of interest rates depends on the level of the riskless rate. We re-estimate and rank these eight models according to their GMM-based empirical performance by using similar data up to the mid of the financial crisis. But we extend the aforementioned analysis by two aspects: First, we use longer time periods. Second, we use three different currencies.

Chan et al. (1992) point out that many single and multifactor term structure models imply a dynamic behavior of the short-term riskless rate r which follows this stochastic differential equation:

$$dr = \left(\alpha + \beta r\right) dt + \sigma r^{\gamma} dz \tag{4}$$

Table 1 shows the term structure models used in the literature and their relationship to the basic stochastic differential equation (4).

Table 1. Interest rate model definitions

Model	α	β	σ^2	γ
Unrestricted				
Merton (1973)		0		0
Vasicek (1977)				0
Cox/Ingersoll/Ross (1985)				0.5
Dothan (1978)	0	0		1
GBM (Black/Scholes, 1973)	0			1
Brennan/Schwartz (1977)				1
Cox/Ingersoll/Ross variable-rate (CIR VR, 1980)	0	0		1.5
Constant Elasticity of Variance (CEV, Cox, 1975)	0			
>>> nests Dothan (1978), Brennan/Schwartz (1977), CIR VR				

Brennan and Schwartz (1982), Dietrich-Campbell and Schwartz (1986), Sanders and Unal (1988), estimate the parameters of the continuous-time model using this discrete-time econometric specification:

$$\begin{aligned} & r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{t+1} \\ & E\left[\varepsilon_{t+1}\right] = 0, \;\; E\left[\varepsilon_{t+1}^2\right] = \sigma^2 r_t^{2\gamma} \end{aligned} \tag{5}$$

Following Hansen (1982), Chan et al. (1992) and others, we also use the Generalized Method of Moments (GMM) to test (5) as a set of over-identifying restrictions on a system of moment equations. The advantages of this approach are that the GMM-method does not require a normal distribution of interest rate changes. Only stationarity and ergodicity for the distribution of interest rate changes are required. Another advantage is that the GMM estimators and their standard errors are consistent even in cases where the disturbances are conditionally heteroskedastic. This facilitates the temporal aggregation problem which arises from the estimation of a continuous-time process with discrete-time data.

Let θ be the parameter vector with elements α, β, σ^2 and γ . With $\varepsilon_{t+1} = r_{t+1} - r_t - \alpha - \beta r_t$, the vector $f_t\left(\theta\right)$ is defined as:

$$f_t(\theta)=\begin{bmatrix}\varepsilon_{t+1}\\ \varepsilon_{t+1}r_t\\ \varepsilon_{t+1}^2-\sigma^2 r_t^{2\gamma}\\ \left(\varepsilon_{t+1}^2-\sigma^2 r_t^{2\gamma}\right)r_t\end{bmatrix} \tag{6}$$

Under the null hypothesis that the restrictions implied in (5) are true, the expectation of vector $f_t(\theta)$ equals zero, i.e. $E\left[f_t(\theta)\right]=0$. Using a time series of length *T* observations, the GMM procedure replaces $E\left[f_t(\theta)\right]$ with its sample counterpart $g_T(\theta)$, using the *T* observations, where $g_T(\theta)=1/T\sum_{t=1}^{T}f_t(\theta)$. In the next step the parameter estimates are chosen, which minimize the quadratic form $J_T(\theta)=g_T'(\theta)W_T(\theta)g_T(\theta)$. Here $W_T(\theta)$ is a positive-definite weighting matrix (Note 8). For the nested interest rate models detailed in Table 1, the GMM estimates of the over-identified parameter subvector of θ depend on the choice of W_T. Hansen (1982) shows that choosing $W_T(\theta)=S^{-1}(\theta)$ with $S(\theta)=E\left[f_t(\theta)f_t'(\theta)\right]$ results in the GMM estimator for θ with the smallest asymptotic covariance matrix. Defining an estimator of this covariance matrix as $S_0(\theta)$, the asymptotic covariance matrix for the GMM estimate of θ is $1/T\left(D_0'(\theta)S_0^{-1}(\theta)D_0(\theta)\right)^{-1}$, where $D_0(\theta)$ is the Jacobian evaluated at the estimated parameters. This covariance matrix is used to test the significance of the individual parameters. The minimized value of the quadratic form $J_T(\theta)$ is distributed χ^2 under the null hypothesis that the model is true with degrees of freedom equal to the number of orthogonality conditions net of the number of parameters to be estimated. The χ^2 measure provides a goodness-of-fit test for the model, which indicates misspecification when the value of the statistic is high.

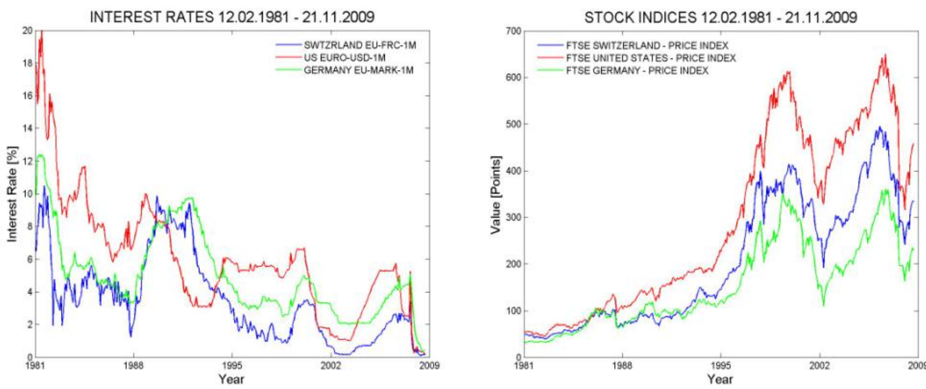
4. Empirical Results

4.1 Data Description

For the calibration of the interest rate models, the short-term riskless rate of interest is proxied by a one-month interest rate. Ball and Torous (1999), Duffee (1996) and others argue that the idiosyncratic variation of U.S. Treasury yields increased since the early 1980ies. Therefore one should not rely exclusively on Treasury yields in calibrating models of short-term interest rate dynamics for the U.S. market. Following Ball and Torous (1999) and to ensure international comparability of the short-term interest rate dynamics, we use one-month rates drawn from the London Euro-currency market. Each of these rates is a London interbank rate denominated in a given currency. In particular, we use monthly observations of the one-month Euro-Dollar, Euro-Mark/Euro and Euro-Swiss Franc middle rates taken from Datastream over the sample period February 1981 to November 2009, giving 346 observations for each series (Note 9).

The equity markets are proxied with the “FTSE All-World Index Series” (in prices), which is the successor index series of the “FT Actuaries / Goldman Sachs International Indexes” used in Roll (1992) (Note 10). The sample is also taken from Datastream and covers – as in the case of the interest rate data – the time period from February 1981 to November 2009, giving the 346 mentioned observations. We base our analysis on this time span, because it comprises several historical all time highs and lows in interest rates and excludes the abnormal low interest rate period after the financial crisis. Figure 2 provides a graphical overview and descriptive statistics on the data sample.

