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How correlated are changes in banks' net interest income and in their present value?

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Abstract

We use portfolios of passive investment strategies to replicate the interest risk of banks' banking books. The following empirical statements are derived: (i) Changes in banks' present value and in their net interest income are highly correlated, irrespective of the banks' portfolio composition. (ii) However, banks' portfolio composition has a huge impact on the ratio of changes in net interest income relative to changes in present value.

Keywords: Interest rate risk; term transformation; interest income; change in present value

JEL classification: G11, G21

Non-technical summary

There are two parallel indicators for measuring banks' interest rate risk, namely the losses in present value of the interest rate portfolio and the decline in net interest income. In principle, both indicators should display the same risk, i.e. the risk arising from the different maturities of the banks' assets and liabilities.

This paper investigates the extent to which these two indicators are really co-moving. We look at two aspects: We determine the correlation between changes in the present value and in the net interest income and, in addition, we estimate the expected decrease in net interest income in the event that the present value of the interest rate portfolio goes down by one euro.

The investigation is composed of two steps. First, we analyse the dynamics of the term structure of German government bonds. It turns out that the movement of the term structure can be very precisely described using three parameters. In the second step, these three parameters are used to investigate passive investment strategies. These passive investment strategies consist in revolvingly investing in risk-free bonds of a certain maturity. Using portfolios based on these investment strategies, we want to track the business of banks engaged in commercial banking, i.e. taking short-term deposits and granting long-term loans.

On the basis of a study on the term structure of German government bonds for the period January 1980 to June 2010, we derive the following statements:

- Changes in the present value of the interest rate portfolio and changes in the net interest income are highly correlated, irrespective of the maturities of the banks' assets and liabilities.

- The expected decrease in net interest income given a loss of one euro in the present value of the interest rate portfolio depends to a large extent on the composition of the banks' assets and liabilities.

Nichttechnische Zusammenfassung

Zur Messung des Zinsänderungsrisikos von Banken gibt es zwei nebeneinanderstehende Indikatoren, nämlich die barwertigen Verluste im Zinsbuch auf der einen Seite und die Minderung des Zinsüberschusses auf der anderen Seite. Grundsätzlich sollten die beiden Indikatoren dasselbe Risiko abbilden, d.h. das Risiko, das sich aus den unterschiedlichen Laufzeiten von Aktiva und Passiva der Banken ergibt.

Dieses Papier untersucht, inwieweit diese beiden Indikatoren zur Messung des Zinsänderungsrisikos tatsächlich gleichlaufend sind. Wir betrachten zwei Aspekte: Zum einen wird die Korrelation bestimmt zwischen der Änderung im Barwert und der Änderung im Zinsüberschuss; zum anderen wird der Rückgang des Zinsüberschusses abgeschätzt im Falle, dass der Barwert des Zinsbuchs um einen Euro fällt.

Die Untersuchung besteht aus zwei Schritten: Zunächst wird die Dynamik der Zinsstrukturkurve deutscher Staatsanleihen untersucht, wobei sich herausstellt, dass sich die Bewegung der Zinsstrukturkurve mit Hilfe von drei Parametern sehr genau beschreiben lässt. Diese drei Parameter werden dann im zweiten Schritt zur Untersuchung von passiven Handelsstrategien genutzt. Diese passiven Handelsstrategien bestehen darin, revolvierend in risikolose Anleihen einer bestimmten Laufzeit zu investieren. Mit Portfolios aus diesen Handelsstrategien soll das traditionelle Geschäft der Banken abgebildet werden, das heißt das Annehmen kurzlaufender Kundeneinlagen und das Herauslegen langfristiger Kredite.

Auf Basis einer Untersuchung für die Zinsstrukturkuve deutscher Staatsanleihen für den Zeitraum Januar 1980 bis Juni 2010 ergeben sich folgende Aussagen:

- Änderungen im Barwert des Zinsbuchs und Änderungen in dem Zinsüberschuss sind hoch korreliert, und zwar unabhängig davon, welche Laufzeiten auf der Aktivseite und der Passivseite der Banken unterstellt werden.
- Der erwartete Rückgang des Zinsüberschusses je Euro Verlust an Barwert im Zinsbuch hängt sehr stark davon ab, wie sich die Aktiva und Passiva der Banken zusammensetzen.

Contents

How correlated are changes in banks' net interest income and in their present value?[1]

1 Introduction

Changes in the term structure have an impact on both the present value of banks' equity and banks' net interest income. Qualitatively, changes in equity and net interest income should point in the same direction. It may be argued that, when the interest rate increases, the banks' financial assets and the financial liabilities both decrease in present value. As the maturities on the asset side tend to be longer than on the liability side, the losses in present value on the asset side are greater than the losses on the liability side. Hence, the present value of the equity, as the residual, diminishes when the interest rate level goes up. The impact on the banks' interest income is as follows: Since, as stated above, the maturities on the asset side are greater than on the liability side, there is much more renewed business on the liability side than on the asset side. For instance, assume that a bank hands out loans with an initial maturity of ten years and collects deposits with a maturity of one year. In each year, only ten per cent of the loans mature and are replaced by new ones, whereas the entire amount of liabilities is replaced in one year. Therefore, changes in the interest rate level have a much stronger effect on the interest expenses than on the interest income, because only renewed business is affected by changes in the interest rates. As a result, the net interest income goes down, when the interest rate increases.

However, the story is not as simple as described above. A single interest rate does not exist. Instead, there is an entire curve of interest rates, depending on the different maturities. It is possible to think of changes in the yield curve which barely affect the present value of a bank, but which have a strong impact on its net interest income – for instance, a change in the steepness of the term structure. Conversely, changes in the long-term interest rates hardly affect the net interest income (at least in the short run); they do, however, have a huge impact on the present value of banks' equity.

