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## Performance of maturity transformation strategies

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# Non-technical summary

### Research question

Maturity transformation is an important source of both profit and risk for banks. As a result of customers' wishes for long-term fixed interest rates for loans on the one hand and short-term availability of deposits on the other, in the typical bank balance sheet long-term assets are refinanced in the short term. With a normal yield curve, such a maturity transformation leads to positive profit contributions as interest rates for shorter maturities are lower than those for longer maturities. However, the differences in maturities are also associated with an interest rate risk. As maturity transformation can be managed separately from customer business, the study examines whether dominant maturity transformation strategies can be identified from a risk/return perspective.

### Contribution

The study analyses the success of maturity transformation strategies for both high and low interest rate phases. The data is based on the yields of listed German Government par bonds. Synthetic maturity transformation strategies based on the concept of moving averages are constructed and compared in terms of return, risk and performance measured as risk/return relation. The analyses are carried out both from a periodic earnings-based and market value-based perspective.

### Results

Our analyses show that the return and risk from maturity transformation increases with increasing maturity differences in each interest rate phase and regardless of the underlying perspective (earnings- or value-based). In addition, dominant maturity transformation strategies for short to medium maturities can be observed for the currently prevailing low-interest phase.

# Nichttechnische Zusammenfassung

## Fragestellung

Fristentransformation ist eine bedeutende Erfolgs-, aber auch Risikoquelle für Banken. Bedingt durch die Wünsche der Kunden nach langfristiger Zinsfestschreibung von Krediten auf der einen und kurzfristiger Verfügbarkeit von Einlagen auf der anderen Seite werden in der typischen Bankbilanz langfristige Aktiva kurzfristig refinanziert. Eine derartige Fristentransformation führt bei einer normalen Zinsstrukturkurve zu positiven Erfolgsbeiträgen, da kürzere Laufzeiten niedriger als längere Laufzeiten verzinst werden. Mit den Laufzeitunterschieden ist aber gleichzeitig ein Zinsänderungsrisiko verbunden.

Da die Fristentransformation losgelöst vom Kundengeschäft gesteuert werden kann, untersucht die Studie in dem Papier, ob sich unter Rendite-/Risikogesichtspunkten dominante Fristentransformationsstrategien identifizieren lassen.

## Beitrag

Die Studie analysiert den Erfolg von Fristentransformationsstrategien sowohl für Hoch- als auch Niedrigzinsphasen. Die Daten basieren auf den Renditen deutscher Staatsanleihen. Es werden Fristentransformationsstrategien auf Basis des Konzepts der gleitenden Durchschnitte konstruiert und im Hinblick auf Rendite, Risiko und Performance im Sinne von Rendite/Risikoverhältnis verglichen. Die Analysen erfolgen sowohl aus periodischer Erfolgs- als auch aus barwertorientierter Perspektive.

## Ergebnisse

Unsere Analysen zeigen, dass die Rendite und das Risiko aus der Fristentransformation mit zunehmenden Laufzeitunterschieden steigen, und zwar in jeder Zinsphase und unabhängig von der Perspektive (periodisch oder barwertorientiert). Zudem lassen sich für die aktuell vorherrschende Niedrigzinsphase dominante Fristentransformationsstrategien für kurze bis mittlere Laufzeiten beobachten.

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# Performance of maturity transformation strategies

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**Abstract**

This paper analyses the performance of maturity transformation strategies during a period of high and low interest rates. Based on German government bond yields from September 1972 to May 2019, we construct a rolling window of bond ladders where long-term assets are financed by short-term liabilities. Risk and return increase significantly with maturity gaps for both sample periods. During the period of low interest rates, dominant strategies can be observed for short-term and medium-term gaps. With respect to different financial reporting standards, we address maturity transformation results from an earnings-based perspective as well as from a market value-based perspective.

**J.E.L. Classification:** G11, G12, G21

**Keywords:** Maturity Transformation, Bond Ladders, Period of Low Interest Rates, Performance, Interest Rate Risk

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## 1. Introduction

Maturity transformation is one of the most important tasks that banks perform in an economy (see, e.g., Bhattacharya and Thakor (1993); Segura and Suarez (2017)), and banks have been using maturity transformation as a source of income for many years. Closely related to maturity transformation are two major types of risk: liquidity risk (see, e.g., Diamond and Dybvig (1983); de Haan and van den End (2013)), on the one hand, and interest rate risk, on the other (see, e.g., Resti and Sironi (2007)). Liquidity risk means the risk of being unable to meet payment obligations on time. Interest rate risk is the risk of a decline in the interest margin or a reduction in the net market value of assets and liabilities due to changes in market interest rates. Thus, liquidity risk management deals with a bank's ability to avoid bankruptcy, whereas the management of interest rate risk focuses on achieving an adequate risk/return relationship in maturity transformation.

During the current period of low interest rates, banks are facing the problem of decreasing operating earnings, which causes considerable pressure. This might lead management to increase the bank's risk exposure, even if the expected return from the risk taken decreases (Memmel, Seymen, and Teichert (2016)). In the case of long-term assets financed by short-term liabilities, an increase in interest rates will lead to major disturbances in the banking sector, which is why banking supervision is closely monitoring interest rate risk (Abdymomunov and Gerlach (2014); BCBS (2016)).

If management regards maturity transformation as a source of profit, the bank's risk taking has to be balanced with its resilience and management's risk appetite. A bank's resilience is assured if its significant risks can be covered at all times by its existing available financial resources. With respect to liquidity and performance risks, the regulatory framework for resilience distinguishes between liquidity adequacy and capital adequacy (BCBS (2017); ECB (2018a, 2018b)). Thus, banks need to be able to assure both their liquidity and capital adequacy. Only interest rate risk, as a subgroup of performance risk, can be considered in the context of a risk/return analysis.

Prudent management of bond or bank portfolios requires maturity transformation to be investigated from two perspectives: the earnings-based perspective (EBP) and the market value-based perspective (MVBP). In line with financial reporting standards, EBP addresses annual periods (Baltussen, Post, and van Vliet (2012)). MVBP, by contrast, considers the net present value of an institution's cash flows determined by the asset and liability structure of its interest-bearing transactions. EBP returns can be described as the difference between the asset and liability coupon payments (CPs) (Memmel (2008)). MVBP returns are calculated as the difference between the one-year-ahead present value (PV) of assets and liabilities relative to their current present value. Both perspectives are influenced by changes in interest rates, and maturity transformation results are highly correlated (English (2002)). However, EBP effects usually occur with a time lag and intensify in the following years (Memmel (2008)). In this paper, we choose both perspectives to consider supervisory requirements, financial reporting standards and management application in practice. To construct portfolios free from arbitrage opportunities for EBP and MVBP, assets are financed by liabilities on a one-to-one basis.

The article examines the differences in maturity transformation strategies in terms of risk and return. The aim is to analyse whether a dominant strategy can be identified. We use a long data history of German government bond yields from September 1972 to May 2019. We build a bond ladder structure to measure the risk and return from maturity transformation. The data include the whole range of yield curves i.e. low and high, positive and negative, normal and inverse yield curves. Our methodology provides the opportunity to disentangle the success of maturity transformation strategies. We calculate for a rolling window bond ladder one-year returns from long-term capital market investments (10 years) and short to medium-term capital market borrowings (1 to 9 years) in order to quantify the impact of maturity transformation.

The paper is structured as follows. Based on the background of previous studies and the decomposition of maturity transformation performance, the hypotheses are identified in section 2. Section 3 describes the database and Section 4 the methodology. Empirical results and robustness checks follow in Sections 5 and 6. The article concludes with a brief summary of the major findings in Section 7.

## 2. Literature and Hypotheses

The field of interest rate risk in banks has been examined in various research areas and in different literature streams. Our paper is based on literature dealing with the risk and return generated by maturity transformation. A large part of the literature deals primarily with interest rate risk. Initial studies (Lynge and Zumwalt (1980); Fraser, Madura, and Weigand (2002); Czaja, Scholz, and Wilkens (2009, 2010); English, Van den Heuvel, and Zakrajšek (2018)) examine interest rate risk indirectly by measuring the sensitivity of banks' equity prices to changes in interest rates. Other studies use direct accounting-based or supervisory data to consider interest rate risk (Entrop et al. (2008)). But they do not cover explicitly the risk from maturity transformation.

The idea of maturity transformation, using the differences between long and short term interest rates, can be found in the literature concerning riding-the-yield-curve-strategies. These are active investment strategies, in which longer-dated fixed-income securities are bought and sold before maturity instead of investments with a maturity that matches the investment horizon to earn a term premium. Starting with Dyl and Joehnk (1981), several studies have investigated the profitability of such investment strategies. The results are heterogeneous and vary depending on the design of the studies.[1] Grieves and Marcus (1992) provide evidence for riding, Pelaez (1997) against, especially because the increased returns may be outweighed by the increased risk. Chua, Koh, and Ramaswamy (2005) provide evidence for and against riding. A recent study from Galvani and Landon (2013) provides no support for the riding-the-yield-curve investment strategy in Canada and the USA. The authors examine ex post average returns and the Sharpe Ratio, as is usually the case, and use in addition the spanning analysis to provide formal statistical evidence.

In contrast to riding-the-yield-curve our approach of maturity transformation pursues a passive strategy, which is commonly used in banks for interest rate risk management either as strategy itself or at least as benchmark for an active strategy (Memmel (2011)). With the help of bond ladders, as illustrated in Bohlin and Strickland (2004) and Schmidhammer (2018), passive maturity transformation strategies can be applied. Like the riding-the-yield-curve approach banks aim to benefit from the steepness of the curve. When following a passive maturity transformation strategy bank management has to define a duration which reflects the maturity transformation with the desired risk-/return profile in line with the bank´s risk-bearing capacity and bank management´s risk appetite. The concept ensures that expiring

[1] Galvani and Landon (2013) give as well a brief literature review.

funds are reinvested when due in new investments holding the duration of the portfolio constant over time (Memmel (2008)). Bieri and Chincarini (2005) analyse such a strategy for US Treasuries and call it duration-neutral riding strategy but in contrast to our approach they achieve a constant duration through a mix of short-term and long-term investments.