This sample is used for two purposes. First, the interest rate data is used to estimate and benchmark different interest rate models. Second, the data on both capital market segments (interest rates and stock market returns) are used to calibrate the stochastic processes. Then the Monte Carlo simulation can be started.



One-month London Euro-currency market interest rates p.a.

	μ	σ
SWTZRLAND EU-FRC-1M	3.46%	2.60%
US EURO-USD-1M	5.93%	3.54%
GERMANY EU-MARK-1M	4.93%	2.51%

Stock market performance FTSE All-World Index Series p.a.

	μ	σ
FTSE SWITZERLAND - PRICE INDEX	8.59%	18.97%
FTSE UNITED STATES - PRICE INDEX	8.85%	16.22%
FTSE GERMANY - PRICE INDEX	9.17%	21.09%

Figure 2. Data sample descriptive statistics February 1981 – November 2009

The unconditional average level of the one-month interest rates for the Swiss Franc is 3.46% with a standard deviation of 2.60%. For the US-Dollar the values are 5.93% with a standard deviation of 3.54%. The Euro (German Mark) shows a mean interest rate of 4.93% with a standard deviation of 2.51%. Table 2 shows the autocorrelations in the interest rate levels, which decay slowly.

Table 2. Autocorrelation coefficients

Autocorrelation coefficients of the annualized monthly Euro-CHF/USD/EUR middle rates from the London Euro-currency market from Feb./1981 to Nov./2009 (N=346 observations). The variable r_t denotes the yield maturing in one month and r_{t+1}- r_t is the associated monthly yield change, ρ_j denotes the autocorrelation coefficient of order j.

Variable	*N*	Mean	Standard Deviation	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6
Panel 1: SWTZRLAND EU-FRC-1M – MIDDLE RATE									
r_t	346	0.034639	0.025982	0.970	0.951	0.930	0.899	0.871	0.716
r_{t+1}- r_t	345	-0.000104	0.002070	-0.217	0.015	0.017	0.024	-0.109	0.068
Panel 2:US EURO-$-1M – MIDDLE RATE									
r_t	346	0.059276	0.035368	0.966	0.943	0.914	0.876	0.843	0.773
r_{t+1}- r_t	345	-0.000048	0.001192	-0.100	0.007	-0.312	0.215	0.093	0.065
Panel 3: GERMANY EU-MARK-1M – MIDDLE RATE									
r_t	346	0.049250	0.025115	0.981	0.956	0.929	0.899	0.866	0.662
r_{t+1}- r_t	345	-0.000064	0.000697	0.261	0.217	0.194	0.212	0.176	0.110

With regard to the month-to-month changes of the respective time series, the autocorrelations are small. They are neither consistently positive nor negative (except for the German interest rate). This gives evidence that short-term interest rates are stationary. The balance sheet exposures in Figure 1 give an impression of the overall business risk of the bank, if the correlations between the various risk factors are considered. Table 3 shows that significant risk reduction effects in terms of negative correlations are given between Swiss interest rates and the national and international stock market exposures.

Table 3. Correlations of balance sheet risk factors

	Interest rates CHF	Interest rates EUR	Interest rates USD	Stocks CH	Stocks Germany	Stocks USA
Interest rates CHF	1	0.9196	0.5838	-0.6539	-0.5548	-0.6457
Interest rates EUR	0.9196	1	0.6387	-0.6269	-0.5610	-0.6209
Interest rates USD	0.5838	0.6387	1	-0.5592	-0.5383	-0.6009
Stocks CH	-0.6539	-0.6269	-0.5592	1	0.9748	0.9857
Stocks Germany	-0.5548	-0.5610	-0.5383	0.9748	1	0.9690
Stocks USA	-0.6457	-0.6209	-0.6009	0.9857	0.9690	1

However, no risk reduction effect can be obtained in the international term-transformation business of the bank, as interest rates are highly correlated between the three markets.

4.2 Results of the GMM-Estimations of Interest Rate Models

Table 4 reports the parameter estimates, asymptotic *t*-statistics, and GMM minimized criterion χ^2-values for the unrestricted model and for each of the eight nested models. Since the unrestricted model represents an exactly identified system, the minimized GMM criterion value is exactly equal to zero. The unrestricted model for the Euro-Swiss Franc middle rate differs from the originally estimated model in Chan et al. (1992) insofar, as the parameter γ is significantly below 1, since here $\gamma = 0.3766$. Hence, we cannot confirm that the conditional volatility of the real interest rate movements would be highly sensitive to the level of the short-term rate. As Chan et al. (1992), we find only weak and insignificant evidence of mean reversion as measured by the parameter β in the unrestricted version of the model.

Table 4. GMM-estimation of the SWITZERLAND EU-FRC-1M – MIDDLE RATE

The estimation horizon for r_t, the annualized monthly Euro-Swiss Franc middle rates from the London Euro-currency market, is February 1981 to November 2009 (346 observations). The parameters are estimated by the Generalized Method of Moments with t-statistics in parentheses. Tests evaluate overidentified restrictions imposed by alternative models on the unrestricted model. The χ^2 test statistics are reported with *p*-values in parentheses and associated degrees of freedom (d.f.). The existence of a unit root is rejected according to the Augmented Dickey-Fuller test with intercept and drift (lag-length 4, Akaike criterion). The parameters are estimated from the following discrete-time system of equations:

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{t+1}, \quad \text{s.t.: } E\left[\varepsilon_{t+1}\right] = 0, \ E\left[\varepsilon_{t+1}^2\right] = \sigma^2 r_t^{2\gamma}$$

Model	α	β	σ^2	γ	χ^2 (*p*-value)	*df*
Unrestricted	0.0007	-0.0253	0.0005	0.3766		0
	(1.7570)	(-1.9041)	(1.6006)	(3.9427)		
Merton	0.00025	*0.0*	0.000021	*0.0*	19.0766	2
	(0.9300)		(4.8194)		(0.000072)	
Vasicek	0.0012	-0.0418	0.0000	*0.0*	12.7432	1
	(3.3556)	(-3.3504)	(5.2054)		(0.000357)	
CIR SR	0.0005	-0.0194	0.0009	*0.5*	1.4360	1
	(1.3749)	(-1.5670)	(6.4037)		(0.2308)	
Dothan	*0.0*	*0.0*	0.0114	*1.0*	15.6345	3
			(5.4971)		(0.0013)	
GBM	*0.0*	-0.0065	0.0113	*1.0*	15.0177	2
		(-0.7218)	(5.4108)		(0.000548)	
Brennan-Schwartz	0.0002	-0.0109	0.0110	*1.0*	14.9175	1
	(0.4662)	(-0.8425)	(5.0526)		(0.000112)	
CIR VR	*0.0*	*0.0*	0.1176	*1.5*	22.4460	3
			(4.7325)		(0.000052)	
CEV	*0.0*	-0.0078	0.0007	0.4466	3.0071	1
		(-0.8769)	(1.6979)	(4.7193)	(0.0829)	

In the case of the Euro-Swiss Franc middle rate from the London Euro-currency market, the χ^2-tests for goodness-of-fit suggest that six models are misspecified. These models are: Merton (1973), Vasicek (1977), Dothan (1978), GBM of Black and Scholes (1973), Brennan-Schwartz (1979) and CIR VR (1980). All these six models have χ^2-values in excess of 6 and can thus be rejected at the 95% confidence level. Only the CEV model by Cox (1975) and the CIR SR (1985) model fit the actual interest rate movements (during Feb 81 and Nov 09) well. The χ^2-values and *p*-values are low and indicate that these two models cannot be rejected even on the 90% confidence level. In terms of the significance of the interest rate variance, we obtain similar results as in Chan et al. (1992), but we cannot confirm that the ranking may be done according to the γ-values.