The aim of this paper is to investigate the relationship between changes in banks' interest income and in banks' present value. For this purpose, we replicate the banks' cash flows in their banking book using investment strategies based on passive bond portfolios. We

[1]I thank the participants at the Bundesbank's Research Seminar. The opinions expressed in this paper are those of the author and do not necessarily reflect the opinions of the Deutsche Bundesbank.

derive closed-form expressions for the effect of marginal changes in the term structure on the investment strategies' present value and interest income. In addition, we condense the dynamics of the entire term structure into three parameters. Using these two analytical tools, we investigate the relationship between changes in present value and in net interest income of various stylized banks. The empirical results can be summarized in two core statements: (i) Changes in banks' present value and in their net interest income are highly correlated, irrespective of the banks' portfolio composition. (ii) However, banks' portfolio composition has a huge impact on the extent of changes in net interest income relative to changes in present value.

The structure of the paper is as follows: Section 2 gives an overview of the literature in this field. In Section 3, we describe the central analytical tools. Section 4 deals with the empirical fit of the model, and in Section 5 we report the empirical results. Section 6 concludes.

2 Literature

This paper contributes to three strands of literature. The first strand is about the factors explaining movements in the term structure. Litterman and Scheinkman (1991), Knez et al. (1994) and Bliss (1997) identify three factors, namely shift, change in slope and in curvature, that account for a large share of changes in the term structure. The authors mentioned above apply these results to improve the performance of hedges of bond portfolios. We, instead, combine these factors with the parametric model of the term structure by Nelson and Siegel (1987) and transform the factors into parameter changes of this model.

The second strand deals with the net interest income of banks and the term structure. English (2002), Maudos and de Guevara (2004) and Maudos and Solís (2009) introduce the steepness of the term structure as an explanatory variable into regressions with the net interest income as the dependent variable. Our contribution is to analyse as well the impact of shifts and changes in the curvature of the yield curve on the net interest income. Moreover, we provide closed-form expressions and quantify the relative impact of the three types of term structure movements (which we do also for the change in present value of the banks' equity).

As just mentioned, we also contribute to the question of how changes in the term structure affect the present value of banks' equity. Questions like this are often the subject of stress testing exercises (See, for instance, Deutsche Bundesbank (2006)). There are also many papers that estimate the impact of parallel shifts in the term structure from the banks' balance sheets (See, for instance, Sierra and Yeager (2004) and Entrop et al. (2008)). Using stock market data, Czaja et al. (2009) analyse the impact of level, slope and curvature on the present value of the banks' equity. To our knowledge, there has been no paper so far that investigates the relationship of changes in the banks' present value and their net interest income.

3 Components

In this section, we present the two main building blocks of the analysis in this paper: the dynamics of the term structure and the passive investment strategies. In Subsection 3.1, we show how to describe the dynamics of the entire yield curve with three parameters and how these parameters can be obtained from principal component analysis (PCA). Subsection 3.2 is about the question of how the present value and the interest income of the passive investment strategies are affected by marginal movements of the term structure.

3.1 Term Structure

The term structure of interest rates gives the yield of riskless zerobonds for each maturity, i.e. in each point in time, there is not a single interest rate level, but a whole curve. To make the problem more manageable, we do not deal with the whole curve, but with parameters that describe this curve. The approach of Nelson and Siegel (1987) describes the entire yield curve with four parameters. A further development is the approach by Svensson (1994) which uses six parameters to describe the curve. In practice, it turns out that the Nelson-Siegel approach fits rather well and that the Svensson approach tends to over-fitting. Therefore, we use the Nelson-Siegel approach.

$$r(M) = \beta_0 + \beta_1 \frac{1-\exp(-\lambda M)}{M\lambda} + \beta_2 \left(\frac{1-\exp(-\lambda M)}{M\lambda} - \exp(-\lambda M) \right) \quad \lambda > 0, \tag{1}$$

where M is the maturity [in years], $r(M)$ is the yield of risk-free zero-bonds and β_0, β_1, β_2 and λ are parameters that govern the yield curve. The parameter β_0 is said to measure the long-term interest rate, β_1 gives the steepness of the yield curve and β_2 its curvature.

Apart from the parameter λ, all parameters enter the equation above in a linear way. To keep the analytical results tractable, we set the parameter λ constant. Diebold and Li (2006) use the same simplification and they find that this simplification does not come at much cost regarding the fit of the term structure. Setting the parameter λ constant to $\bar{\lambda} = 0.0609 \cdot 12$ (as Diebold and Li (2006) did), we can express changes in the term structure as linear combinations of $\Delta\beta_0$, $\Delta\beta_1$ and $\Delta\beta_2$:

$$\Delta r(M) = \Delta\beta_0 + \Delta\beta_1 \frac{1-\exp(-\bar{\lambda}M)}{M\bar{\lambda}} + \Delta\beta_2 \left(\frac{1-\exp(-\bar{\lambda}M)}{M\bar{\lambda}} - \exp(-\bar{\lambda}M) \right) \quad (2)$$

Next, we turn to the empirically observed term structure. Let

$$\Delta r_t(M) := r_t(M) - r_{t-1}(M) \quad (3)$$

be the change in the interest rate of maturity M in time t. The vector Δr_t includes the corresponding changes of different maturities. Assume there are n different maturities. Without loss of generality, we set n equal to 20 and use maturities in an equal step of half a year, i.e. the shortest maturity is 0.5 years and longest maturity is ten years. Using principal component analysis (PCA), we can express the change in interest rates as follows:

$$\Delta r_t = L \; f_t \quad (4)$$

where $L \in R^{n\times n}$ is the matrix of orthogonal factor loadings and f_t is a vector of the n factors. We partition the matrix $L = (L_{(1)}L_{(2)})$ and the vector $f_t' = (f_{t,(1)}' \; f_{t,(2)}')$:

$$\Delta r_t = L_{(1)}f_{t,(1)} + L_{(2)}f_{t,(2)} \quad (5)$$

We collect the three most important factors in the matrix $L_{(1)}$ and the 17 remaining ones in the matrix $L_{(2)}$.