Literature focusing on the return from maturity transformation refers to the determinants that influence the interest margin (Ho and Saunders (1981); Saunders and Schumacher (2000); Entrop et al. (2015); Cruz-García, Fernández de Guevara, and Maudos (2019)). One study that looks in greater detail at the profitability of maturity transformation is that of Memmel (2011), which draws upon on the methodology used in an earlier paper (Memmel (2008)). Memmel (2011) uses a set of data from German banks in order to investigate interest rate risk, the income from maturity transformation, and the dynamics of the term structure.

The key question explored in our paper is the profitability of maturity transformation, this being an important source of income for banks. How much it contributes to a bank's current income depends on both current and past yield curves. Future income from maturity transformation depends on future interest rate movements as well. Thus, both the volatility and level of interest rates have a major effect on the net interest income of banks. Memmel (2011) focuses on savings banks and cooperative banks in Germany. However, maturity transformation does not necessarily require customer transactions. It can also be carried out synthetically using capital market products. The analysis in our paper is not confined to a specific business model.

Unlike earlier studies which use specific bank data to analyse interest rate risk in general or the impact of stress scenarios defined by BCBS (2016) in particular or the results of term transformation (Memmel (2008, 2011)), our study investigates the risk/return profile of predefined maturity transformation strategies. To the best of our knowledge, the research question of optimal maturity transformation strategies across a comprehensive set of yield curves and yield levels has not yet been investigated by researchers. We address this question and construct various maturity transformation strategies by applying a ten-year bond ladder for assets and one- to nine-year ladders for liabilities. Memmel (2014) shows that the balance sheet structure has a major influence on banks' net interest income and their market values. Hence, we address both perspectives, EBP and MVBP. We build portfolios using German government bonds where assets are financed one-to-one by liabilities. Thus, we construct synthetic capital-market-oriented banks (Roengpitya, Tarashev, and Tsatsaronis (2014); Ayadi et al. (2016)), thereby allowing us to focus solely on maturity transformation independent of idiosyncratic business strategies or balance sheet structures.

Our hypotheses are based on the decomposition of maturity transformation and Markowitz's portfolio theory (1952) where risk and return are used to characterize equity portfolios. For bond portfolios Fogler, Groves, and Richardson (1977) suggest the application of risk and return relations rather than Treynor or Sharpe ratios measure the return as the excess return above the risk-free rate of return. In the case of a normal yield curve where long-term maturity yields exceed those of short-term maturities, increasing maturity mismatches between (long-term) assets and (short-term) liabilities should cause net interest income to rise. As normal yield curves have been observed on average in the past, we expect rising returns with rising maturity gaps. We define risk as the standard deviation of maturity transformation returns (Fama and MacBeth (1973); Merton (1980); Hirtle and Stiroh (2007)) and calculate performance as the relationship between risk and return (Hirtle and Stiroh (2007)), denominated as risk-adjusted return (RAR). In accordance with Markowitz (1952), we expect increasing risk with increasing maturity gaps. However, relying on Fama (1970, 1991) there should be no risk/return combination that dominates other portfolios without consideration of a bank's risk appetite. Similar can be found in some riding-the-yield-curve literature. Consistent with the liquidity premium theory (see Hicks (1939); Kessel (1965)) riding strategies produce higher average returns, but do not necessarily yield excess risk-adjusted returns (see Pelaez (1997); Galvani and Landon (2013)). This is in line with the pure expectations theory (see Fisher (1896)). Our research design is illustrated in Figure 1.

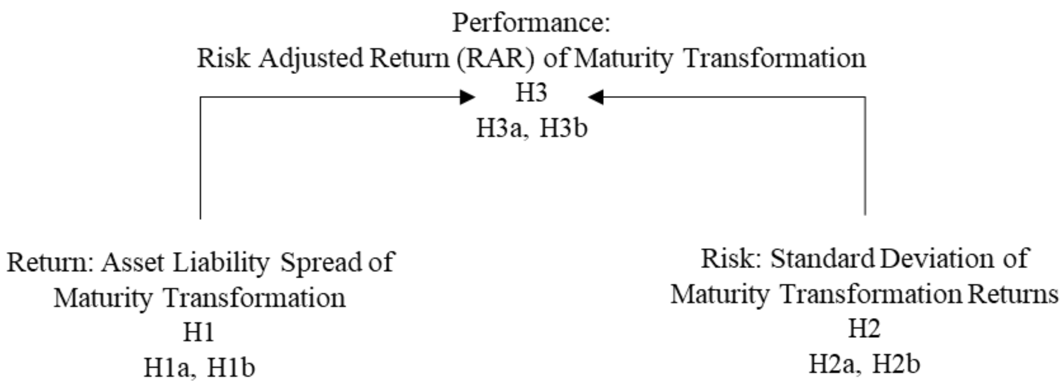


**Figure 1:** Composition of maturity transformation performance

Based on our preliminary considerations, we define the following hypotheses:

H1: Increasing maturity gaps lead to rising maturity transformation returns.

H1a: Increasing maturity gaps lead to rising maturity transformation returns during a period of high interest rates.

H1b: Increasing maturity gaps lead to rising maturity transformation returns during a period of low interest rates.

H2: Increasing maturity gaps lead to rising maturity transformation risk.

H2a: Increasing maturity gaps lead to rising maturity transformation risk during a period of high interest rates.

H2b: Increasing maturity gaps lead to rising maturity transformation risk during a period of low interest rates

H3: There is no efficient maturity transformation strategy.

H3a: There is no optimal risk/return combination during a period of high interest rates.

H3b: There is no optimal risk/return combination during a period of low interest rates.

We investigate each hypothesis for EBP and MVBP.

## 3. Data

We use monthly returns on German government par bonds as published by the Deutsche Bundesbank. The data cover the period from September 1972 to May 2019, i.e. 561 observations. The interest rates used range from one to ten years. The Deutsche Bundesbank uses the Svensson method (1994) to estimate the yield curve, which is based on the Nelson and Siegel method (1987). We use government bonds as they are free of counterparty default risk, allowing just the risk of maturity transformation to be considered (Fama and French (1993); Gultekin and Rogalski (1985); Yawitz, Hempel, and Marshall (1975)).

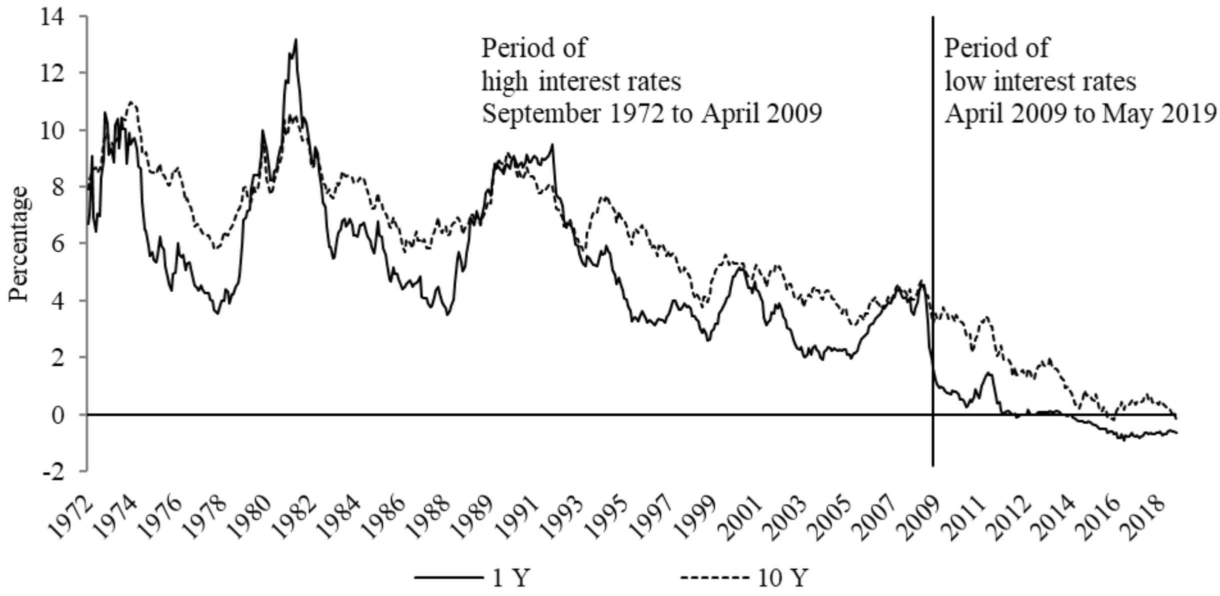


**Figure 2:** Evolution of yields over time for one-year and ten-year German government bonds

In addition, we divide the observation period into two phases: a period of high interest rates (440 observations) and a period of low interest rates (121 observations), as shown in Figure 2 above. The period between May 2009 and May 2019 was chosen to represent the low interest rate phase, as the European Central Bank cut the key interest rate to a historic low of 1% in May 2009.[2]

[2] Similar arguments can be found in Schmidhammer (2018).

| Total data history: September 1972 to May 2019 (561 observations) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Minimum | -0.92% | -0.92% | -0.86% | -0.74% | -0.63% | -0.56% | -0.47% | -0.38% | -0.29% | -0.21% |
| Maximum | 13.17% | 12.38% | 12.07% | 11.85% | 11.62% | 11.38% | 11.14% | 10.92% | 10.88% | 10.97% |
| Mean | 4.29% | 4.50% | 4.70% | 4.88% | 5.03% | 5.15% | 5.26% | 5.35% | 5.43% | 5.49% |
| Median | 4.11% | 4.39% | 4.70% | 5.02% | 5.23% | 5.41% | 5.59% | 5.71% | 5.81% | 5.92% |
| Volatility | 3.16% | 3.12% | 3.09% | 3.06% | 3.02% | 2.97% | 2.92% | 2.88% | 2.83% | 2.79% |
| **Sample I: Period of high interest rates from September 1972 to April 2009 (440 observations)** | | | | | | | | | | |
| Years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean | 5.49% | 5.72% | 5.94% | 6.11% | 6.25% | 6.36% | 6.45% | 6.52% | 6.58% | 6.63% |
| Median | 4.84% | 5.22% | 5.59% | 5.82% | 6.02% | 6.19% | 6.34% | 6.45% | 6.54% | 6.61% |
| Volatility | 2.45% | 2.32% | 2.23% | 2.16% | 2.10% | 2.05% | 2.00% | 1.97% | 1.93% | 1.90% |
| **Sample II: Period of low interest rates from May 2009 to May 2019 (121 observations)** | | | | | | | | | | |
| Years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean | -0.06% | 0.06% | 0.21% | 0.39% | 0.58% | 0.76% | 0.93% | 1.09% | 1.24% | 1.37% |
| Median | -0.03% | -0.04% | 0.04% | 0.19% | 0.35% | 0.53% | 0.71% | 0.91% | 1.10% | 1.27% |
| Volatility | 0.58% | 0.71% | 0.83% | 0.91% | 0.98% | 1.03% | 1.07% | 1.10% | 1.12% | 1.14% |

**Table 1:** Descriptive statistics of the dataset

In Table 1 we report the descriptive statistics of our dataset. On average, normal interest rate curves can be observed. The spread between short-term and long-term interest rates is 1.2% on average. The one-year spread between interest rates decreases as maturity increases. Short-term interest rates are more volatile than long-term ones. Income volatility is 3.16% for the one-year interest rate, dropping to 2.83% for the ten-year interest rate. A similar structure exists within the two sub-periods. On average, the yield curve in the low interest rate phase is slightly steeper than in the period of high interest rates. Over the entire period, there were more interest rate cuts than increases.