Turning to the estimation results for the Euro-Dollar middle rates from the London Euro-currency market in Table 5, we can see better conformity with the results of Chan et al. (1992).

Table 5. GMM-estimation of the US EURO-$ 1 MTH – MIDDLE RATE

The estimation horizon for r_t, the annualized monthly Euro-Dollar middle rates from the London Euro-currency market, is from February 1981 to November 2009 (346 observations). The parameters are estimated by the Generalized Method of Moments with t-statistics in parentheses. Tests evaluate overidentified restrictions imposed by alternative models on the unrestricted model. The χ^2 test statistics are reported with *p*-values in parentheses and associated degrees of freedom (d.f.). The existence of a unit root is rejected according to the Augmented Dickey-Fuller test with intercept and drift (lag-length 4, Akaike criterion). The parameters are estimated from the following discrete-time system of equations:

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{t+1}, \quad \text{s.t.: } E[\varepsilon_{t+1}] = 0 \quad , \quad E[\varepsilon_{t+1}^2] = \sigma^2 r_t^{2\gamma}$$

Model	α	β	σ^2	γ	χ^2 (*p*-value)	*df*
Unrestricted	0.0010	-0.0262	0.0148	1.1654		0
	(1.1491)	(-1.4438)	(0.7439)	(4.0698)		
Merton	-0.00029	*0.0*	0.000019	*0.0*	8.6991	2
	(-1.2752)		(3.6600)		(0.0129)	
Vasicek	0.0019	-0.0440	0.0000	*0.0*	6.3585	1
	(2.2564)	(-2.6761)	(3.6243)		(0.0117)	
CIR SR	0.0016	-0.0392	0.0004	*0.5*	3.3031	1
	(1.9607)	(-2.3815)	(4.1696)		(0.0691)	
Dothan	*0.0*	*0.0*	0.0067	*1.0*	3.6049	3
			(4.8463)		(0.3074)	
GBM	*0.0*	-0.0066	0.0069	*1.0*	1.8429	2
		(-1.4480)	(5.0372)		(0.3979)	
Brennan-Schwartz	0.0012	-0.0301	0.0067	*1.0*	0.3203	1
	(1.4332)	(-1.8061)	(4.7436)		(0.5714)	
CIR VR	*0.0*	*0.0*	0.0654	*1.5*	3.4015	3
			(5.2941)		(0.3338)	
CEV	*0.0*	-0.0060	0.0205	1.2269	1.2372	1
		(-1.2990)	(0.8272)	(4.6056)	(0.2660)	

For the case of the unrestricted model we find a γ-value of 1.1654 (Chan et al. (1992) find 1.4999). This confirms that the conditional volatility of the interest rate process is sensitive to the level of the short-term rate in the U.S.-market. We also find comparable (although insignificant) t-statistics for interest rate volatility, σ^2, and our estimates for β confirm mean reversion in the unrestricted model. In contrast to the findings of Chan et al. (1992), our values for the intercept, mean reversion and volatility are significantly smaller, though. This finding may be explained by the generally lower and falling interest rate level during the time period of our study. As Chan et al. (1992) report for the U.S. market, we find that the Merton (1973), Vasicek (1977), and CIR SR (1985) models are misspecified and can be rejected on the 90% confidence level. Furthermore, the best-performing model for our sample is clearly – as in the Chan et al. (1992) case – the Brennan-Schwartz (1979) model which has the lowest χ^2-value.

Table 6. GMM-estimation GERMANY EU-MARK 1M – MIDDLE RATE

The estimation horizon for r_t, the annualized monthly Euro-Mark/Euro middle rates from the London Euro-currency market, is from February 1981 to November 2009 (346 observations). The parameters are estimated by the Generalized Method of Moments with *t*-statistics in parentheses. Tests evaluate over-identified restrictions imposed by alternative models on the unrestricted model. The χ^2 test statistics are reported with *p*-values in parentheses and associated degrees of freedom (d.f.). The existence of a unit root is rejected according to the Augmented Dickey-Fuller test with intercept and drift (lag-length 4, Akaike-criterion). The parameters are estimated from the following discrete-time system of equations:

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{t+1}, \quad \text{s.t.: } E[\varepsilon_{t+1}] = 0 \quad , \quad E[\varepsilon_{t+1}^2] = \sigma^2 r_t^{2\gamma}$$

Model	α	β	σ^2	γ	χ^2 (*p*-value)	df
Unrestricted	0.0002	-0.0094	0.0005	0.6622		0
	(0.5124)	(-1.0823)	(0.6765)	(2.7867)		
Merton	-0.00022	*0.0*	0.0000070	*0.0*	8.1218	2
	(-1.5028)		(7.4781)		(0.0172)	
Vasicek	0.0005	-0.0175	0.0000	*0.0*	3.6339	1
	(1.4613)	(-2.3147)	(7.3593)		(0.0566)	
CIR SR	0.0003	-0.0119	0.0002	*0.5*	0.3912	1
	(0.8295)	(-1.5487)	(7.7650)		(0.5317)	
Dothan	*0.0*	*0.0*	0.0040	*1.0*	4.0499	3
			(8.0942)		(0.2561)	

GBM	*0.0*	-0.0041	0.0039	*1.0*	2.5552	2
		(-1.2271)	(7.7820)		(0.2787)	
Brennan-Schwartz	-0.0000	-0.0037	0.0039	*1.0*	2.5565	1
	(-0.0576)	(-0.4653)	(7.5462)		(0.1098)	
CIR VR	*0.0*	*0.0*	0.0550	*1.5*	15.6157	3
			(7.1023)		(0.0014)	
CEV	*0.0*	-0.0053	0.0007	0.7067	0.2620	1
		(-1.5419)	(0.7817)	(3.3959)	(0.6087)	

Table 6 shows the results for the German Euro-Mark/Euro middle rate. These are similar to the results of the Swiss case in the unrestricted version of the model. Again we cannot find a significant connection between the conditional volatility of the interest rate process and the level of the short-term yield. There is only weak and insignificant evidence of mean reversion (measured by β in the unrestricted version of the model). Thus we have to reject the Merton and CIR VR (1980) model on the 95% confidence level. Our finding is that the best performing models are the CEV model by Cox (1975) followed by the CIR SR (1985) model. As in the case of Switzerland and in contrast to Chan et al. (1992), we estimate a γ-value below 1 with $\gamma = 0.7067$.