Using the simplified Nelson and Siegel (1987) representation of the term structure, we can express the change in the interest rates as

$$\Delta r_t = H \; \Delta\beta_t, \quad (6)$$

where H is a matrix of $n\times 3$; its entries correspond to the factors in Equation (2). The first row of the matrix H, for example, consists of (1, 0.838, 0.144). The vector $\Delta\beta_t$ includes the changes of the parameters, i.e. $\Delta\beta_{0,t}$, $\Delta\beta_{1,t}$ and $\Delta\beta_{2,t}$. Combining (5) and (6), we can extract the changes in the parameters $\Delta\beta_{0,t}$, $\Delta\beta_{1,t}$ and $\Delta\beta_{2,t}$ from the observed yield curve (See Appendix 6):

$$\Delta\beta_t = \left(L_{(1)}' H \right)^{-1} f_{t,(1)} \quad (7)$$

Equation (7) makes it possible to translate the three most important factors of the change in interest rates into the changes in three parameters that govern the yield curve (as displayed in Equation (2)). Note that the three factors $f_{t,(1)}$ and change in the three parameters, $\Delta\beta_t$ include the same information. In Subsection 4.1, we give empirical evidence that the omitted components can be neglected.

3.2 Passive Investment Strategy

We analyse investment strategies $S(M)$ which consist in revolvingly investing in par-yield bonds of maturity M. The interest is taken away and, when the principal is repaid, it is reinvested in the present par-yield bond of maturity M. For instance, assume the maturity M to be equal to two years and the timely discretion to be one month. In this setting, 1/24 euro is invested each month in par-yield bonds of (initial) maturity of two years. The banking book can be seen as a portfolio of these investment strategies (See Memmel (2008)), because these investment strategies fit with the continuous business model that characterizes commercial banking (See Subsection 4.2 for an empirical justification).

We investigate the impact of marginal movements in the term structure on the interest income and present value of these investment strategies. The setting of the movement in the yield curve is as follows: The change in the yield curve happens exactly at the beginning of the financial year in $t = 0$. We investigate the effects on the Strategy $S(M)$ of the change in the term structure with respect to two measures: the interest income of the following 12 months and the change in present value.

We start with the change in interest income $\Delta IC(M)$: The interest income of the strategy $S(M)$ is affected by two factors: the average amount of renewed business in one year $N(M)$ and the change in interest rates of par-yield bonds $\Delta c(M)$.

$$\Delta IC(M) = N(M)\ \Delta c(M) \tag{8}$$

with

$$N(M) = \int_0^1 n(M,t)dt \tag{9}$$

and

$$n(t,M) = \begin{cases} t/M & t < M \\ 1 & t \geq M \end{cases}, \tag{10}$$

i.e. $n(t,M)$ is the fraction of new business in t. Note that interest on interest is not accounted for. In Appendix 6, we give the formula for the case of compound interest.

It is only possible to derive closed-form solutions for the derivatives of (8) when dealing with a term structure that is flat at $t = 0$, i.e. we determine the derivative at $\beta_1 = 0$, $\beta_2 = 0$ and, therefore, $c = r$. The results are given in Appendix 6. To avoid lengthy expressions, we display the derivatives under the additional assumption that $\beta_0 \to 0$:

$$\frac{\partial IC(M)}{\partial \beta_0} = N(M) \tag{11}$$

$$\frac{\partial IC(M)}{\partial \beta_1} = N(M)\ \frac{1 - \exp(-\bar{\lambda} M)}{M\bar{\lambda}} \tag{12}$$

$$\frac{\partial IC(M)}{\partial \beta_2} = N(M)\ \left(\frac{1 - \exp(-\bar{\lambda} M)}{M\bar{\lambda}} - \exp(-\bar{\lambda} M)\right) \tag{13}$$

with (See Appendix 6):

$$N(M) = \begin{cases} 1 - 1/2M & M < 1 \\ 1/(2M) & M \geq 1 \end{cases} \tag{14}$$

The change in interest income depends crucially on the amount of renewed business in the year that follows the change in the term structure. When one invests revolvingly in par-yield bonds of one year of initial maturity $M = 1$, the weighted average of new business $N(M)$ is 0.5 (See Equation (14)), this means that, when the respective interest rate goes up by 1 percentage point, the interest income increases by 1/2 percentage point. Note that, due to the simplifying assumptions, the second factors in the Equations (12) and (13) are identical to the corresponding factors in Equation (2).

Now, we turn to the analysis of the present value of the investment strategies $S(M)$. The present value of the strategy $S(M)$ is the present value of the cash flow of the underlying former (and the present) par-yield bond, i.e.

$$PV(M) = \int_0^M CF(t)\ \exp(-r(t)\ t)dt \tag{15}$$

with

$$CF(t) = \frac{1}{M} + c\left(1 - \frac{t}{M}\right) \quad 0 \leq t \leq M \tag{16}$$

In each period dt, the redemption of the former par-yield bonds yields $1/M\ dt$. In addition, there are coupon payments of $c\ dt$ of those bonds that have not reached their redemption. In time t, the share of bonds not yet redeemed is $1 - t/M$.

At $\beta_1 = 0$ and $\beta_2 = 0$ and $c = r$, we can express partial derivatives as closed-form expressions. Again, we make the additional assumption $\beta_0 \to 0$ and obtain (See Appendix 6 for the case of arbitrary β_0):

$$\frac{\partial PV(M)}{\partial \beta_0} = -\frac{M}{2} \tag{17}$$

$$\frac{\partial PV(M)}{\partial \beta_1} = \frac{1}{M\bar{\lambda}^2}\left(1 - \exp(-\bar{\lambda}M) - \bar{\lambda}M\right) \tag{18}$$

$$\frac{\partial PV(M)}{\partial \beta_2} = \frac{2}{M\bar{\lambda}^2}\left(1 - \exp(-\bar{\lambda}M) - \bar{\lambda}M\right) + \frac{1 - \exp(-\bar{\lambda}M)}{\bar{\lambda}} \tag{19}$$

Equation (17) can be interpreted as follows: The duration of the Strategy $S(M)$ is roughly one half of the Maturity M.[2] For instance, when one invests revolvingly in par-yield bonds of ten years of initial maturity, the modified duration is about five (the exact value at $r = 5\%$ is 4.26).