## 4. Methodology

### *4.1 Bond ladders*

Maturity transformation can be implemented by an infinite number of bond portfolio strategies. Fogler, Groves, and Richardson (1977) analyse ladders, dumbbell strategies and long maturity portfolios. The authors describe bond ladders as strategies where equal portions of a portfolio are invested on a revolving basis in each maturity up to a pre-defined maximum. A dumbbell strategy combines short-term and long-term investments, while long maturity portfolios consist primarily of long-term investments. These portfolios commonly follow a passive investment strategy. Judd, Kubler, and Schmedders (2011) find that the length of bond ladder investments contributes positively to welfare. Their results support the application of long-term bond ladders. Schmidhammer (2018) shows that ten-year bond ladders significantly outperform short-term ones. Relying on Judd, Kubler, and Schmedders (2011) or Schmidhammer (2018), we apply ten-year bond ladders as a benchmark for the assets side in our analysis. For the liabilities side, bond ladders are systematically changed to model the different maturity transformation strategies.

To explain how the bond ladders used in our analysis are constructed, we illustrate the cash flow structure of two arbitrarily selected ladders. Table 2 shows the composition of five- and ten-year bond ladders when 100 units of capital are invested. In line with the properties of German government bonds, coupon payments are due annually. For illustrative purposes, payments are assumed to amount to five percent over time. For a five-year bond ladder, each year 20 units of capital are due. If an investment matures, 20 units are reinvested for five years. Since for each maturity coupons are due annually, a payment of five units results after one year. From the perspective of an investment that matures in two years, coupon payments result from four (remaining) units of invested capital which leads to a payment of four units. This calculation can be continued for each maturity. According to Memmel (2008), interest income and expenses represent a moving average of coupon payments. For a ten-year ladder, the capital units, coupon payments and cash flows can be derived in the same manner. For both structures, the result is a slightly decreasing cash flow consisting of capital and coupon payments. With respect to the two perspectives considered, the earnings-based perspective focuses on the income and expenses for the present one-year period. The market value-based perspective, by contrast, requires and processes the information of the total cash flow structure.

| Maturity (years) | Five-year ladder | | | Ten-year ladder | | |
|---|---|---|---|---|---|---|
| | Capital | Coupon | Cash flow | Capital | Coupon | Cash flow |
| 1 | 20 | 5 | 25 | 10 | 5 | 15 |
| 2 | 20 | 4 | 24 | 10 | 4.5 | 14.5 |
| 3 | 20 | 3 | 23 | 10 | 4 | 14 |
| 4 | 20 | 2 | 22 | 10 | 3.5 | 13.5 |
| 5 | 20 | 1 | 21 | 10 | 3 | 13 |
| 6 | | | | 10 | 2.5 | 12.5 |
| 7 | | | | 10 | 2 | 12 |
| 8 | | | | 10 | 1.5 | 11.5 |
| 9 | | | | 10 | 1 | 11 |
| 10 | | | | 10 | 0.5 | 10.5 |

**Table 2:** Five- and ten-year bond ladders

### *4.2 Maturity transformation*

Maturity transformation results from maturity mismatches between assets and liabilities. Entrop et al. (2015) describe maturity transformation as long-term liquidity provision for loans financed by short-term deposits. Memmel (2008) delivers an approach to capture the maturity of an institution's assets and liabilities by applying revolving investment strategies. In line with the construction of bond ladders, he assumes that funds that fall due are reinvested with the same maturity. Once implemented, such a passively managed strategy does not change over time. Memmel (2008) calls his bond ladder construction a "tracking bank", since the maturity of a bond portfolio is designed to match that of an institution. Tracking banks are also applied in Memmel (2011) and Entrop et al. (2015). In Memmel (2011) the assets side of the tracking banks is invested in ten-year maturity ladders, while the liabilities side is financed short-term in one-year maturities. Based on this structure, the author connects maturity transformation with interest rate risk for individual banks.

We use the setting applied in Memmel (2011) to analyse the return, risk and performance of maturity transformation strategies. We generate maturity transformation by investing in ten-year bond ladders and selling $10 - n$ year bond ladders with $n = 1, \dots, 9$. This leads to $j$ different maturity transformation gaps $MTG_j$ between assets and liabilities stretching from one year to nine years, with $j = 1, \dots, 9$. In order to generate comparable portfolio results regardless of the amount of invested capital (IC), we assume that the assets are fully financed by liabilities.

Maturity transformation returns from the earnings-based perspective (EBP) $R_{j,t}^{EBP}$ are determined for the annual period at time $t$ and the maturity transformation gap $j$ as follows:

$$R_{j,t}^{EBP} = \frac{\text{Ø}CP_{10,t+1y}^{Asset} - \text{Ø}CP_{10-n,t+1y}^{Liability}}{IC_t} \quad (1)$$

In line with the data available for German government bonds, monthly periods $t$ are used. The average coupon payments at time $t$ for bond ladder $l$ with $l = 1, \dots, 10$ are denoted as $\text{Ø}CP_{l,t}$. Returns are determined as the difference between $\text{Ø}CP_{l,t}$ for assets due in one year at time $t + 1y$ for ten-year bond ladders $\text{Ø}CP_{10,t+1y}^{Asset}$ and $\text{Ø}CP_{l,t}$ for liabilities due in one year at time $t + 1y$ for $10 - n$ year bond ladders $\text{Ø}CP_{10-n,t+1y}^{Liability}$ relative to $IC$ at time $t$, $IC_t$. The value of assets equals the value of liabilities at time $t$, captured by $IC_t$.

According to Memmel (2008), EBP returns can be described as the difference between the moving averages of the asset and liability CPs. The construction of rolling windows is used for the market value-based perspective (MVBP) as well. As with EBP, annual periods are analysed. We follow Baltussen, Post, and van Vliet (2012) and calculate MVBP returns for one-year intervals as well due to financial statement requirements:

$$R_{j,t}^{MVBP} = \frac{PV_{10,t+1y}^{Asset} - PV_{10-n,t+1y}^{Liability}}{PV_t} \quad (2)$$

The maturity transformation returns $R_{j,t}^{MVBP}$ of the market value-based perspective are determined for the maturity transformation gap $j$ at time $t$. Returns are calculated as the difference between the present value (PV) of assets at time $t + 1y$ for ten-year bond ladders, $PV_{10,t+1y}^{Asset}$, and the present value of liabilities at time $t + 1y$ for $10 - n$ year bond ladders, $PV_{10-n,t+1y}^{Liability}$, relative to the present value at time $t$, $PV_t$. Since $PV_t$ of asset and liability bond ladders do not necessary match at time $t$, maturity transformation results can be biased at time $t + 1y$. To match $PV_t$ of assets and liabilities which corresponds to the strategy that assets are financed by liabilities, CFs are adjusted by multiplication with the inverse of the corresponding $PV_t$. Alternatively, CFs can be adjusted at time $t + 1y$ which is applied in this paper. This leads to equal PVs of assets and liabilities, $PV_t$, employed as denominator of equation (2). The adjustment provides a pure focus on annual maturity transformation returns, free from biases due to PV differences of assets and liabilities at time $t$.

The application of the German government bond yield structure make possible a consistent derivation of discount factors *DF*. $PV_{l,t}$ are calculated each month $t$ for each bond ladder $l$:

$$PV_{l,t} = \sum_{i=1}^{l} CF_{i,t} \cdot DF_{i,t} \tag{3}$$

The number of CFs $i$ at time $t$, $CF_{i,t}$ is determined by the maximum maturity $l$ of a bond ladder. Each $CF_{i,t}$ is multiplied by the corresponding DF $i$ at time $t$, $DF_{i,t}$. To obtain annual returns as illustrated in equation (2), PVs at time $t + 1y$ for each bond ladder $l$ and time $t$, $PV_{l,t+1y}$, are included:

$$PV_{l,t+1y} = \sum_{i=1}^{l} CF_{i,t} \cdot DF_{i-1y,t+1y} \tag{4}$$

Each $CF_{i,t}$ is multiplied by the corresponding DF *i* derived from the yield structure at time $t + 1y$. Since CFs are discounted by $t - 1y$ at time $t + 1y$, the corresponding DF is determined for $i - 1y$, $DF_{i-1y,t+1y}$.

### *4.3 Risk and performance*

Following Fama and MacBeth (1973), Merton (1980) and Hirtle and Stiroh (2007), we calculate risk $\sigma_{j,t}$ as the standard deviation of annual maturity transformation returns. According to Merton (1980), we apply a rolling window, where $\sigma_{j,t}$ is calculated each month $t$ for $MTG_j$.[3] In line with using the ten-year bond ladder as the benchmark, $\sigma_{j,t}$ includes ten years of preceding annual returns $R_{j,t-1y}$, $R_{j,t-2y}$, …, $R_{j,t-10y}$.