Summarizing, we rank the different results of the parameter estimation for stochastic interest rate processes in the three different currencies according to the χ^2-test (Table 7):

Table 7. Performance ranking of interest rate models in different currencies

	Rank 1	*Rank 2*	*Rank 3*	*Rank 4*	…	*Rank 8*
SFR	CIR SR	CEV	Dothan	GBM		CIR VR
USD	B-S	GBM	CIR VR	Dothan		Vasicek
EUR	CEV	CIR SR	GBM	Dothan		CIR VR
Chan et al. (1992)	*GBM*	*B-S*	*Dothan*	*CIR VR*		*Vasicek*

A well-known fact is that the sensitivity of GMM-estimations to alternative specifications of the length of time series is large. This leaves room for the question, which time horizon will be adequate. If the regulated banks choose different time frames (which results in alternative specifications of the interest rate models), the stability of the financial system could either be enhanced by naive diversification or endangered by (unintended) system-wide risk clustering.

5. Simulation Results

As we have seen, the explanatory power of the models depends on the currency. It therefore makes sense not to choose one model and use it for all three currencies. Appropriate models should better be chosen for each currency and then combined to a set. In our Monte Carlo simulations of the assets and liabilities of the bank (Figure 1) we combine the eight interest models to Interest Model Sets (IMS) according to their rank as shown in Table 7. The risks associated with selecting models of different explanatory power can then better and more accurately be assessed. In total, we consider four Interest Model Sets, denoted by IMS 1, IMS 2, IMS 3, and IMS 8. These sets are defined by forming the four best combinations of models for each of the three currencies and they have the highest explanatory power:

Table 8. Interest rate model sets (IMS)

	CHF	*USD*	*EUR*
IMS 1	CIR SR	Brennan-Schwartz	CEV
IMS 2	CEV	GBM	CIR SR
IMS 3	Dothan	CIR VR	GBM
IMS 8	CIR VR	Vasicek	CIR VR

The tables in the appendix contain the descriptive statistics on the performance of the different Interest Model Sets (IMS) after 60 simulation periods and 120 simulation periods, respectively. The empirically best performing model set is IMS 1. In spite of the high empirical power (which is certainly positive), the set however shows the largest number of defaults after 60 and 120 simulation periods (which is negative). IMS 1 is closely followed by the empirically worst performing model set IMS 8. The second best performing model set IMS 2 displays the smallest number of defaults after 60 and 120 simulation periods (positive for financial stability). It is closely followed by the third-best performing model set IMS 3 (Note 11). Therefore, from a financial stability perspective, IMS 2 would be strongly favorable.

IMS 1 and IMS 8 as well as IMS 2 and IMS 3 are similar regarding the number of defaults during all the simulation runs, whereas the former sets IMS 1 and IMS 8 always generate more defaults than the latter. It becomes evident that the worst performing sets (IMS 1 and IMS 8) contain the Brennan-Schwartz (1979) and the Vasicek (1977) models, which take mean-reversion and an intercept into account. The Vasicek (1977) model does not reflect conditional volatility scaling, and the Brennan-Schwartz (1979) model reflects volatility scaling only to a very small extent.

IMS 2 and IMS 3 abstain from mean-reversion and intercept ($\alpha = 0,\ \beta = 0$) and they scale the conditional volatility with a higher interest rate level (see Dothan (1978) and GBM (1973)). We can conclude: the lack of mean reversion and intercept combined with a high conditional volatility scaling are the winning attributes of models and sets of models.

The importance to select an optimal IMS is underlined in Table 9 by the low *p*-values of the Kruskal-Wallis test. Since the *p*-values are very close to zero, we conclude, that at least one distribution of the actual equity distributions is significantly different from the others. This points out the importance of the choice of Interest Model Sets (IMS), as financial system stability strongly depends on the equity distributions generated by the sets of models.

Table 9. Kruskal-Wallis test of interest model sets (IMS) with respect to the distribution of actual equity capital, MV_t *(Equity)*

Term-structure	p-Value 12% Equity	p-Value 15% Equity
Normal	0.0075	0.0039
Flat	0.0069	0.0036
Inverse	0.0064	0.0033

Another result is the robustness of our simulations in terms of the interest rate term structure. Different term structures have only minor effects on the number of defaults. The maximum difference in the number of defaults after 120 periods is less than 0.3% between the three term structure types “normal”, “flat” and “inverse”. A normal structure generates the lowest and a flat term structure the highest amount of defaults. From a regulator’s point of view the most important outcome is consequently this fact: An increase of a bank’s equity from 12% to 15% cuts the default rate in half for any given IMS. Although an increase of the equity requirement by some 3% appears to be a drastic demand, it would contribute strongly to a more stable financial system.

Our results disclose the complexity of the decisions, which must be made by the management of a bank. Following the shareholder value approach one would suggest to choose either IMS 3 in the short run or IMS 8 in the long run, as these two models give the highest expected economic value of equity. But a viable consideration for the management may also be to minimize the regulatory capital requirements in order to enhance the profitability of the bank. According to this argument, managers may prefer IMS 2 in the short run and in the long run, as this model set produces a minimum target equity capital requirement. Unfortunately, this interest rate model produces also the second highest number of defaults in the financial system during the 10,000 simulation runs.

We also report that the distributions of market values of equity significantly change during the course of the simulations. This observation is made for all interest rate model sets. In the short-run of 5 years the distribution of the market values of equity is tight, while it becomes increasingly right-skewed and wider in the long run after 10 years. Hence, the probability that outlier banks occur clearly increases over time. However, for 12% (15%) equity at the starting point, overall default rates are below 16% (6%) for the five-year horizon and they reach 20% (10%) for the worst IMS in the ten-year horizon.

Summing up, all stochastic models of interest rates and sets of such models show that even a little bit more equity strongly enhances the solvency of a bank and increases financial system stability. But there is no relation between empirical performance of an interest rate model or sets of these models and the resulting financial system stability. Some models or sets of models are performing well regarding the empirical description of interest rate movements, but they show many defaults in the simulation runs. Other well-accepted models make the bank look safer, but they are poorer in there empirical power to explain real movements of interest rates. The freedom to choose the interest model in the Basel regulation consequently appears to be questionable. This is the case, because the differences among the models regarding empirical power and the demand of equity are large and there is no model, which would be superior in all categories.