The change in interest income and in present value can be expressed as a linear function of $\Delta\beta$:

$$\Delta IC(M) = \frac{\partial IC(M)}{\partial \beta_0}\Delta\beta_0 + \frac{\partial IC(M)}{\partial \beta_1}\Delta\beta_1 + \frac{\partial IC(M)}{\partial \beta_2}\Delta\beta_2 \tag{20}$$

and

$$\Delta PV(M) = \frac{\partial PV(M)}{\partial \beta_0}\Delta\beta_0 + \frac{\partial PV(M)}{\partial \beta_1}\Delta\beta_1 + \frac{\partial PV(M)}{\partial \beta_2}\Delta\beta_2 \tag{21}$$

4 Empirical Fit of the Model

The analysis in this paper is based on two crucial assumptions: (i) The dynamics of the term structure can be accurately described by the simplified version of the Nelson and Siegel (1987) model, and (ii) the banks do not abruptly change their exposure to interest rate risk (business model much affected by proprietary trading), but adjust their exposure gradually (business model dominated by commercial banking). To investigate the validity of the first assumption, we run a principal component analysis (PCA) of the changes in the interest rates of different maturities (See Subsection 4.1). In Subsection 4.2, we analyze how quickly banks adjust their exposure to interest rate risk.

4.1 Principal component analysis (PCA) of the Term Structure

We use monthly data from January 1980 to June 2010 of zero bond yields derived from German listed government bonds. The data are provided by the Deutsche Bundesbank which uses the method according to Svensson (1994) to derive the yield curve from listed government bonds. We carry out the principal component analysis as described in Subsection 3.1. We use 12-month changes in the yield curve; we choose this time span, because we

[2] The exact duration is given in Appendix 6 and is slightly smaller.

want to investigate traditional commercial banking (and not proprietary trading), where this time span seems to be appropriate. In addition, the calibration of the regulation for interest rate risk in the banking book is also based on one-year changes of interest rates (See Basel Committee on Banking Supervision (2004)). Table 1 gives the percentage of explained variation of the three most important components. We see that the cumulative

Component	Explained variation	
	single	cumulated
1st	91.36%	91.36%
2nd	7.67%	99.03%
3rd	0.82%	99.85%
Rest (4th-20th)	0.15%	100.00%

Table 1: PCA of the one-year change in interest rates. Maturities from 0.5 to 10 years in steps of half a year. Monthly data from 1/1980 to 6/2010.

explained variation of the first three components is 99.85% of the variation, i.e. the other 17 components explain only 0.15%. Since the parameters $\Delta\beta$ are a linear transformation of the three principal factors (See Equation (7)), the neglected explained variation of the simplified Nelson-Siegel model is also 0.15%. This result is an empirical justification for the use of the linear three-factor model. Even with two factors the loss in explained variation is less than one percent. For the US, Bliss (1997) finds comparable percentages of explained variation. For the period January 1970 to December 1995, the three factors account for 95.3% of the variation. However, he uses monthly changes in interest rates, whereas, in this paper, we use yearly changes.

Figure 1 shows the loadings of the first three factors. The first component is an upward shift of the yield curve; it is not a parallel shift – instead, interest rates of shorter maturity are shifted more strongly. This is in line with the empirical observation that interest rates of shorter maturities are more volatile. The second component is a change in the steepness of the term structure and the third component a change in the yield curve's curvature, with maximal impact at 2.5 years. The empirical finding that the three most important components of the change in the term structure correspond to a shift, a change in the steepness and a change in the curvature, is an empirical justification for the Nelson and Siegel (1987) model, where these kinds of movements were imposed. With the PCA, we find this structure without imposing it. Note, however, that the matrix $(L'_{(1)}H)^{-1}$, which turns the three factors into parameter changes of the Nelson-Siegel model (See Equation (7)), is far from a unity or diagonal matrix. This means that there is no one-to-one correspondence between the three factors and the three parameter changes – for instance, the first factor does not correspond to changes in the parameter β_0.[3]

To sum up, with only tiny loss in accuracy, the changes in the yield curve can be summarized in three factors: shift, change in steepness and in curvature. These factors can be translated into changes in the parameters of the simplified Nelson-Siegel model.

4.2 Modeling Commercial Banking

To analyze how quickly banks adjust their exposure to interest rate risk, we investigate estimates for the systematic component of the change in the German banks' exposure to interest rate risk (See Memmel (2011)). We compare these changes with two benchmarks. The first benchmark is the difference between the yields of ten-year and one-year government bonds. The second benchmark consists of the return difference of the revolving investment strategies for ten and one year maturity, respectively. If banks' business model is strongly impacted by proprietary trading (i.e. the application of many interest rate derivatives and the attempt at exploitation of (expected) term structure movements), the banks' exposure to interest rate risk will move in sync with the first benchmark, i.e. the current steepness of the term structure. If, instead, banks adjust their exposure to interest rate risk mainly by changing the maturity of their renewed business, the second benchmark, i.e. the investment strategies described in this paper, is a suitable means of modeling the banks interest rate risk.

In Figure 2, we show (for the period September 2005 to December 2009) the cumulative estimated change in the banks' exposure to interest rate risk and the two benchmarks. The estimated change in exposure is much closer to the second benchmark than to the first one. This finding provides evidence that German banks gradually adjust their exposure to interest rate risk and that, therefore, the revolving investment strategies can be believed to accurately capture the banks' business model and their attitude towards interest rate

[3]Bliss (1997) also derives three factors that explain a large percentage of changes in US interest rates. He makes an additional adjustment: He rotates the components so that the first component is as close as possible to a parallel shift.

risk. The results of Memmel (2008) can be seen as additional evidence; In an empirical study for German savings and cooperative banks, he finds that the banks' interest income and expenses can be suitably modeled with the revolving investment strategies described in this paper. Note that the sample for the estimation of the change in exposure to interest rate risk was very much dominated by the small and medium-sized German cooperative and saving banks. Large banks may have a different attitude towards exposure to interest rate risk.

5 Empirical Results

5.1 Impact on interest income and on present value

Using the Equations (20) and (21), we can determine the change in interest income and the change in present value, respectively. Note that we use Equations (38) and (40) to calculate the amount of new business $N(M)$ (i.e. we take interest on interest into account) and that we use the more precise derivatives from the appendices (rather than the limits in the main text). The changes in the parameters β_0 to β_2 are derived from Equation (7) and the factors from the principal component analysis. We obtain a time series of changes in present value and of changes in interest income for each maturity from half a year to ten years. In Figure 3, the 99th percentile of the changes in present value and interest income are displayed (using one-year changes of interest rates). We see that the impact of the changes in the term structure on the present value and on the interest income is quite different. Whereas the interest income of the strategies with short maturities is most affected, we find the opposite effect with respect to the present value. This finding is in line with the observation in stress tests that the losses in the banks' present value are mainly driven by the changes in the long-term interest rates (See, for instance, Deutsche Bundesbank (2006)).