[3] This also corresponds to the determination of returns as a moving average.

In the financial literature, risk-adjusted return measures are widely used to evaluate performance. One example is Milne and Onorato (2012), who discuss risk measures in the context of value creation and risk management. Buch, Dorfleitner, and Wimmer (2011) apply a RORAC (return on risk-adjusted capital) figure to address optimal capital allocation. RORAC is defined as the relation between return and "risk capital", which is frequently applied as a value-at-risk measure to comply with regulatory standards.[4] Since our focus is purely economic, we rely on Hirtle and Stiroh (2007), who determine performance as the relationship between return and risk, the latter being measured as the standard deviation of returns. Thus, we calculate performance as risk-adjusted returns (RAR) as follows:

$$RAR_{j,t} = \frac{R_{j,t}}{\sigma_{j,t}} \tag{5}$$

$RAR_{j,t}$ is determined for $MTG_j$ and time $t$.

### *4.4 Regression models*

The purpose of this paper is to determine the influence of maturity transformation strategies on return, risk and performance. First, we estimate the effect of maturity transformation strategies on annual returns. The ordinary least squares (OLS) regression specification is estimated as follows:

$$R_{j,t}^{EBP,MVBP} = \alpha + \beta_1 \cdot Level_t + \beta_2 \cdot Slope_t + C' \cdot D_y^{Time} + E' \cdot D_j^{MTG} + \varepsilon_{j,t} \tag{6}$$

Returns of maturity transformation strategies $MTG_j$ and time $t$ are defined as the dependent variable. Both the EBP and MVBP perspectives are addressed. The coefficient α is a constant term. Coefficient $\beta_1$ captures the impact of the yield curve level and $\beta_2$ the impact of the slope. $C$ is a $(Y-1) \times 1$ vector of annual time effects. The corresponding $(Y-1) \times 1$ vector of time dummies is denoted $D_y^{Time}$. The construction of maturity transformation dummies $D_j^{MTG}$ allows the return differences of maturity transformation strategies to be estimated. $D_j^{MTG}$ is a vector of $(J-1) \times 1$ dummies comprising eight maturity gaps, $MTG_2$ to $MTG_9$. $MTG_1$ is selected as the reference and represents the maturity differences

4 Examples are the Pillar 1 capital ratios under the Basel III framework, where risk measures such as credit risk in the internal ratings-based (IRB) approach are based on value-at-risk concepts. The same holds for Pillar 2 risk measures.

between a ten-year bond ladder of assets and a nine-year bond ladder of liabilities. $E$ is a $(J-1) \times 1$ vector of coefficients that captures return differences between maturity transformation strategies and $MTG_j$. $\varepsilon_{j,t}$ represents the sample's residuals. To correct for heteroskedasticity and autocorrelation, Newey and West (1987) is applied for regression specifications (6), (7) and (8).

According to returns, the impact of maturity transformation strategies on risk $\sigma_j^{EBP,MVBP}$ is analysed. Again, both EBP and MVBP perspectives are addressed:

$$\sigma_{j,t}^{EBP,MVBP} = \alpha + \beta_1 \cdot Level_t + \beta_2 \cdot Slope_t + C' \cdot D_y^{Time} + E' \cdot D_j^{MTG} + \varepsilon_{j,t} \quad (7)$$

Coefficients of equation (7) can be interpreted according to equation (6). The same holds for the performance analysis according to equation (8):

$$RAR_{j,t}^{EBP,MVBP} = \alpha + \beta_1 \cdot Level_t + \beta_2 \cdot Slope_t + C' \cdot D_y^{Time} + E' \cdot D_j^{MTG} + \varepsilon_{j,t} \quad (8)$$

Performance, measured as the relationship between return and risk, is defined as the dependent variable $RAR_{j,t}^{EBP,MVBP}$. For the regression specifications (6) to (8), results are illustrated for EBP and MVBP during periods of high and low interest rates.

The purpose of the paper is to identify unbiased effects of maturity transformation strategies. Hence, we control for a possible impact of level, slope and time effects. Arguments are illustrated in the following. Fama and French (1993), for example, include bill rates as level to determine excess bond returns. Czaja, Scholz, and Wilkens (2009) identify an influence of changes in the level of the term structure of interest rates when analysing the equity value of banks. Since our data set includes periods with high and low interest rates, we control for the level of the yield curve in regression specifications. The level of the yield curve is captured by one-year bonds due to the shortest maturity at time $t$, denominated as $Level_t$.

Memmel (2008) shows that changes in the slope have a significant impact on interest income. Since our data set includes all kind of yield curve structures with various degrees of steepness, we include slope as independent variable. The slope is measured as the difference between ten-year and one-year bond yields. As the slope also depends on the yield curve level and thus multicollinearity can occur between the independent variables, we additionally estimate regression specifications that exclude slope as independent variable to control whether the identified advantageous maturity transformation strategies still hold. Results are illustrated in section 6.2 as robustness tests.

Relying on Merton (1980) and Memmel (2011) we construct a rolling window of maturity transformation returns. Due to the availability of German government bond data, annual returns can be calculated each month. However, investment strategies of financial institutions are determined once a year and not on a monthly basis.[5] Hence, we apply annual time dummies $D_y^{Time}$ to control for this fact. Annual time dummies also contribute to capture time-specific macroeconomic effects like the financial crisis between 2007 and 2009 or the European Central Bank's quantitative easing policy starting in 2015.

## 5. Empirical results

### *5.1 Descriptive maturity transformation results*

First we illustrate descriptive statistics of maturity transformation returns, as depicted in equation (1). Table 3 shows the results for EBP for the two different samples. Sample I reflects the period of high interest rates, and the second the period of low interest rates. Although German government bonds are available from September 1971, the period of high interest rates includes only results from September 1991. This is the case since the construction of a ten-year bond ladder requires ten years of preceding data. Further, and consistent with the longest maturity ladder, return volatility is calculated including the preceding ten years of annual returns. Details of the volatility construction are described in the next section.

For the period of high interest rates, means and medians increase with $MTG_j$. For gap one, where a ten-year bond ladder of assets is financed by a nine-year bond ladder of liabilities, mean and median values amount to 0.14%. Overall, returns increase from 0.14% to 2.02% for means, and to 2.29% for medians from $MTG_1$ to $MTG_9$. Negative minimum values as observed in sample I result from an inverse yield structure during the early 1990s. Sample II includes data from May 2009 to May 2019. Since MVBP requires the yield structure at time $t + 1y$, maturity transformation results are restricted to May 2018. It

[5] This is in line with annual reporting standards as illustrated in Baltussen, Post, and van Vliet (2012).

is interesting to observe that for sample II, representing the period of low interest rates, mean and median maturity transformation returns exceed those of sample I.

| Sample I: Period of high interest rates from September 1991 to April 2009 (212 observations) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MTG | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Minimum | -0.13% | -0.27% | -0.40% | -0.48% | -0.61% | -0.91% | -1.46% | -1.62% | -2.00% |
| Maximum | 0.35% | 0.70% | 1.06% | 1.40% | 1.89% | 2.47% | 2.94% | 3.45% | 4.14% |
| Mean | 0.14% | 0.29% | 0.46% | 0.64% | 0.85% | 1.08% | 1.36% | 1.68% | 2.02% |
| Median | 0.14% | 0.34% | 0.50% | 0.76% | 1.07% | 1.37% | 1.63% | 1.82% | 2.29% |
| Volatility | 0.13% | 0.26% | 0.39% | 0.54% | 0.71% | 0.90% | 1.09% | 1.26% | 1.45% |
| **Sample II: Period of low interest rates from May 2009 to May 2018 (109 observations)** | | | | | | | | | |
| MTG | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Minimum | 0.13% | 0.33% | 0.45% | 0.57% | 0.72% | 0.61% | 0.74% | 1.38% | 2.21% |
| Maximum | 0.44% | 0.86% | 1.29% | 1.68% | 2.15% | 2.55% | 2.88% | 3.29% | 3.91% |
| Mean | 0.25% | 0.52% | 0.83% | 1.17% | 1.52% | 1.91% | 2.32% | 2.72% | 3.03% |
| Median | 0.21% | 0.43% | 0.74% | 1.24% | 1.71% | 2.11% | 2.44% | 2.74% | 2.96% |
| Volatility | 0.08% | 0.17% | 0.27% | 0.37% | 0.45% | 0.50% | 0.45% | 0.36% | 0.37% |

**Table 3:** EBP maturity transformation returns during periods of high and low interest rates

According to equation (2), Table 4 illustrates maturity transformation results for MVBP. For both samples, means and medians increase with gaps. MVBP results are comparable to EBP results. Since MVBP includes total cash flows, both volatility as well as differences between minimum and maximum exceed those of EBP.

| Sample I: Period of high interest rates from September 1991 to April 2009 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MTG | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Minimum | -0.55% | -1.15% | -1.83% | -2.58% | -3.42% | -4.32% | -5.29% | -6.22% | -6.84% |
| Maximum | 0.70% | 1.43% | 2.16% | 2.93% | 3.71% | 4.56% | 6.02% | 7.77% | 9.58% |
| Mean | 0.14% | 0.30% | 0.49% | 0.70% | 0.95% | 1.25% | 1.59% | 1.96% | 2.36% |
| Median | 0.16% | 0.36% | 0.56% | 0.85% | 1.22% | 1.57% | 2.01% | 2.39% | 2.86% |
| Volatility | 0.26% | 0.54% | 0.84% | 1.17% | 1.54% | 1.94% | 2.39% | 2.87% | 3.33% |
| **Sample II: Period of low interest rates from May 2009 to May 2018** | | | | | | | | | |
| MTG | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Minimum | -0.31% | -0.59% | -0.85% | -1.05% | -1.21% | -1.31% | -1.35% | -1.36% | -1.33% |
| Maximum | 0.93% | 1.89% | 2.94% | 4.04% | 5.19% | 6.36% | 7.52% | 8.63% | 9.73% |
| Mean | 0.29% | 0.60% | 0.92% | 1.26% | 1.60% | 1.94% | 2.25% | 2.52% | 2.72% |
| Median | 0.26% | 0.54% | 0.83% | 1.13% | 1.41% | 1.64% | 1.84% | 1.97% | 2.20% |
| Volatility | 0.29% | 0.58% | 0.87% | 1.17% | 1.47% | 1.77% | 2.06% | 2.34% | 2.58% |

**Table 4:** MVBP maturity transformation returns during periods of high and low interest rates

*5.2 Return, risk and performance results*

First, we address hypothesis H1 as to whether net interest income increases with maturity gaps. H1a and H1b distinguish between the periods of high and low interest rates. Table 5 illustrates regression (6) results where net interest income and economic values are captured by equation (1) and (2) returns as the dependent variable. Sample I comprises 1,908 observations during the period of high interest rates between September 1991 and April 2009 (212 observations for nine different maturity gaps). Sample II comprises 981 observations during the period of low interest rates between May 2009 and May 2018 (109 observations for nine different maturity gaps).