6. Conclusion

In this article we analyze interest rate models for banks regulated under the Basel framework. We calibrate eight representative interest rate models and find that the criterion of best empirical performance does neither induce financial system stability in the short nor in the long run. Models which make a bank look safer, however, are poor in their power to describe real movements of interest rates.

We consider a typical Swiss Bank and allow combinations of different interest rate models for the three currencies USD, CHF and EUR, which determine the assets and liabilities of the hypothetical bank. Interest rate models and sets of models with no mean-reversion parameters but with conditional volatility scaling factors would be preferable from a regulatory point of view, since they exhibit a minimum of defaults during the simulation runs. The empirically mediocre performing model sets IMS 2 and IMS 3 surprisingly deliver the best results regarding financial stability. This is true for horizons of both five and ten years.

Financial stability crucially depends on the objectives of the bank management, i.e., whether shareholder value will be maximized or profitability enhanced through low equity holdings. We observe that the objective may be viable from a business perspective, namely enhancing the profitability of a bank, but that this objective turns out to be contrary to the goal of financial stability. Thereby, even small increases in bank equity have strong positive effects on financial stability. Our simulations with 12% of equity and 15% of equity respectively confirm that the new capital requirements in Basel III with up to 13% equity must be considered as absolutely necessary.

Our results also show that management objectives can be linked directly to the performance of the aggregate financial system, if regulatory provisions allow for an internal capital adequacy process, such as the one stipulated in the Basel framework. The paradox is that the regulatory framework on interest rate risk legally outsources the decision of risk model choice to the individual agents of the economy (banks). Our work shows that this can lead to more profitable banks, but it may also have negative effects on the overall stability of the financial system. Hence, regulators have to be particularly careful in judging the internal risk models banks choose. Individual first-best solutions are not the first-best solutions for the financial system.

For the recent result of the negotiations in the Basel Committee on Banking Supervision on the use of internal risk models our study also indicates, that choosing a benchmark model and defining a variability range to set limits to the model results is a viable way to foster financial stability. Using output floors to set these limits is practical to control model results. Moreover, cutting back on the complexity of bank internal risk models and thereby enhancing transparency in setting bank capital requirements is necessary in the future. Further studies could therefore focus on the effect of different output floor designs on financial stability, as well as on the development of models to calculate bank capital requirements, which capture uncertainty and risk and are still tractable in practice.

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Notes

Note 1. Banks are expected to implement the new standards on interest rate risk in the year 2018 based on information as of 31. December 2017. In comparison to the Basel II standard, the new Basel III standards on interest rate risk in the banking book request six prescribed interest rate shock scenarios, as well as frequent model tests and sensitivity analyses. The amount of total capital to be reserved remains at 8 percent. Hence, the economic outcomes under the old and the new standard are comparable.

Note 2. Staikouras (2006) gives an overview of methods.

Note 3. The values of 12% and 15% were chosen to represent the region of the Basel II/BIS-conform Tier 1 year-end capital ratios of Credit Suisse (16.3% in 2009 and 13.3% in 2008) and UBS (15.4% in 2009 and 11.0% in 2008) during the financial crisis (cp. UBS and Credit Suisse annual reports 2008 and 2009).

Note 4. Risk weights are based on the aggregated balance sheet total weights of UBS, Credit Suisse and Canton Bank of Zurich as of the respective annual reports 2008, (14% credit risk, 2% market risk, 2% operational risk).

Note 5. The Basel III capital requirements are accompanied by extensive reporting requirements. The Handbook on Securities Statistics, published by The Bank of International Settlement, demands a four-dimensional reporting on debt securities holdings (BIS 2010). Banks have to classify their debt security holdings with respect to residence (issuer), currency, maturity and interest rate (fixed/variable).

Note 6. $Equity_{min1}$ equals Minimum Total Capital (tier 1 capital plus tier 2 capital).

Note 7. For ease of exposition, longer maturities are extrapolated from simulated monthly rates in terms of a constant liquidity premium factor – positive in the normal term structure, negative for an inverse term structure and zero in the flat term structure.

Note 8. Minimizing $J_T(\theta)$ with respect to θ is equivalent to solving the homogeneous system of equations, $D'(\theta)W_T(\theta)g_T(\theta)=0$. $D(\theta)$ is the Jacobian matrix of $g_T(\theta)$ with respect to θ. In the case of the unrestricted model, the parameters are identified. $J_T(\theta)$ is zero for all choices of $W_T(\theta)$.

Note 9. Datastream files ECUS$1M, ECWGM1M, ECSWF1M, respectively.

Note 10. Datastream files WIUSAM$, WIWGRML, WISWITL, respectively.

Note 11. The only small exceptions are the two 15%-equity simulations for inverse and flat interest rate curves for the period 60 to 120, where IMS 8 generates the largest number of defaults and IMS 1 performs second worst.

Appendix

Table A1. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 12% Equity - interest rate term structure: normal

60 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	1,542	1,412	1,423	1,540
Number of defaults [%]	15.42	14.12	14.23	15.40
Equity capital $_{ACTUAL}$, MV_t ***(Equity)*** **[monetary units]**				
Maximum	105.2186	105.5057	106.0331	105.7956
Minimum	4.7179	5.0020	4.9748	5.1050
Mean	24.8106	25.2805	25.1385	24.7816
Median	22.5273	23.0973	22.9146	22.4928
Standard Deviation	12.1567	12.1960	12.1705	12.1304
Standard Deviation [%]	48.9981	48.2428	48.4138	48.9490
Kurtosis	5.4312	5.3802	5.4195	5.4610
Skewness	1.2109	1.1980	1.2075	1.2201
Equity capital $_{TARGET}$, ***Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	9.7418	9.7980	9.8452	9.8083
Minimum	4.5354	4.5954	4.7402	4.7640
Mean	5.7103	5.7941	5.7691	5.6999
Median	5.5920	5.6798	5.6495	5.5778
Standard Deviation	0.6203	0.6214	0.6100	0.6088
Standard Deviation [%]	10.8621	10.7247	10.5730	10.6811
Kurtosis	5.4221	5.3583	5.5805	5.6123
Skewness	1.2059	1.1926	1.2838	1.2929
Balance Sheet Total [monetary units]				
Maximum	191.4661	192.5707	193.4984	192.7736
Minimum	89.1399	90.3190	91.7828	92.1414
Mean	112.0396	113.6552	113.2069	111.8971
Median	109.8274	111.4948	111.0358	109.6268
Standard Deviation	12.3682	12.4161	12.2051	12.1319
Standard Deviation [%]	11.0391	10.9244	10.7813	10.8420
Kurtosis	8.8708	9.1534	9.3193	9.3984
Skewness	1.7003	1.7429	1.7743	1.7813