The change in present value $\Delta PV_t(M)$ and the change in interest income $\Delta IC_t(M)$ are linear combinations of the three factors $f_{t,1}$, $f_{t,2}$ and $f_{t,3}$ of the principal component analysis. In addition, the three factors are, by construction, mutually uncorrelated. Therefore, we can break down the variance of the change in present value and interest income, respectively, into shares that are explained by the different factors. This variance breakdown is shown in Table 2. Concerning changes in present value, the first factor accounts for up to

98.8% of the variation, especially for investment strategies of longer maturities. But even for the shortest maturity under consideration (half a year) the share is about two-thirds. With respect to changes in interest income, we see a maximum impact of the first factor (more than 99% explained variation) at a maturity of four years. For very short and very long maturities the share is still more than three quarters. Apart from short maturities, the impact of the second (and third) factor is very low for both the change in interest income and in present value.

We can summarize the findings as follows: With respect to interest income, investment strategies of short maturity are much more affected by a change in the term structure than strategies with long maturities. Concerning the present value, the opposite is true. The first factor, i.e. the shift of the yield curve, has by far the largest impact on both the change in interest income and the change in present value.

5.2 Portfolios

Concerning their interest rate risk, commercial banks can be seen as a portfolio of the investment strategies with different maturities. We investigate a portfolio that is long in the strategy $S(M_L)$ and short in the strategy of $S(M_S)$, i.e. the bank hands out loans of M_L years of initial maturity and uses deposits of M_S years of maturity.

For instance, for $M_L = 10$ and $M_S = 1$ year, respectively, (and for an interest rate level of 5%, i.e. $\beta_0 = 0.05$), we derive the following linear relationship for the interest income and the present value of the portfolio P mentioned above:

$$\Delta IC_t(P) = -0.139 \cdot f_{t,1} + 0.205 \cdot f_{t,2} + 0.072 \cdot f_{t,3} \qquad (22)$$

$$\Delta PV_t(P) = -0.866 \cdot f_{t,1} - 0.396 \cdot f_{t,2} + 1.272 \cdot f_{t,3} \qquad (23)$$

Concerning the change in interest income, the first, second and third factors account for 84.4% and 15.4% and 0.2%, respectively. The corresponding figures for the change in present value are 96.4%, 1.69% and 1.86%.

First, we explain the impact of the first factor: The coefficients for the first factor are negative in both equations, i.e. in (22) and in (23). An upward shift of the yield curve reduces the present value of both the long position and the short position of the portfolio. Since the maturity of the long-position is much longer than the maturity of the short position, the effects on the long-position are much stronger than those on the short-position.

That is why the net impact on the portfolio's present value is clearly negative. Concerning the impact of the first factor on the portfolios' interest income, it is possible to argue as follows: The interest income and the interest expenses increase when the interest rates go up. Owing to the shorter maturity of the short position, there is much more new business than on the long-position. Therefore, the interest income of the short position, i.e. the interest expenses, is affected much more than the interest income of the long- position. The net effect is that the (net) interest income declines. The first factor, i.e. the shift of the yield curve, has qualitatively the same effect on both the present value and the net interest income.

The coefficients for the second factor, the change in the steepness (Interest rates with a maturity of less than 3.5 years decrease the other ones increase (see Figure 1)), is positive for the interest income and negative for the present value. Explaining the effect is relatively straightforward: An increase in the steepness leads to a higher net interest income of the portfolio, because the interest expenses de- and the interest income increase. The loss in present value is due to the increase in interest rates of long maturity, which have a huge impact on the present value of the investment strategies with long maturity (see Figure 3). This means: the opposite signs of the coefficients are responsible for a correlation that is not close to one. As the the first factor has a huge impact for changes in net interest income and in present value, the correlation between these two variables is high: 0.845.

To investigate the universal validity of the results, we analyse the following linear regression:

$$\Delta IC_t(P) = \alpha + \beta\ \Delta PV_t(P) + \eta_t \tag{24}$$

The coefficient of determination R^2 of the regression equals the square of the correlation coefficient. The β-coefficient gives the average magnitude of a change in net interest income relative to changes in present value. In Table 3, we report this two measures for different pairs of maturities for the long- and short-positions, respectively. This table reads as follows: For the case of $M_S = 1$ and $M_L = 10$ (See the seventh row of the table), the R^2 amounts to 0.715 (which corresponds to a correlation of 0.845). A loss of one euro in present value leads – on average – to a loss of 15 cents in net interest income, which means that, for this pair of maturities, the loss in present value is about seven times as high as the loss in net interest income. When we look through the table, we notice that the coefficient of determination is always relatively high, irrespective of the pair of maturities under consideration (from $R^2 = 0.62$ for the pair of maturities $M_L = 10$ and $M_S = 0.5$, to $R^2 = 0.84$ for the pair of maturities $M_L = 8$ and $M_S = 3$). In contrast, the loss in net interest income relative to the loss in present value very much depends on the actual portfolio composition, i. e. when the maturity of the short positions is very short (less than one year), then the impact on the interest expenses in the first year is very large. This means that, in the case of rising interest rates, the decrease in the first year's net interest income is relatively high compared to the loss in present value. If, instead, the maturities on the liability side are relatively long, then the decrease in net interest rate income is spread over several years, for instance for the case of $M_L = 8$ and $M_S = 4$, where the net interest income decreases by 4 cent for every euro loss in present value.

6 Conclusion

With the help of passive investment strategies, we replicate the cash flow of banks engaged in traditional commercial banking. Irrespective of the underlying portfolio composition, changes in the banks' present value and in their net interest income seem to be highly correlated. However, the relative magnitude of the impact on the present value and on the net interest income is quite different and largely depends on the portfolio composition: The shorter the maturities on the asset side and the longer the maturities on the liability side are, the more of the change in net interest income is spread over several years and, therefore, the less is the effect on the first year's net interest income. This finding provides evidence that interest rate stress tests only with respect to the banks' present value may not be enough to gain a complete picture of a bank's exposure to interest rate risk.