Consistent with a normal yield structure during a period of high and low interest rates (see Table 1) where yields increase with maturity, Table 5 shows that maturity transformation returns increase with gaps. This is valid for EBP and MVBP as well as for sample I and II. For MVBP and sample I, coefficients increase from $MTG_2$ to $MTG_9$ from 0.16% to 2.22%, but at different levels of significance.

Since $MTG_1$ is omitted as a reference, coefficients have to be interpreted relative to $MTG_1$. $MTG_4$ returns, for example, significantly exceed $MTG_1$ returns by 0.56%. Level and slope results differ between EBP and MVBP. For EBP, level results are slightly negative. For MVBP, level and slope are positive and significant, which implies that market value-based returns increase with level and slope. These results are expected due to the calculation of annual returns based on discounted cash flows as described in equations (3) and (4). For EBP, slope coefficients are not significant. One argument is that EBP includes income and expenses of one-year periods captured by $MTG$ coefficients. To control for time effects, annual time dummies are included. As a result, hypotheses H1 "Increasing maturity gaps lead to rising maturity transformation returns", H1a "Increasing maturity gaps lead to rising maturity transformation returns during a period of high interest rates" and H1b "Increasing maturity gaps lead to rising maturity transformation returns during a period of low interest rates" cannot be rejected. This applies to both perspectives, EBP as well as MVBP.

| | **Sample I** | | | | | | **Sample II** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 0.54 | * | 2.04 | -8.43 | *** | -8.92 | -0.11 | | -0.53 | -5.82 | *** | -6.57 |
| Level°° | -0.19 | *** | -3.44 | 1.38 | *** | 9.82 | -0.18 | ** | -2.57 | 2.45 | *** | 5.97 |
| Slope°° | 0.00 | | 0.02 | 2.64 | *** | 10.08 | 0.00 | | 0.07 | 2.09 | *** | 7.83 |
| $MTG_2$ | 0.15 | | 0.98 | 0.16 | | 0.62 | 0.28 | *** | 4.38 | 0.31 | | 1.04 |
| $MTG_3$ | 0.32 | ** | 2.16 | 0.35 | | 1.45 | 0.58 | *** | 8.89 | 0.63 | ** | 2.33 |
| $MTG_4$ | 0.50 | *** | 3.65 | 0.56 | ** | 2.50 | 0.92 | *** | 12.77 | 0.97 | *** | 3.76 |
| $MTG_5$ | 0.71 | *** | 5.45 | 0.81 | *** | 3.61 | 1.28 | *** | 15.93 | 1.31 | *** | 5.03 |
| $MTG_6$ | 0.94 | *** | 7.18 | 1.11 | *** | 4.51 | 1.66 | *** | 19.27 | 1.65 | *** | 5.90 |
| $MTG_7$ | 1.22 | *** | 8.24 | 1.44 | *** | 5.02 | 2.07 | *** | 25.10 | 1.96 | *** | 6.32 |
| $MTG_8$ | 1.54 | *** | 8.81 | 1.82 | *** | 5.23 | 2.47 | *** | 28.43 | 2.23 | *** | 6.37 |
| $MTG_9$ | 1.88 | *** | 8.76 | 2.22 | *** | 5.29 | 2.78 | *** | 22.02 | 2.43 | *** | 6.21 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.695 | | | 0.583 | | | 0.912 | | | 0.709 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 5:** Maturity transformation returns

Risk is measured as the standard deviation of maturity transformation returns. Table 6 illustrates the results with risk as the dependent variable. Maturity transformation coefficients are again interpreted relative to $MTG_1$. For EBP and MVBP as well as for sample I and II, risk increases with maturity gaps. It can be observed that MVBP results are considerably higher than EBP results. One argument is that MVBP risk is captured by total cash-flow return volatility, while EBP volatility is based on one-year net interest income returns. Altogether, hypotheses H2 "Increasing maturity gaps lead to rising maturity transformation risk", H2a "Increasing maturity gaps lead to rising maturity transformation risk during a period of high interest rates" and H2b "Increasing maturity gaps lead to rising maturity transformation risk during a period of low interest rates" cannot be rejected. This also applies to both EBP and MVBP.

| | **Sample I** | | | | | | **Sample II** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | -0.32 | *** | -3.18 | 0.04 | | 0.25 | 0.06 | | 1.36 | 0.28 | ** | 2.49 |
| Level°° | 0.06 | *** | 4.45 | 0.02 | | 0.79 | 0.02 | | 1.08 | 0.03 | | 0.41 |
| Slope°° | 0.04 | | 1.51 | 0.04 | | 0.78 | -0.01 | | -0.52 | -0.08 | * | -1.95 |
| $MTG_2$ | 0.13 | ** | 2.34 | 0.30 | *** | 8.14 | 0.05 | ** | 2.46 | 0.27 | *** | 9.64 |
| $MTG_3$ | 0.26 | *** | 5.09 | 0.63 | *** | 17.99 | 0.09 | *** | 5.12 | 0.54 | *** | 19.95 |
| $MTG_4$ | 0.39 | *** | 8.46 | 0.99 | *** | 28.69 | 0.15 | *** | 7.92 | 0.84 | *** | 29.21 |
| $MTG_5$ | 0.54 | *** | 12.46 | 1.38 | *** | 38.33 | 0.23 | *** | 10.17 | 1.15 | *** | 36.30 |
| $MTG_6$ | 0.72 | *** | 16.50 | 1.80 | *** | 45.09 | 0.36 | *** | 14.82 | 1.49 | *** | 40.24 |
| $MTG_7$ | 0.92 | *** | 18.53 | 2.27 | *** | 48.67 | 0.55 | *** | 24.62 | 1.84 | *** | 40.59 |
| $MTG_8$ | 1.14 | *** | 18.84 | 2.77 | *** | 49.95 | 0.78 | *** | 33.96 | 2.23 | *** | 38.40 |
| $MTG_9$ | 1.38 | *** | 19.61 | 3.25 | *** | 49.25 | 1.04 | *** | 32.84 | 2.64 | *** | 35.79 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.868 | | | 0.910 | | | 0.936 | | | 0.885 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 6:** Maturity transformation return volatility

Table 7 shows the performance results of maturity transformation strategies as the dependent variable. Sample I coefficients of EBP reveal superior performance for medium-term and long-term gaps.

Although not significant, during the period of high interest rates, gap coefficients increase for MVBP from 1.46% to 15.43%. EBP and MVBP results indicate that medium-term and long-term gaps slightly dominate during periods of high interest rates. During periods of low interest rates, significant performance differences can be observed for EBP and MVBP maturity transformation strategies. For EBP, $MTG_3$ to $MTG_6$ coefficients are significantly positive. For MVBP, coefficients $MTG_8$ and $MTG_9$ are significantly negative. The results show that during the period of low interest rates, short-term and medium-term maturity transformation strategies dominate from a market value as well as from an earnings-based perspective. Thus, hypothesis H3 "There is no efficient maturity transformation strategy" has to be rejected. In the case of sample I, EBP medium and long-term coefficients significantly exceed $MTG_1$. For MVBP, sample I coefficients show a slight tendency toward long-term gaps. Although we cannot clearly reject hypothesis H3a "There is no optimal risk return combination during a period of high interest rates", performance results indicate that medium-term and long-term gaps slightly dominate during the period of high interest rates. In the period of low interest rates, a dominant risk/return relationship prevails for short-term to medium-term gaps for EBP and MVBP. Thus, hypothesis H3b "There is no optimal risk/return combination during a period of low interest rates" can be rejected as well since dominant risk/return relationships are observed for maturity transformation strategies.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 304.06 | *** | 8.60 | -431.07 | *** | -14.25 | 255.91 | ** | 2.29 | -355.90 | *** | -7.56 |
| Level°° | -37.52 | *** | -6.82 | 77.25 | *** | 17.56 | -85.81 | ** | -2.37 | 173.15 | *** | 13.24 |
| Slope°° | -15.30 | | -1.60 | 152.89 | *** | 23.30 | 0.41 | | 0.01 | 176.79 | *** | 9.86 |
| $MTG_2$ | 9.54 | | 0.47 | 1.46 | | 0.17 | 95.56 | * | 1.73 | -0.59 | | -0.04 |
| $MTG_3$ | 21.04 | | 1.07 | 3.20 | | 0.39 | 176.81 | *** | 3.20 | -1.46 | | -0.10 |
| $MTG_4$ | 37.82 | * | 1.86 | 5.17 | | 0.64 | 223.96 | *** | 4.16 | -3.09 | | -0.21 |
| $MTG_5$ | 50.53 | ** | 2.43 | 7.36 | | 0.91 | 215.75 | *** | 3.52 | -5.85 | | -0.41 |
| $MTG_6$ | 50.24 | ** | 2.57 | 9.60 | | 1.16 | 117.38 | ** | 2.39 | -9.85 | | -0.71 |
| $MTG_7$ | 48.20 | ** | 2.42 | 11.73 | | 1.36 | 27.06 | | 0.62 | -15.36 | | -1.13 |
| $MTG_8$ | 45.99 | ** | 2.14 | 13.58 | | 1.49 | -35.20 | | -0.79 | -22.70 | * | -1.67 |
| $MTG_9$ | 42.05 | * | 1.80 | 15.43 | | 1.58 | -83.64 | * | -1.83 | -31.61 | ** | -2.30 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.605 | | | 0.721 | | | 0.428 | | | 0.782 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 7:** Performance of maturity transformation strategies