120 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	437	393	395	422
Number of defaults [%]	4.37	3.93	3.95	4.22
Total number of defaults	1,979	1,805	1,818	1,962
Total number of defaults [%]	19.79	18.05	18.18	19.62
Equity capital $_{ACTUAL}$, MV_t ***(Equity)*** **[monetary units]**				
Maximum	246.6662	248.9084	248.8449	249.4086
Minimum	5.5237	4.7261	5.1466	5.3175
Mean	42.7466	43.0693	42.7501	42.5531
Median	37.1487	37.4966	37.1683	37.0164
Standard Deviation	25.3866	25.3807	25.3503	25.3248
Standard Deviation [%]	59.3887	58.9300	59.2989	59.5135
Kurtosis	8.1651	8.1226	8.1561	8.2005
Skewness	1.6548	1.6427	1.6498	1.6567
Equity capital $_{TARGET}$, ***Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	18.1844	18.2443	18.3158	18.3043
Minimum	4.5103	4.6529	4.7861	4.8318
Mean	6.6332	6.7163	6.6676	6.6010
Median	6.3472	6.4345	6.3772	6.3118
Standard Deviation	1.2996	1.2934	1.2899	1.2890
Standard Deviation [%]	19.5929	19.2573	19.3459	19.5281
Kurtosis	9.0892	9.2725	9.4321	9.5504
Skewness	1.7364	1.7536	1.7808	1.7919
Balance Sheet Total [monetary units]				
Maximum	340.7305	340.5640	334.7214	335.8107
Minimum	88.6464	90.4078	91.4927	91.9197
Mean	130.1900	131.8212	130.8814	129.6100
Median	124.7474	126.4635	125.3378	124.0526
Standard Deviation	25.6017	25.4803	25.3980	25.3312
Standard Deviation [%]	19.6649	19.3295	19.4053	19.5442
Kurtosis	8.1651	8.1226	8.1561	8.2005
Skewness	1.6548	1.6427	1.6498	1.6567

Table A2. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 12% Equity - interest rate term structure: flat

60 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	1,552	1,425	1,434	1,551
Number of defaults [%]	15.52	14.25	14.34	15.51
Equity capital $_{ACTUAL}$, MV_t (Equity)				
[monetary units]				
Maximum	105.2116	105.5005	106.0309	105.7916
Minimum	4.7086	4.9933	4.9718	5.1018
Mean	24.8212	25.2986	25.1526	24.7946
Median	22.5305	23.1045	22.9216	22.5004
Standard Deviation	12.1541	12.1937	12.1688	12.1279
Standard Deviation [%]	48.9667	48.1993	48.3798	48.9135
Kurtosis	5.4335	5.3826	5.4215	5.4627
Skewness	1.2123	1.1990	1.2079	1.2207
Equity capital $_{TARGET}$, Equity $_{min1/min2}$				
[monetary units]				
Maximum	9.7414	9.7987	9.8451	9.8081
Minimum	4.5343	4.5948	4.7482	4.7700
Mean	5.7116	5.7963	5.7710	5.7014
Median	5.5923	5.6812	5.6500	5.5781
Standard Deviation	0.6195	0.6204	0.6086	0.6077
Standard Deviation [%]	10.8467	10.7032	10.5459	10.6583
Kurtosis	5.4357	5.3763	5.6086	5.6347
Skewness	1.2102	1.1978	1.2936	1.3017
Balance Sheet Total				
[monetary units]				
Maximum	191.4590	192.5848	193.4962	192.7696
Minimum	89.1171	90.3058	91.7770	92.1376
Mean	112.0490	113.6725	113.2209	111.9101
Median	109.8351	111.5162	111.0459	109.6328
Standard Deviation	12.3680	12.4153	12.2036	12.1294
Standard Deviation [%]	11.0380	10.9220	10.7786	10.8385
Kurtosis	8.8785	9.1615	9.3283	9.4034
Skewness	1.7037	1.7469	1.7786	1.7857

120 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	432	395	396	420
Number of defaults [%]	4.32	3.95	3.96	4.20
Total number of defaults	1,984	1,820	1,830	1,971
Total number of defaults [%]	19.84	18.20	18.30	19.71
Equity capital $_{ACTUAL}$, MV_t (Equity)				
[monetary units]				
Maximum	246.6566	248.9013	248.8364	249.4024
Minimum	5.5146	4.7170	5.1401	5.3120
Mean	42.7487	43.1078	42.7991	42.5643
Median	37.1466	37.5289	37.2109	37.0232
Standard Deviation	25.3874	25.3811	25.3490	25.3306
Standard Deviation [%]	59.3875	58.8782	59.2279	59.5113
Kurtosis	8.1675	8.1255	8.1582	8.1976
Skewness	1.6555	1.6433	1.6499	1.6565
Equity capital $_{TARGET}$, Equity $_{min1/min2}$				
[monetary units]				
Maximum	18.1653	18.2248	18.2958	18.2833
Minimum	4.5094	4.6664	4.7875	4.8411
Mean	6.6340	6.7189	6.6708	6.6021
Median	6.3469	6.4358	6.3806	6.3125
Standard Deviation	1.2988	1.2926	1.2890	1.2885
Standard Deviation [%]	19.5784	19.2381	19.3224	19.5169
Kurtosis	9.0886	9.2699	9.4306	9.5394
Skewness	1.7386	1.7557	1.7831	1.7932
Balance Sheet Total				
[monetary units]				
Maximum	340.7601	340.5934	334.7169	335.8045
Minimum	88.6275	90.3987	91.4862	91.9143
Mean	130.1913	131.8597	130.9306	129.6212
Median	124.7419	126.4889	125.4040	124.0661
Standard Deviation	25.6023	25.4815	25.3967	25.3370
Standard Deviation [%]	19.6651	19.3247	19.3971	19.5470
Kurtosis	8.1675	8.1255	8.1582	8.1976
Skewness	1.6555	1.6433	1.6499	1.6565

Table A3. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 12% Equity - interest rate term structure: inverse

60 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	1,569	1,441	1,446	1,564
Number of defaults [%]	15.69	14.41	14.46	15.64
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)*** **[monetary units]**				
Maximum	105.2045	105.4954	106.0287	105.7876
Minimum	4.7418	4.9845	5.2407	5.0986
Mean	24.8432	25.3217	25.1670	24.8095
Median	22.5604	23.1368	22.9265	22.5170
Standard Deviation	12.1510	12.1927	12.1678	12.1245
Standard Deviation [%]	48.9107	48.1510	48.3480	48.8703
Kurtosis	5.4354	5.3825	5.4223	5.4662
Skewness	1.2131	1.1990	1.2086	1.2217
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	9.7411	9.7994	9.8450	9.8079
Minimum	4.5331	4.5941	4.7570	4.7930
Mean	5.7137	5.7990	5.7731	5.7032
Median	5.5939	5.6828	5.6503	5.5784
Standard Deviation	0.6186	0.6191	0.6072	0.6063
Standard Deviation [%]	10.8265	10.6766	10.5171	10.6316
Kurtosis	5.4519	5.3970	5.6381	5.6625
Skewness	1.2147	1.2037	1.3042	1.3121
Balance Sheet Total [monetary units]				
Maximum	191.4519	192.5990	193.4940	192.7656
Minimum	89.0943	90.2925	91.7712	92.1338
Mean	112.0701	113.6966	113.2362	111.9249
Median	109.8570	111.5730	111.0492	109.6384
Standard Deviation	12.3660	12.4141	12.2021	12.1261
Standard Deviation [%]	11.0341	10.9186	10.7758	10.8342
Kurtosis	8.8799	9.1660	9.3403	9.4130
Skewness	1.7056	1.7504	1.7836	1.7908