Useful integrals

For $\delta > 0$ and $M > 0$, we obtain

$$\int_0^M \exp(-\delta t)dt = \frac{1}{\delta}\left(1 - \exp(-\delta M)\right) \tag{25}$$

$$\int_0^M t\exp(-\delta t)dt = \frac{1}{\delta^2}\left(1 - (1 + \delta M)\exp(-\delta M)\right) \tag{26}$$

$$\int_0^M t^2\exp(-\delta t)dt = \frac{1}{\delta^3}\left(2 - (2 + 2\delta M + \delta^2 M^2)\exp(-\delta M)\right) \tag{27}$$

Extracting $\Delta\beta_t$

From (5) and (6), we obtain

$$H\ \Delta\beta_t = L_{(1)}f_{t,(1)} + L_{(2)}f_{t,(2)} \tag{28}$$

We multiply the right-hand and left-hand side by $L'_{(1)}$ and use the fact that the matrix L is orthogonal, i.e. $L'L = I_n$, $L'_{(1)}L_{(1)} = I_3$ and $L'_{(1)}L_{(2)} = \underline{0}$

$$L'_{(1)}H\ \Delta\beta_t = f_{t,(1)} \tag{29}$$

Multiplying both sides of the equation with $\left(L'_{(1)}H\right)^{-1}$, we obtain the estimate for the changes in the parameters $\Delta\beta_{0,t}$, $\Delta\beta_{1,t}$ and $\Delta\beta_{2,t}$ as displayed in Equation (7).

Incidentally, there is another possibility of extracting estimates for $\Delta\beta_t$: The left-hand and right-hand side of (28) can be multiplied by $\left(H'H\right)^{-1}H'$ and the factors $f_{t,(2)}$ set to zero. This procedure yields

$$\Delta\hat{\beta}_t^{alt} = \left(H'H\right)^{-1}H'L_{(1)}f_{t,(1)} \tag{30}$$

The alternative estimator $\Delta\hat{\beta}_t^{alt}$ can be used when the matrix $L_{(1)}$ does not consist of three factor loadings, but, for example, of two or four factor loadings. If the matrix $L_{(1)}$ includes all factors, i.e. $L_{(1)} = L$ and $f_{t,(1)} = f_t$, then the estimator in Equation (30) has a different interpretation: It can be seen as the OLS estimate of the following regression:

$$\Delta r_t(M) = \Delta\beta_{0,t} + \Delta\beta_{1,t}\frac{1 - \exp(-\bar{\lambda}M)}{M\bar{\lambda}} + \Delta\beta_{2,t}\left(\frac{1 - \exp(-\bar{\lambda}M)}{M\bar{\lambda}} - \exp(-\bar{\lambda}M)\right) + \varepsilon_t \tag{31}$$

This regression is performed at each point in time t and is based on n observations. In our example n equals 20. Empirically, it turns out that the estimators in Equation (7) and (31) do not differ much.

Average renewed business

First, we derive the average solution, neglecting interest on interest. In the event that $M < 1$, we obtain (see Equation (10))

$$N(M) := \int_0^1 n(M,t) = \int_0^M \frac{t}{M} dt + \int_M^1 1 dt \tag{32}$$

$$= 1 - \frac{1}{2} M. \tag{33}$$

Otherwise, i.e. when $M \geq 1$, we obtain

$$N(M) := \int_0^1 n(M,t) = \int_0^1 \frac{t}{M} dt \tag{34}$$

$$= \frac{1}{2\ M} \tag{35}$$

When we take the interest on interest into account, (10) becomes

$$N(M) = \int_0^1 n(t,M) \exp((1-t)r) dt \tag{36}$$

For $M < 1$, we obtain (see (32))

$$N(M) = \frac{\exp(r)}{M} \int_0^M t \exp(-rt) dt + \exp(r) \int_M^1 \exp(-rt) dt \tag{37}$$

Using (26), we obtain

$$N(M) = \frac{\exp(r) - \exp((1-M)r) - rM}{Mr^2} \tag{38}$$

For $M \geq 1$, we obtain (see (32))

$$N(M) = \frac{\exp(r)}{M} \int_0^1 t \exp(-rt) dt \tag{39}$$

Using (26) of Appendix 6, we get:

$$N(M) = \frac{\exp(r) - (1+r)}{Mr^2} \tag{40}$$

The change in the coupon of par-yield bonds

By definition, the coupon $c(M)$ of par yield bonds is

$$1 = c(M) \int_0^M \exp(-r(t)t) dt + \exp(-r(M)M). \tag{41}$$

The derivatives with respect to the three parameters of the yield curve can be expressed as

$$\frac{\partial c(M)}{\partial \beta_i} = -\frac{-c(M)\int_0^M t\frac{\partial r(t)}{\partial \beta_i}\exp(-r(t)t)dt - M\frac{\partial r(M)}{\partial \beta_i}\exp(-r(M)M)}{\int_0^M \exp(-r(t)t)dt} \tag{42}$$

At $\beta_1 = 0$ and $\beta_2 = 0$, the term structure is flat and the coupon of a par-yield bond $c(M)$ equals the interest rate r, i.e $c(M) = r$. Moreover, Equation (42) then simplifies to

$$\frac{\partial c(M)}{\partial \beta_i} = \frac{r^2\int_0^M t\frac{\partial r(t)}{\partial \beta_i}\exp(-rt)dt + rM\frac{\partial r(M)}{\partial \beta_i}\exp(-rM)}{1-\exp(-rM)}, \tag{43}$$

where we apply Equation (25) of Appendix 6 to the denominator.