### *5.3 AR terms*

Return, risk and performance results are controlled for heteroscedasticity and autocorrelation according to Newey and West (1987). Since dependent variables are constructed as a rolling window, we also apply the Breusch (1978) and Godfrey (1978) serial autocorrelation LM test. Relying on test results and the Schwarz information criterion (SIC), AR terms are used to estimate the returns, risk and performance of maturity transformation strategies.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 0.85 | *** | 4.41 | -7.05 | *** | -6.29 | 0.31 | | 1.11 | -1.55 | *** | -4.18 |
| Level°° | -0.20 | *** | -17.64 | 1.28 | *** | 17.04 | -0.17 | * | -9.06 | 0.89 | *** | 9.95 |
| Slope°° | -0.02 | | -1.34 | 1.67 | *** | 18.67 | 0.03 | *** | 2.84 | 1.35 | *** | 13.66 |
| $MTG_2$ | 0.16 | | 0.63 | 0.20 | | 0.14 | 0.25 | | 0.65 | 0.31 | | 0.86 |
| $MTG_3$ | 0.34 | | 1.36 | 0.42 | | 0.29 | 0.62 | | 1.59 | 0.65 | * | 1.77 |
| $MTG_4$ | 0.53 | ** | 2.08 | 0.69 | | 0.47 | 0.83 | ** | 2.14 | 0.99 | *** | 2.72 |
| $MTG_5$ | 0.75 | *** | 2.97 | 1.00 | | 0.68 | 1.19 | *** | 3.05 | 1.34 | *** | 3.67 |
| $MTG_6$ | 1.00 | *** | 3.97 | 1.36 | | 0.93 | 1.48 | *** | 3.76 | 1.68 | *** | 4.60 |
| $MTG_7$ | 1.32 | *** | 5.23 | 1.78 | | 1.22 | 1.75 | *** | 4.38 | 1.99 | *** | 5.47 |
| $MTG_8$ | 1.68 | *** | 6.64 | 2.24 | | 1.53 | 2.02 | *** | 4.99 | 2.26 | *** | 6.20 |
| $MTG_9$ | 2.17 | *** | 8.56 | 2.72 | * | 1.86 | 2.57 | *** | 6.54 | 2.45 | *** | 6.72 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.993 | | | 0.942 | | | 0.996 | | | 0.947 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 8:** Maturity transformation return results including AR terms

Table 8 shows the results of maturity transformation returns according to regression specification (6). For sample I and II of EBP and MVBP, gap coefficients increase from $MTG_2$ to $MTG_9$. During the period of high interest rates, only coefficient $MTG_9$ is significant for MVBP. However, t statistics increase with maturity gaps. Altogether, we interpret the results to mean that hypotheses H1, H1a and H1b cannot be rejected when AR terms are included.

Return volatility results including AR terms as illustrated in Table 9 largely correspond to the Table 6 results. For EBP and MVBP, maturity gap coefficients significantly increase from short-term to long-term gaps. Again, MVBP coefficients exceed those of EBP due to the inclusion of total cash flows. Consistent with the Table 6 results, hypotheses H2, H2a and H2b cannot be rejected when AR terms are included.

| | Sample I | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 0.11 | | 1.01 | 0.30 | | 1.51 | 0.09 | ** | 2.34 | 0.29 | *** | 5.15 |
| Level°° | 0.00 | | -0.23 | -0.03 | *** | -3.61 | 0.01 | | 5.15 | -0.02 | | -1.01 |
| Slope°° | 0.00 | | 1.25 | -0.01 | | -0.50 | 0.00 | | -1.34 | -0.09 | *** | -7.71 |
| $MTG_2$ | 0.13 | | 0.85 | 0.29 | | 1.11 | 0.05 | | 1.10 | 0.26 | *** | 5.42 |
| $MTG_3$ | 0.26 | * | 1.77 | 0.60 | ** | 2.31 | 0.10 | ** | 2.12 | 0.54 | *** | 11.13 |
| $MTG_4$ | 0.39 | *** | 2.63 | 0.94 | *** | 3.62 | 0.15 | *** | 3.31 | 0.83 | *** | 17.16 |
| $MTG_5$ | 0.54 | *** | 3.63 | 1.31 | *** | 5.05 | 0.23 | *** | 5.21 | 1.14 | *** | 23.57 |
| $MTG_6$ | 0.71 | *** | 4.80 | 1.72 | *** | 6.61 | 0.36 | *** | 8.04 | 1.47 | *** | 30.42 |
| $MTG_7$ | 0.93 | *** | 6.24 | 2.18 | *** | 8.35 | 0.56 | *** | 12.38 | 1.83 | *** | 37.78 |
| $MTG_8$ | 1.17 | *** | 7.91 | 2.68 | *** | 10.25 | 0.78 | *** | 17.32 | 2.21 | *** | 45.71 |
| $MTG_9$ | 1.58 | *** | 10.52 | 3.19 | *** | 12.09 | 1.00 | *** | 21.96 | 2.63 | *** | 53.78 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.999 | | | 0.994 | | | 0.999 | | | 0.995 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 9:** Maturity transformation return volatility results including AR terms

Performance results including AR terms are illustrated in Table 10. Sample I maturity coefficients are not significant for EBP and MVBP. According to the Table 7 results, we cannot reject hypothesis H3a. However, maturity transformation coefficients again increase with gaps. Also in line with Table 7, short-term to medium-term gaps dominate during the period of low interest rates. Hence, hypothesis H3 and H3b can be rejected.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 181.15 | *** | 5.82 | -590.85 | *** | -3.52 | 214.64 | *** | 2.64 | -616.63 | *** | -25.30 |
| Level°° | -19.33 | *** | -11.15 | 106.87 | *** | 20.57 | -32.56 | *** | -2.73 | 193.34 | *** | 21.17 |
| Slope°° | -3.03 | | -1.44 | 127.55 | *** | 21.74 | 18.76 | ** | 2.37 | 238.06 | *** | 32.19 |
| $MTG_2$ | 1.48 | | 0.04 | 34.80 | | 0.16 | 90.63 | | 0.88 | -0.71 | | -0.11 |
| $MTG_3$ | 14.88 | | 0.37 | 41.16 | | 0.18 | 186.50 | * | 1.82 | -1.77 | | -0.27 |
| $MTG_4$ | 26.07 | | 0.65 | 44.21 | | 0.19 | 214.80 | ** | 2.09 | -3.60 | | -0.55 |
| $MTG_5$ | 37.99 | | 0.95 | 47.09 | | 0.21 | 212.38 | ** | 2.07 | -6.52 | | -0.99 |
| $MTG_6$ | 35.54 | | 0.89 | 50.15 | | 0.22 | 113.73 | | 1.11 | -10.64 | | -1.62 |
| $MTG_7$ | 37.77 | | 0.95 | 53.06 | | 0.23 | 20.80 | | 0.20 | -16.15 | ** | -2.46 |
| $MTG_8$ | 38.76 | | 0.97 | 58.64 | | 0.26 | -39.64 | | -0.39 | -23.35 | *** | -3.56 |
| $MTG_9$ | 47.59 | | 1.20 | 92.15 | | 0.39 | -64.91 | | -0.63 | -31.92 | *** | -4.86 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.984 | | | 0.920 | | | 0.959 | | | 0.926 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 10:** Maturity transformation performance results including AR terms

## 6. Robustness

### 6.1 Changes in yield levels

During the period of low interest rates, a dominant maturity transformation strategy can be identified for short-term to medium-term gaps. In order to demonstrate the robustness of the results, we analyse the performance for upward and downward movements in yield levels. The results can also be applied for decisions that include future expectations. To capture the changes for all maturities, we calculate average yield levels at time $t$, $\emptyset Level_t$. Changes in average yield levels are identified by the annual differences between $\emptyset Level_t$ and $\emptyset Level_{t+1y}$. We estimate regression specification (8) for increases and decreases in average yield levels. Again, both perspectives, EBP and MVBP, are included. EBP returns are not influenced by annual changes in the average yield level since coupon payments at time $t+1y$ are fixed at time $t$. Hence, we expect that EBP subsample results qualitatively correspond to

Table 7. MVBP results are influenced by changes in the average yield level since CFs are discounted at time $t + 1y$ by applying DFs that rely on the yield structure at time $t + 1y$.

| | **Upward movement** | | | | | | **Downward movement** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 56.13 | | 0.60 | -125.79 | *** | -5.28 | 171.90 | | 1.30 | -301.96 | *** | -5.86 |
| Level°° | -104.55 | *** | -2.86 | 118.38 | *** | 8.66 | 20.89 | | 0.37 | 257.50 | *** | 11.52 |
| Slope°° | 135.58 | ** | 2.34 | 292.62 | *** | 22.53 | -1.96 | | -0.05 | 129.58 | *** | 7.57 |
| $MTG_2$ | 31.64 | | 0.45 | -2.98 | | -0.16 | 120.97 | * | 1.82 | 0.36 | | 0.03 |
| $MTG_3$ | 121.69 | ** | 2.08 | -7.33 | | -0.42 | 198.71 | *** | 2.84 | 0.88 | | 0.07 |
| $MTG_4$ | 228.70 | ** | 2.44 | -13.08 | | -0.78 | 222.08 | *** | 3.88 | 0.87 | | 0.07 |
| $MTG_5$ | 196.50 | ** | 2.38 | -20.54 | | -1.27 | 223.39 | *** | 3.05 | -0.01 | | 0.00 |
| $MTG_6$ | 114.88 | * | 1.90 | -29.79 | * | -1.89 | 118.38 | ** | 1.96 | -1.93 | | -0.16 |
| $MTG_7$ | 44.61 | | 0.72 | -41.02 | ** | -2.58 | 20.09 | | 0.40 | -5.16 | | -0.44 |
| $MTG_8$ | -32.69 | | -0.56 | -54.14 | *** | -3.31 | -36.19 | | -0.68 | -10.20 | | -0.86 |
| $MTG_9$ | -99.44 | | -1.64 | -68.67 | *** | -4.01 | -77.37 | | -1.39 | -16.88 | | -1.38 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 279 | | | 279 | | | 702 | | | 702 | | |
| Adj. $R^2$ | 0.503 | | | 0.895 | | | 0.415 | | | 0.735 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 11:** Performance of maturity transformation strategies for changing average yield levels