120 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	431	398	405	419
Number of defaults [%]	4.31	3.98	4.05	4.19
Total number of defaults	2,000	1,839	1,851	1,983
Total number of defaults [%]	20.00	18.39	18.51	19.83
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)*** **[monetary units]**				
Maximum	246.6470	248.8941	248.8278	249.3962
Minimum	5.5054	4.7079	5.1336	5.3066
Mean	42.7859	43.1506	42.8493	42.5831
Median	37.2077	37.5569	37.2577	37.0370
Standard Deviation	25.3933	25.3870	25.3447	25.3315
Standard Deviation [%]	59.3497	58.8335	59.1486	59.4871
Kurtosis	8.1646	8.1241	8.1645	8.2005
Skewness	1.6546	1.6433	1.6511	1.6574
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	18.1460	18.2054	18.2756	18.2621
Minimum	4.5084	4.6858	4.7964	4.8630
Mean	6.6365	6.7220	6.6741	6.6037
Median	6.3505	6.4387	6.3822	6.3124
Standard Deviation	1.2985	1.2919	1.2878	1.2877
Standard Deviation [%]	19.5666	19.2189	19.2959	19.5001
Kurtosis	9.0780	9.2665	9.4344	9.5366
Skewness	1.7384	1.7579	1.7865	1.7961
Balance Sheet Total [monetary units]				
Maximum	340.7899	340.6230	334.7125	335.7983
Minimum	88.6086	90.3896	91.4796	91.9088
Mean	130.2265	131.9030	130.9816	129.6401
Median	124.7993	126.5470	125.4356	124.0646
Standard Deviation	25.6103	25.4875	25.3920	25.3377
Standard Deviation [%]	19.6659	19.3229	19.3859	19.5447
Kurtosis	8.1646	8.1241	8.1645	8.2005
Skewness	1.6546	1.6433	1.6511	1.6574

Table A4. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 15% Equity - interest rate term structure: normal

60 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	579	489	497	554
Number of defaults [%]	5.79	4.89	4.97	5.54
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)***				
[monetary units]				
Maximum	108.1589	108.4629	109.0149	108.7607
Minimum	4.9626	4.7842	5.3057	5.2205
Mean	26.3423	26.8927	26.7506	26.2797
Median	24.2865	24.8569	24.7150	24.2008
Standard Deviation	12.4444	12.4973	12.4553	12.4196
Standard Deviation [%]	47.2413	46.4710	46.5608	47.2594
Kurtosis	5.2153	5.1584	5.2059	5.2416
Skewness	1.1442	1.1277	1.1414	1.1516
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$				
[monetary units]				
Maximum	9.7418	9.7980	9.8452	9.8083
Minimum	4.4064	4.4931	4.7134	4.7640
Mean	5.6469	5.7357	5.7130	5.6392
Median	5.5295	5.6215	5.5848	5.5133
Standard Deviation	0.6249	0.6247	0.6086	0.6072
Standard Deviation [%]	11.0664	10.8913	10.6536	10.7674
Kurtosis	5.3838	5.3427	5.6605	5.6995
Skewness	1.2006	1.1930	1.3284	1.3468
Balance Sheet Total				
[monetary units]				
Maximum	191.4661	192.5707	193.4984	192.7736
Minimum	86.6045	86.8139	89.1567	89.1243
Mean	110.5712	112.2228	111.8116	110.4246
Median	108.5465	110.2703	109.7577	108.3583
Standard Deviation	12.6750	12.7392	12.4954	12.4222
Standard Deviation [%]	11.4632	11.3517	11.1754	11.2495
Kurtosis	8.9980	9.3006	9.4752	9.5589
Skewness	1.7337	1.7826	1.8169	1.8279

120 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	314	279	296	338
Number of defaults [%]	3.14	2.79	2.96	3.38
Total number of defaults	893	768	793	892
Total number of defaults [%]	8.93	7.68	7.93	8.92
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)***				
[monetary units]				
Maximum	249.6999	251.8487	251.7699	252.3542
Minimum	5.1747	5.6907	5.5518	5.4879
Mean	43.0204	43.5230	43.2581	42.9073
Median	37.5929	38.1724	37.8360	37.4493
Standard Deviation	25.3606	25.3533	25.3338	25.2851
Standard Deviation [%]	58.9501	58.2527	58.5642	58.9295
Kurtosis	8.0512	8.0251	8.0433	8.0945
Skewness	1.6353	1.6286	1.6323	1.6416
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$				
[monetary units]				
Maximum	18.1844	18.2443	18.3158	18.3043
Minimum	4.3328	4.5410	4.6911	4.8318
Mean	6.5045	6.5952	6.5512	6.4769
Median	6.2128	6.3010	6.2588	6.1837
Standard Deviation	1.2882	1.2807	1.2768	1.2762
Standard Deviation [%]	19.8050	19.4187	19.4898	19.7036
Kurtosis	9.0902	9.3128	9.4726	9.5638
Skewness	1.7482	1.7792	1.8083	1.8161
Balance Sheet Total				
[monetary units]				
Maximum	340.7305	340.5640	334.7214	335.8107
Minimum	85.1574	88.9909	89.7439	89.6205
Mean	127.4628	129.2267	128.3836	126.9965
Median	122.0763	123.8321	123.0110	121.5344
Standard Deviation	25.5781	25.4625	25.3803	25.2904
Standard Deviation [%]	20.0671	19.7038	19.7691	19.9143
Kurtosis	8.0512	8.0251	8.0433	8.0945
Skewness	1.6353	1.6286	1.6323	1.6416

Table A5. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 15% Equity - interest rate term structure: flat