The derivative $\frac{\partial r(t)}{\partial \beta_0}$ is equal to one; using (26) of Appendix 6, we can show that the Equation (43) simplifies to

$$\frac{\partial c(M)}{\partial \beta_0} = 1\ . \tag{44}$$

Applying Equations (25) and (26) to Equation (43), we can determine the other two derivatives, i.e.

$$\frac{\partial IC(M)}{\partial \beta_1} = N(M)\ \frac{r}{\bar\lambda}\ \frac{1-\frac{r}{r+\bar\lambda}-\frac{\bar\lambda}{r+\bar\lambda}\exp(-(r+\bar\lambda)M)}{1-\exp(-rM)} \tag{45}$$

$$\frac{\partial IC(M)}{\partial \beta_2} = \frac{\partial IC(M)}{\partial \beta_1} - N(M)\ \frac{r^2}{(r+\bar\lambda)^2}\ \frac{1-\exp(-(r+\bar\lambda)M)\left(1+(r+\bar\lambda)M-\frac{(r+\bar\lambda)^2}{r}M\right)}{1-\exp(-rM)} \tag{46}$$

Present Value of the Investment Strategies

Combining (15) with (16), we obtain for the derivatives of the present value with respect to the parameters β_0 to β_2:

$$\frac{\partial PV(M)}{\partial \beta_i} = \int_0^M \left(\frac{1}{M} + c\left(1-\frac{t}{M}\right)\right)\frac{\partial}{\partial \beta_i}\exp(-r(t)\ t)dt \tag{47}$$

Using (25) to (27), we obtain (at $\beta_1 = 0$ and $\beta_2 = 0$)

$$\frac{\partial PV(M)}{\partial \beta_0} = \frac{1}{Mr^2}\left(1-\exp(-rM)-rM\right) \tag{48}$$

$$\frac{\partial PV(M)}{\partial \beta_1} = -\frac{1}{\bar\lambda}\left(\frac{1}{M}+r\right)\left(f(r,M)-f(r+\bar\lambda,M)\right) + \frac{r}{\bar\lambda M}\left(g(r,M)-g(r+\bar\lambda,M)\right) \tag{49}$$

$$\frac{\partial PV(M)}{\partial \beta_2} = \frac{\partial PV(M)}{\partial \beta_1} + \frac{f(\bar\lambda+r,M)}{M(r+\bar\lambda)}\left(1+Mr-2\frac{r}{(\bar\lambda+r)}\right) - \exp(-(\bar\lambda+r)M)\frac{\bar\lambda-r}{(\bar\lambda+r)^2} \tag{50}$$

with

$$f(x,t) = \frac{1}{x}\,(1 - \exp(-x\ t)) \tag{51}$$

$$g(x,t) = \frac{1}{x^2}\,(1 - (1 + x\ t)\exp(-x\ t)) \tag{52}$$

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Tables and Figures

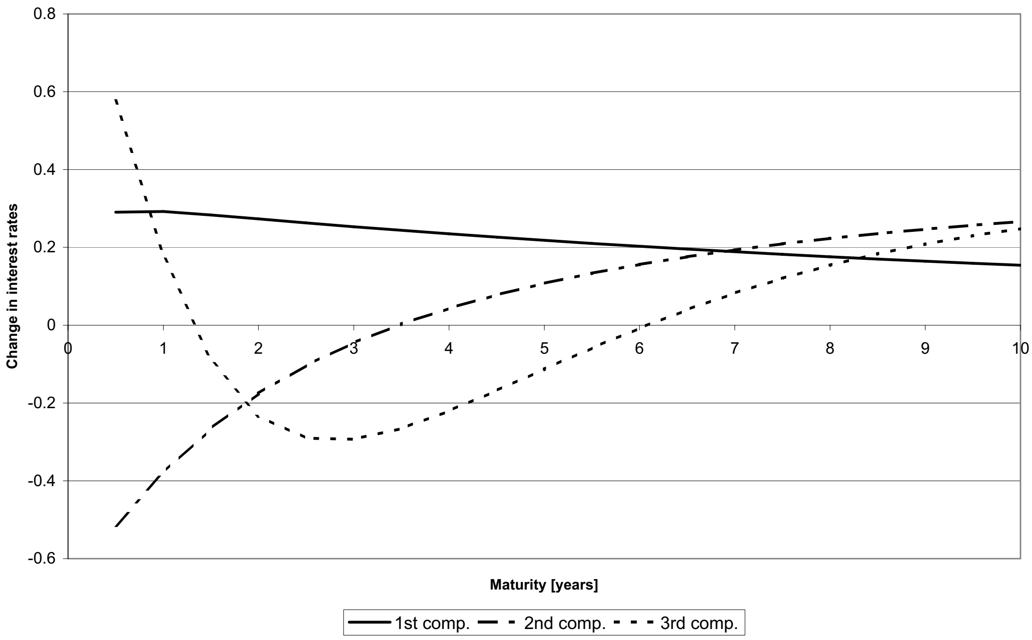

Figure 1: Loadings of the first three components of the PCA of the 12-month interest rate changes; 20 maturities in equal steps from 0.5 to 10 years. Period January 1980 to June 2010.