The Table 11 results show that EBP coefficients are qualitatively comparable to Table 7. For upward movements, short-term to medium-term gaps show a dominant risk/return relationship. Although not to a significant level, for downward movements, short-term and medium-term coefficients exceed those of long-term gaps for MVBP. This is also the case for the EBP results, but at a significant level.

| | Upward movement | | | | | | Downward movement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | -286.79 | | -1.38 | -86.39 | *** | -6.56 | 200.37 | ** | 2.39 | -696.96 | *** | -28.33 |
| Level°° | -161.01 | *** | -7.42 | -42.16 | *** | -3.40 | -67.98 | *** | -3.75 | 179.89 | *** | 14.01 |
| Slope°° | -124.86 | | -4.80 | 176.58 | *** | 26.09 | 32.75 | *** | 3.29 | 273.14 | *** | 35.17 |
| $MTG_2$ | 132.14 | | 0.50 | -3.53 | | -0.54 | 93.23 | | 0.96 | -0.11 | | -0.02 |
| $MTG_3$ | 262.23 | | 0.97 | -7.39 | | -1.13 | 212.25 | ** | 2.19 | -0.19 | | -0.04 |
| $MTG_4$ | 220.35 | | 0.82 | -11.68 | * | -1.78 | 268.82 | *** | 2.77 | -0.60 | | -0.12 |
| $MTG_5$ | 216.26 | | 0.83 | -17.93 | ** | -2.74 | 266.41 | *** | 2.74 | -1.75 | | -0.34 |
| $MTG_6$ | 280.87 | | 1.07 | -25.63 | *** | -3.91 | 154.43 | | 1.59 | -3.75 | | -0.72 |
| $MTG_7$ | 267.99 | | 1.02 | -35.79 | *** | -5.46 | 54.27 | | 0.56 | -6.86 | | -1.32 |
| $MTG_8$ | 216.78 | | 0.83 | -48.41 | *** | -7.39 | -18.88 | | -0.19 | -11.54 | ** | -2.21 |
| $MTG_9$ | 194.94 | | 0.75 | -62.72 | *** | -9.51 | -47.89 | | -0.49 | -17.43 | *** | -3.33 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 279 | | | 279 | | | 702 | | | 702 | | |
| Adj. $R^2$ | 0.989 | | | 0.997 | | | 0.959 | | | 0.910 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 12:** Performance of maturity transformation strategies for changing average yield levels including AR terms

Performance results including AR terms are shown in Table 12. Coefficients qualitatively confirm those of Table 11 and Table 7. Altogether, the analysis shows that during the period of low interest rates, short-term and medium-term gaps dominate. This is also the case for upward- and downward-moving yield levels. For moderate developments like those during the sample period of low interest rates, where upward movements range between 0.03% and 0.743% or downward movements between -0.014% and -2.095%, short-term to medium-term gaps are dominant.

6.2 Regression specifications excluding the slope coefficient

To address multicollinearity between level and slope, we conduct further robustness tests. In the following, we illustrate performance characteristics for EBP and MVBP during periods of high and low interest rates, where slope is excluded as influencing factor. Table 13 shows the results of maturity transformation performance as the dependent variable. Regression specifications are controlled for heteroscedasticity and autocorrelation according to Newey and West (1987). Sample 1 and 2 EBP as well as MVBP results closely correspond to Table 7 results.

| | **Sample I** | | | | | | **Sample II** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 259.42 | *** | 10.52 | 15.07 | | 0.89 | 257.03 | *** | 4.91 | 129.92 | *** | 6.89 |
| Level°° | -31.14 | *** | -8.22 | 13.41 | *** | 5.76 | -85.83 | ** | -2.37 | 161.60 | *** | 10.80 |
| $MTG_2$ | 9.54 | | 0.47 | 1.46 | | 0.13 | 95.56 | * | 1.73 | -0.59 | | -0.03 |
| $MTG_3$ | 21.04 | | 1.07 | 3.20 | | 0.28 | 176.81 | *** | 3.20 | -1.46 | | -0.07 |
| $MTG_4$ | 37.82 | * | 1.86 | 5.17 | | 0.46 | 223.96 | *** | 4.16 | -3.09 | | -0.16 |
| $MTG_5$ | 50.53 | ** | 2.44 | 7.36 | | 0.65 | 215.75 | *** | 3.52 | -5.85 | | -0.32 |
| $MTG_6$ | 50.24 | ** | 2.57 | 9.60 | | 0.84 | 117.38 | ** | 2.39 | -9.85 | | -0.55 |
| $MTG_7$ | 48.20 | ** | 2.42 | 11.73 | | 1.01 | 27.06 | | 0.62 | -15.36 | | -0.87 |
| $MTG_8$ | 45.99 | ** | 2.14 | 13.58 | | 1.15 | -35.20 | | -0.79 | -22.70 | | -1.31 |
| $MTG_9$ | 42.05 | * | 1.80 | 15.43 | | 1.26 | -83.64 | * | -1.83 | -31.61 | * | -1.84 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.604 | | | 0.566 | | | 0.428 | | | 0.678 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 13:** Performance of maturity transformation strategies excluding slope

To account for serial autocorrelation, AR terms are applied. Table 14 shows the performance results including AR terms. Again, sample 1 and 2 results qualitatively confirm MTG coefficients as illustrated in Table 10, where the slope is included as independent variable.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 171.37 | *** | 5.57 | -27.43 | | -0.72 | 261.38 | *** | 3.30 | 90.85 | *** | 6.54 |
| Level°° | -17.96 | *** | -12.23 | 24.15 | *** | 7.58 | -34.59 | *** | -2.90 | 154.54 | *** | 13.97 |
| $MTG_2$ | 1.34 | | 0.03 | 1.34 | | 0.03 | 90.22 | | 0.87 | -0.72 | | -0.09 |
| $MTG_3$ | 14.78 | | 0.37 | 3.14 | | 0.06 | 185.71 | * | 1.80 | -1.79 | | -0.22 |
| $MTG_4$ | 25.87 | | 0.64 | 5.16 | | 0.11 | 213.67 | ** | 2.06 | -3.63 | | -0.45 |
| $MTG_5$ | 37.78 | | 0.93 | 7.41 | | 0.15 | 210.82 | ** | 2.04 | -6.56 | | -0.81 |
| $MTG_6$ | 35.26 | | 0.87 | 9.72 | | 0.20 | 112.65 | | 1.09 | -10.69 | | -1.32 |
| $MTG_7$ | 37.50 | | 0.93 | 11.83 | | 0.24 | 20.26 | | 0.20 | -16.21 | * | -2.00 |
| $MTG_8$ | 38.51 | | 0.95 | 13.48 | | 0.28 | -39.56 | | -0.38 | -23.43 | *** | -2.90 |
| $MTG_9$ | 47.64 | | 1.18 | 14.71 | | 0.30 | -64.41 | | -0.62 | -32.04 | *** | -3.96 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.984 | | | 0.892 | | | 0.959 | | | 0.884 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 14:** Maturity transformation performance results excluding slope and including AR terms

### 6.3 Risk and performance results of the 5-year volatility measure

For robustness purposes, we also measure risk as 5-year standard deviation of preceding maturity transformation returns. Examples of 5-year periods of return volatility can be found in Poshakwale and Courtis (2005) and Schmidhammer (2018). The 5-year measure closely corresponds to the period of low interest rates. Since the volatility of maturity transformation returns during the period of low interest rates is below the volatility during the period of high interest rates (see Table 3 results), we expect $MTG$ coefficients below the level of the 10-year measure. Table 15 illustrates the results for EBP and MVBP for sample I and II. To correct for heteroscedasticity in the sample's residuals, Newey and West (1987) is applied. For EBP and MVBP as well as for sample I and II, risk increases with maturity gaps. Altogether, Table 15 results are in line with Table 6 outcomes. As expected, $MTG$ coefficients of the 5-year volatility measure are (slightly) below those of the 10-year measure. Again, MVBP coefficients exceed those of EBP.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **EBP** | | | **MVBP** | | | **EBP** | | | **MVBP** | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | -0.14 | | -1.29 | -0.19 | | -0.64 | 0.15 | | 1.14 | 0.98 | *** | 4.60 |
| Level°° | 0.04 | *** | 2.68 | 0.04 | | 1.02 | 0.02 | | 0.29 | -0.13 | * | -1.88 |
| Slope°° | 0.04 | | 1.21 | 0.05 | | 0.53 | -0.02 | | -0.35 | -0.17 | ** | -2.43 |
| $MTG_2$ | 0.08 | | 1.53 | 0.28 | *** | 4.80 | 0.03 | | 1.01 | 0.26 | *** | 5.81 |
| $MTG_3$ | 0.15 | *** | 2.99 | 0.58 | *** | 10.66 | 0.07 | | 1.58 | 0.53 | *** | 10.93 |
| $MTG_4$ | 0.21 | *** | 4.50 | 0.91 | *** | 16.94 | 0.10 | * | 1.92 | 0.80 | *** | 16.00 |
| $MTG_5$ | 0.30 | *** | 6.55 | 1.27 | *** | 22.31 | 0.17 | *** | 3.39 | 1.09 | *** | 21.26 |
| $MTG_6$ | 0.44 | *** | 9.53 | 1.66 | *** | 25.73 | 0.26 | *** | 6.59 | 1.39 | *** | 25.64 |
| $MTG_7$ | 0.62 | *** | 12.04 | 2.07 | *** | 27.27 | 0.38 | *** | 9.22 | 1.69 | *** | 26.35 |
| $MTG_8$ | 0.81 | *** | 13.16 | 2.51 | *** | 27.66 | 0.53 | *** | 7.60 | 2.02 | *** | 23.03 |
| $MTG_9$ | 1.00 | *** | 13.91 | 2.91 | *** | 27.77 | 0.70 | *** | 6.43 | 2.35 | *** | 18.76 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.760 | | | 0.771 | | | 0.542 | | | 0.763 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 15:** Maturity transformation return volatility based on shorter volatility measure