60 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	583	501	506	565
Number of defaults [%]	5.83	5.01	5.06	5.65
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)***				
[monetary units]				
Maximum	108.1518	108.4577	109.0127	108.7568
Minimum	4.9499	4.9704	5.3009	5.2172
Mean	26.3456	26.9137	26.7646	26.2935
Median	24.2899	24.8799	24.7373	24.2099
Standard Deviation	12.4429	12.4927	12.4520	12.4152
Standard Deviation [%]	47.2297	46.4176	46.5243	47.2176
Kurtosis	5.2164	5.1615	5.2083	5.2450
Skewness	1.1447	1.1286	1.1422	1.1526
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$				
[monetary units]				
Maximum	9.7414	9.7987	9.8451	9.8081
Minimum	4.4054	4.4923	4.7369	4.7700
Mean	5.6491	5.7393	5.7160	5.6417
Median	5.5303	5.6237	5.5861	5.5141
Standard Deviation	0.6233	0.6226	0.6063	0.6051
Standard Deviation [%]	11.0336	10.8480	10.6078	10.7253
Kurtosis	5.4121	5.3766	5.7080	5.7442
Skewness	1.2084	1.2026	1.3428	1.3612
Balance Sheet Total				
[monetary units]				
Maximum	191.4590	192.5848	193.4962	192.7696
Minimum	86.5849	88.0086	89.1519	89.1195
Mean	110.5750	112.2452	111.8258	110.4385
Median	108.5548	110.2919	109.7680	108.3740
Standard Deviation	12.6738	12.7339	12.4920	12.4177
Standard Deviation [%]	11.4617	11.3447	11.1709	11.2440
Kurtosis	9.0096	9.3186	9.4969	9.5786
Skewness	1.7377	1.7879	1.8234	1.8345
120 Periods	**IMS 1**	**IMS 2**	**IMS 3**	**IMS 8**
Defaults				
Number of defaults	317	278	296	338
Number of defaults [%]	3.17	2.78	2.96	3.38
Total number of defaults	900	779	802	903
Total number of defaults [%]	9.00	7.79	8.02	9.03
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)***				
[monetary units]				
Maximum	249.7295	251.8416	251.7613	252.3479
Minimum	5.1644	5.6836	5.5491	5.4854
Mean	43.0373	43.5553	43.2819	42.9288
Median	37.6115	38.2066	37.8518	37.4726
Standard Deviation	25.3604	25.3530	25.3346	25.2832
Standard Deviation [%]	58.9266	58.2088	58.5339	58.8956
Kurtosis	8.0521	8.0260	8.0431	8.0982
Skewness	1.6354	1.6285	1.6320	1.6425
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$				
[monetary units]				
Maximum	18.1653	18.2248	18.2958	18.2833
Minimum	4.3318	4.5402	4.6996	4.8411
Mean	6.5067	6.5982	6.5539	6.4791
Median	6.2148	6.3040	6.2595	6.1844
Standard Deviation	1.2870	1.2793	1.2753	1.2748
Standard Deviation [%]	19.7789	19.3881	19.4580	19.6755
Kurtosis	9.0964	9.3213	9.4837	9.5728
Skewness	1.7512	1.7830	1.8130	1.8209
Balance Sheet Total				
[monetary units]				
Maximum	340.7601	340.5934	334.7169	335.8045
Minimum	85.1371	88.9838	89.7385	89.6162
Mean	127.4800	129.2597	128.4076	127.0181
Median	122.0938	123.8916	123.0250	121.5488
Standard Deviation	25.5786	25.4622	25.3810	25.2885
Standard Deviation [%]	20.0648	19.6985	19.7659	19.9094
Kurtosis	8.0521	8.0260	8.0431	8.0982
Skewness	1.6354	1.6285	1.6320	1.6425

Table A6. Summary statistics of simulation results after 5 and 10 years (t=60 and 120 periods) 15% Equity - interest rate term structure: inverse

60 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	1,569	1,441	1,446	1,564
Number of defaults [%]	15.69	14.41	14.46	15.64
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)*** **[monetary units]**				
Maximum	105.2045	105.4954	106.0287	105.7876
Minimum	4.7418	4.9845	5.2407	5.0986
Mean	24.8432	25.3217	25.1670	24.8095
Median	22.5604	23.1368	22.9265	22.5170
Standard Deviation	12.1510	12.1927	12.1678	12.1245
Standard Deviation [%]	48.9107	48.1510	48.3480	48.8703
Kurtosis	5.4354	5.3825	5.4223	5.4662
Skewness	1.2131	1.1990	1.2086	1.2217
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	9.7411	9.7994	9.8450	9.8079
Minimum	4.5331	4.5941	4.7570	4.7930
Mean	5.7137	5.7990	5.7731	5.7032
Median	5.5939	5.6828	5.6503	5.5784
Standard Deviation	0.6186	0.6191	0.6072	0.6063
Standard Deviation [%]	10.8265	10.6766	10.5171	10.6316
Kurtosis	5.4519	5.3970	5.6381	5.6625
Skewness	1.2147	1.2037	1.3042	1.3121
Balance Sheet Total [monetary units]				
Maximum	191.4519	192.5990	193.4940	192.7656
Minimum	89.0943	90.2925	91.7712	92.1338
Mean	112.0701	113.6966	113.2362	111.9249
Median	109.8570	111.5730	111.0492	109.6384
Standard Deviation	12.3660	12.4141	12.2021	12.1261
Standard Deviation [%]	11.0341	10.9186	10.7758	10.8342
Kurtosis	8.8799	9.1660	9.3403	9.4130
Skewness	1.7056	1.7504	1.7836	1.7908

120 Periods	IMS 1	IMS 2	IMS 3	IMS 8
Defaults				
Number of defaults	431	398	405	419
Number of defaults [%]	4.31	3.98	4.05	4.19
Total number of defaults	2,000	1,839	1,851	1,983
Total number of defaults [%]	20.00	18.39	18.51	19.83
Equity capital $_{ACTUAL}$***, MV*** $_t$ ***(Equity)*** **[monetary units]**				
Maximum	246.6470	248.8941	248.8278	249.3962
Minimum	5.5054	4.7079	5.1336	5.3066
Mean	42.7859	43.1506	42.8493	42.5831
Median	37.2077	37.5569	37.2577	37.0370
Standard Deviation	25.3933	25.3870	25.3447	25.3315
Standard Deviation [%]	59.3497	58.8335	59.1486	59.4871
Kurtosis	8.1646	8.1241	8.1645	8.2005
Skewness	1.6546	1.6433	1.6511	1.6574
Equity capital $_{TARGET}$***, Equity*** $_{min1/min2}$ **[monetary units]**				
Maximum	18.1460	18.2054	18.2756	18.2621
Minimum	4.5084	4.6858	4.7964	4.8630
Mean	6.6365	6.7220	6.6741	6.6037
Median	6.3505	6.4387	6.3822	6.3124
Standard Deviation	1.2985	1.2919	1.2878	1.2877
Standard Deviation [%]	19.5666	19.2189	19.2959	19.5001
Kurtosis	9.0780	9.2665	9.4344	9.5366
Skewness	1.7384	1.7579	1.7865	1.7961
Balance Sheet Total [monetary units]				
Maximum	340.7899	340.6230	334.7125	335.7983
Minimum	88.6086	90.3896	91.4796	91.9088
Mean	130.2265	131.9030	130.9816	129.6401
Median	124.7993	126.5470	125.4356	124.0646
Standard Deviation	25.6103	25.4875	25.3920	25.3377
Standard Deviation [%]	19.6659	19.3229	19.3859	19.5447
Kurtosis	8.1646	8.1241	8.1645	8.2005
Skewness	1.6546	1.6433	1.6511	1.6574