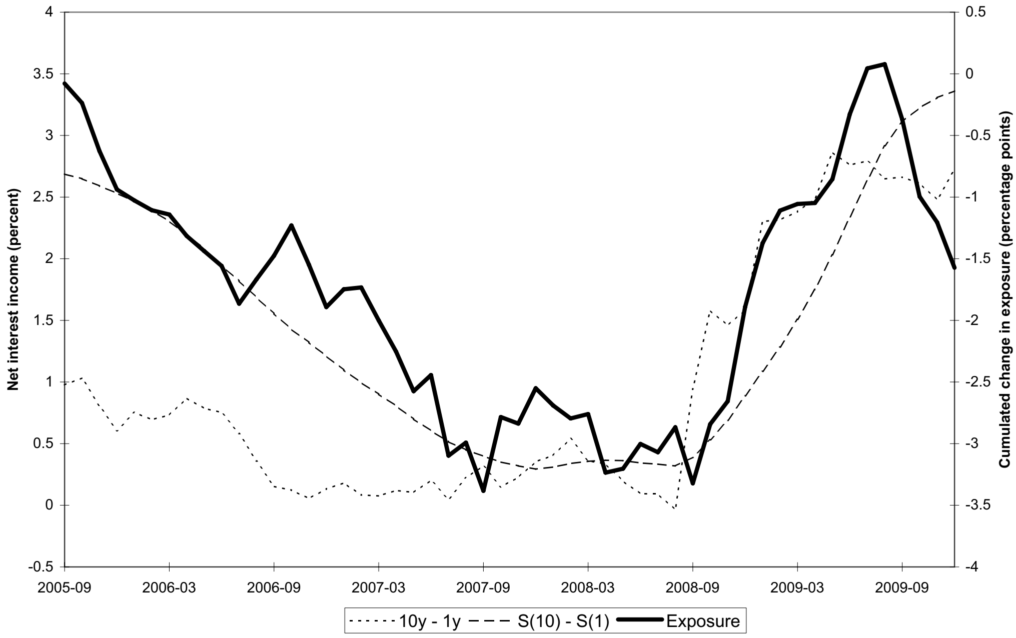

Figure 2: Estimated cumulative change in the exposure to interest rate risk (solid line, right axis, 2005-09 corresponds to 0) against two benchmarks (left axis): Difference between the yields of ten- and one-year German government bonds (dotted line), and return difference of the investment strategies with ten year and one year time to maturity, respectively (dashed line).

Maturity	Change in interest income			Change in present value		
	1st comp.	2nd comp.	3rd comp.	1st comp.	2nd comp.	3rd comp.
0.5	76.7%	20.4%	2.9%	66.4%	20.0%	13.7%
1	87.2%	12.5%	0.2%	80.4%	17.7%	1.9%
1.5	92.8%	7.1%	0.1%	85.9%	14.0%	0.1%
2	95.9%	3.6%	0.5%	88.9%	10.9%	0.1%
2.5	97.6%	1.5%	0.8%	90.9%	8.5%	0.6%
3	98.6%	0.4%	1.0%	92.3%	6.5%	1.1%
3.5	99.1%	0.0%	0.9%	93.4%	5.0%	1.6%
4	99.1%	0.1%	0.7%	94.4%	3.8%	1.9%
4.5	98.8%	0.6%	0.5%	95.2%	2.8%	2.0%
5	98.3%	1.4%	0.3%	95.9%	2.0%	2.1%
5.5	97.4%	2.5%	0.1%	96.5%	1.4%	2.1%
6	96.4%	3.6%	0.0%	97.0%	0.9%	2.1%
6.5	95.1%	4.9%	0.0%	97.5%	0.5%	2.0%
7	93.8%	6.1%	0.0%	97.9%	0.3%	1.8%
7.5	92.4%	7.4%	0.1%	98.2%	0.1%	1.7%
8	91.0%	8.7%	0.3%	98.4%	0.0%	1.5%
8.5	89.5%	10.0%	0.5%	98.6%	0.0%	1.4%
9	88.1%	11.2%	0.7%	98.7%	0.0%	1.2%
9.5	86.7%	12.4%	1.0%	98.8%	0.1%	1.1%
10	85.3%	13.5%	1.2%	98.8%	0.2%	0.9%

Table 2: Percentage of explained variation broken down by the three components. Monthly data from January 1980 to June 2010.

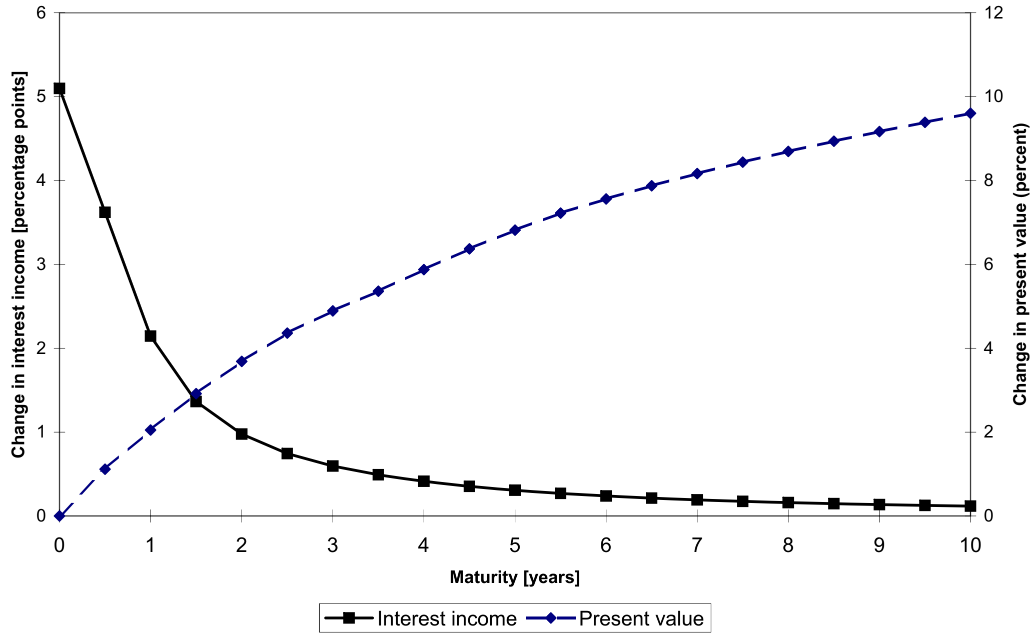

Figure 3: 99th percentile of changes in the interest income and in the present value, respectively, for investment strategies of different maturities. Monthly data from January 1980 to June 2010.

M_S [years]	M_L [years]	R^2	β
0.5	8	0.6529	0.2346
0.5	9	0.6379	0.2172
0.5	10	0.6233	0.2026
1	8	0.7448	0.1690
1	9	0.7296	0.1561
1	10	0.7142	0.1452
2	8	0.8186	0.0922
2	9	0.8027	0.0847
2	10	0.7864	0.0783
3	8	0.8359	0.0644
3	9	0.8195	0.0586
3	10	0.8030	0.0539
4	8	0.8341	0.0494
4	9	0.8183	0.0446
4	10	0.8029	0.0407

Table 3: M_S and M_L are the maturities of the passive investment strategies of the portfolio's short- and long-positions, respectively. R^2 and β are the coefficient of determination and the slope of the following univariate regression: $\Delta IC_t(P) = \alpha + \beta \Delta PV_t(P) + \eta_t$, where $\Delta IC_t(M)$ and $\Delta PV_t(M)$ are changes in the portfolios' net interest income and present value, respectively. Monthly data from January 1980 to June 2010.

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