The same is valid for regression specifications including AR terms as illustrated in Table 16. Coefficients of 5-year period standard deviations increase with maturity gaps. Risk results qualitatively confirm those of 10-year period standard deviation outcomes shown in Table 9.

| | Sample I | | | | | | | Sample II | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 0.06 | | 0.77 | -0.01 | | -0.08 | 0.19 | ** | 2.03 | 0.43 | *** | 3.00 |
| Level°° | 0.01 | | 1.20 | 0.01 | | 0.46 | 0.00 | | -0.53 | -0.14 | *** | -3.05 |
| Slope°° | 0.01 | ** | 2.34 | 0.00 | | -0.21 | 0.00 | | 0.18 | 0.03 | | 0.82 |
| $MTG_2$ | 0.08 | | 0.87 | 0.28 | *** | 2.77 | 0.04 | | 0.31 | 0.26 | ** | 2.35 |
| $MTG_3$ | 0.15 | * | 1.68 | 0.58 | *** | 5.76 | 0.06 | | 0.46 | 0.52 | *** | 4.77 |
| $MTG_4$ | 0.23 | ** | 2.45 | 0.91 | *** | 9.00 | 0.08 | | 0.66 | 0.80 | *** | 7.27 |
| $MTG_5$ | 0.29 | *** | 3.20 | 1.27 | *** | 12.53 | 0.12 | | 0.99 | 1.08 | *** | 9.86 |
| $MTG_6$ | 0.42 | *** | 4.59 | 1.65 | *** | 16.34 | 0.24 | ** | 1.98 | 1.38 | *** | 12.52 |
| $MTG_7$ | 0.59 | *** | 6.43 | 2.07 | *** | 20.45 | 0.38 | *** | 3.11 | 1.68 | *** | 15.27 |
| $MTG_8$ | 0.78 | *** | 8.51 | 2.50 | *** | 24.72 | 0.57 | *** | 4.57 | 2.00 | *** | 18.10 |
| $MTG_9$ | 0.98 | *** | 10.68 | 2.90 | *** | 28.71 | 0.65 | *** | 5.19 | 2.33 | *** | 20.89 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.993 | | | 0.973 | | | 0.991 | | | 0.958 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 16:** Maturity transformation return volatility results based on shorter volatility measure including AR terms

The performance of maturity transformation strategies now relies on a 5-year volatility measure. Table 17 shows the results of maturity transformation performance as the dependent variable. Regression specifications are controlled for heteroscedasticity and autocorrelation according to Newey and West (1987). EBP coefficients reveal superior performance for medium-term and long-term gaps during periods of high interest rates for both samples. Although not significant, sample I gap coefficients increase for MVBP. During the period of low interest rates, short-term and medium-term coefficients are significantly positive. For sample II, MVBP coefficients are negative and increase in value with maturity gaps. For $MTG_9$, a significant negative coefficient can be observed. Table 17 qualitatively confirms the performance results of Table 7, where short-term and medium-term maturity transformation strategies dominate for EBP and MVBP during the period of low interest rates.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 4.08 | *** | 4.08 | -417.22 | *** | -11.76 | 419.27 | | 1.09 | -559.82 | *** | -11.52 |
| Level°° | -0.58 | *** | -4.44 | 77.89 | *** | 15.54 | -194.84 | * | -1.84 | 256.91 | *** | 14.21 |
| Slope°° | -0.26 | | -1.10 | 156.90 | *** | 20.32 | -21.12 | | -0.16 | 211.34 | *** | 12.36 |
| $MTG_2$ | 50.82 | | 1.51 | 1.13 | | 0.08 | 292.32 | * | 1.84 | 0.25 | | 0.02 |
| $MTG_3$ | 126.97 | *** | 3.05 | 2.08 | | 0.15 | 377.38 | ** | 2.44 | -0.50 | | -0.03 |
| $MTG_4$ | 194.38 | *** | 3.87 | 2.95 | | 0.22 | 575.95 | *** | 2.98 | -2.19 | | -0.15 |
| $MTG_5$ | 220.54 | *** | 4.14 | 4.13 | | 0.32 | 255.59 | ** | 1.98 | -5.06 | | -0.37 |
| $MTG_6$ | 164.26 | *** | 3.77 | 5.05 | | 0.39 | 153.52 | | 1.28 | -9.02 | | -0.67 |
| $MTG_7$ | 91.06 | *** | 2.77 | 5.75 | | 0.43 | 220.62 | | 1.48 | -14.18 | | -1.05 |
| $MTG_8$ | 61.40 | * | 1.72 | 6.25 | | 0.44 | 187.00 | | 1.43 | -21.05 | | -1.52 |
| $MTG_9$ | 41.09 | | 1.01 | 7.24 | | 0.45 | 92.93 | | 0.91 | -29.68 | * | -2.02 |
| $D_y^{Time}$ | yes | | | Yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.583 | | | 0.583 | | | 0.141 | | | 0.788 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 17:** Performance of maturity transformation strategies based on shorter volatility measure

To account for serial autocorrelation, AR terms are applied. Table 18 shows the performance results including AR terms. For sample I, EBP and MVBP results are in line with those of Table 10 and qualitatively confirm the performance results based on the 10-year volatility measure. Although not significant, EBP results of short-term to medium-term gaps exceed those of long-term gaps during the period of low interest rates. For MVBP results, long-term gap coefficients are significantly negative which corresponds to Table 10 outcomes. Altogether risk and performance results of the 5-year volatility measure qualitatively confirm those of the 10-year volatility measure.

| | Sample I | | | | | | Sample II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EBP | | | MVBP | | | EBP | | | MVBP | | |
| | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. | Coeff.° (%) | | t Stat. |
| Const. | 299.41 | *** | 2.96 | -293.25 | *** | -6.92 | 203.94 | | 0.63 | -552.70 | *** | -15.56 |
| Level°° | -37.51 | *** | -4.83 | 64.89 | *** | 10.59 | -32.51 | | -0.50 | 241.71 | *** | 18.44 |
| Slope°° | -5.64 | | -0.54 | 134.33 | *** | 13.83 | 43.84 | | 0.86 | 202.29 | *** | 17.57 |
| $MTG_2$ | 47.34 | | 0.39 | 0.95 | | 0.06 | 242.41 | | 0.65 | 0.15 | | 0.02 |
| $MTG_3$ | 124.67 | | 1.04 | 1.69 | | 0.11 | 348.94 | | 0.93 | -0.79 | | -0.09 |
| $MTG_4$ | 197.71 | | 1.64 | 2.31 | | 0.15 | 504.59 | | 1.35 | -2.71 | | -0.31 |
| $MTG_5$ | 240.12 | ** | 1.99 | 3.21 | | 0.21 | 365.01 | | 0.97 | -5.86 | | -0.66 |
| $MTG_6$ | 134.84 | | 1.12 | 3.82 | | 0.25 | 261.07 | | 0.69 | -10.10 | | -1.14 |
| $MTG_7$ | 58.52 | | 0.49 | 4.16 | | 0.27 | 255.75 | | 0.68 | -15.50 | * | -1.75 |
| $MTG_8$ | 35.51 | | 0.30 | 4.27 | | 0.28 | 195.02 | | 0.52 | -22.56 | ** | -2.54 |
| $MTG_9$ | 30.00 | | 0.25 | 4.86 | | 0.32 | 161.73 | | 0.43 | -31.21 | *** | -3.51 |
| $D_y^{Time}$ | yes | | | yes | | | yes | | | yes | | |
| AR terms | yes | | | yes | | | yes | | | yes | | |
| N | 1,908 | | | 1,908 | | | 981 | | | 981 | | |
| Adj. $R^2$ | 0.930 | | | 0.768 | | | 0.840 | | | 0.895 | | |

° Significance levels are 10% = *, 5% = ** and 1% = ***. °° absolute values

**Table 18:** Maturity transformation performance results based on shorter volatility measure including AR terms

## 7. Conclusion

A rich body of papers analyse interest rate risk, determining the sensitivity of banks' equity prices to changes in interest rates. Another literature stream focuses on determinants that influence interest margins. Memmel (2011) looks at the profitability of maturity transformation, relying on moving averages of ten-year bond ladder yields for assets financed by a one-year ladder of liabilities. We extend his methodology and analyse different maturity transformation strategies by varying the maturity ladder for liabilities. Furthermore, we address both an earnings-based and a market value-based perspective.

To the best of our knowledge, this paper is the first to capture the influence of defined maturity transformation strategies in terms of return, risk and performance. We rely on Merton (1980) and Memmel (2011) and apply rolling windows of returns. Due to the availability of German government bond data, we construct monthly rolling windows of annual maturity transformation returns. German government bonds can be considered to be free of default risk, which allows us to focus purely on maturity transformation characteristics. Furthermore, our time span includes a period of high as well as low interest rates.

The idea of maturity transformation, using the differences between long and short-term interest rates, can be found in the literature concerning riding-the-yield-curve-strategies. These are active investment strategies, in which longer-dated fixed-income securities are bought and sold before maturity. In contrast to riding-the-yield-curve our approach pursues a passive strategy as frequently used in banks for interest rate risk management. We use various bond ladders to implement different maturity transformation strategies.

The results show that maturity transformation risk and returns significantly increase with gaps. This can be observed for the period of high and low interest rates. The relationship exists for both EBP and MVBP. Our results are in line with Markowitz's portfolio theory (1952), where increases in returns lead to increases in risk. However, during the period of low interest rates, dominant risk/return relationships can be observed. The performance of short-term to medium-term gaps is significantly higher for EBP and MVBP. Relying on Fama (1970, 1991), our results indicate that market yields are not perfectly efficient.

We validated our results by diverse robustness tests. The inclusion of AR terms confirms the OLS regression results. Further, we analysed performance for yield level changes. In addition, we analyse the performance of maturity transformation strategies when the slope coefficient is excluded as independent variable and we conduct a robustness test using a shorter 5-year volatility measure.

Our results provide valuable insights for strategic decisions concerning the management of a banks' banking book. From a pure risk/return perspective our results suggest short-term to medium-term maturity transformation gaps during periods of low interest rates. However, prudent managers should also take into consideration the risk-bearing capacity of their institution, liquidity constraints, risk appetite and future expectations.

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