Stress Testing of Liquidity Maturity Transformation Risk in Banks

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One of the main causes of the past crisis was the inability of financial institutions to acquire funding at appropriate costs. The importance of applying a good liquidity risk measurement system becomes apparent. The present paper provides an approach to the measurement of liquidity maturity transformation risk within a stress testing framework, for middle-sized banks. The costs of liquidity arising due to a downturn in refinancing conditions are calculated by using modern risk measures. The forward-looking way is based on a liquidity gap report, where the consideration of the counterbalancing capacity enables to gain an insight into the real liquidity needs. The measurement of both, the portfolio-value in the respective time bucket and liquidity costs, is possible. Applying the expected shortfall can easily be included into the calculation. The results show that by using historical simulation, if no sufficient data are available, expected shortfall delivers an approximate value. Still, it can serve as an indicator of insurance against extreme events. The present approach combines a scenario-based view to a possible distress with a quantitative risk measurement. Therewith, it contributes to the bank's wide stress testing as required by the regulatory authorities.

Keywords: liquidity risk, stress testing, value at risk, expected shortfall, funding risk, banking, historical simulation, spread risk, regulatory requirements

Introduction

The aim of this risk management method is to provide a detailed picture on a bank's key risk drivers and its risk positions in a forward-looking manner. Before the crisis, less attention to the measurement of liquidity risk was paid. In general, the used scenarios were too mild, the pre-crisis buffer was too small, and following the integration of liquidity risk stress test results into the decision-making process was poor (BCBS, 2009; 2013). Especially, one of the causes for deepening the crisis was the inability of banks to obtain sufficient amounts of funding at appropriate costs (ECB, 2016, pp. 36, 38).

The crisis also brought changes in the regulatory framework. The Basel Committee introduced new standards to mitigate the liquidity risks. The Liquidity Coverage Ratio (LCR) which requires a bank to hold sufficient liquid assets to resist a brief period of stress and the Net Stable Funding Ratio (NSFR) which limits the structural liquidity risk were introduced. Even if these ratios are a significant improvement of liquidity risk

measurement, additional stress tests are necessary to allow a comprehensive insight into the liquidity situation, especially for a longer time horizon and for analyzing of different scenarios, not just the required ones (Khan, Scheule, & Wu, 11/2015; Georgescu, Gross, Kapp, & Kok, 2017). Results of additional stress tests will also contribute to the future Supervisory Review and Evaluation Process (SREP) decisions. During 2017, the European Banking Authority (EBA) and the European Central Bank (ECB) published several guidelines to update for the revision of the SREP process and supervisory stress tests. The Internal Capital Adequacy Assessment Process (ICAAP) and the Internal Liquidity Adequacy Assessment Process (ILAAP) requirements should ensure that a bank is viable in times of crisis by looking at the current and prospective capital and liquidity sources and needs. To design appropriate stress tests remains a key challenge for banks. It requires implementing models with forecasting abilities, including an increasing number of flexible scenarios and an upgrade of IT infrastructures. Even if stress test is not a predictive tool, it helps to highlight potential problems and to identify opportunities for effective responses, by planning for prevention in advance (Matz, 2011, pp. 183-185). Facing the fact that stress testing guidelines are going to be finalized in 2018, banks should not underestimate the challenge.

There are two important subjects which make the present approach significant: the relevance of the structural liquidity risks and the complying with the regulatory requirements.

The Relevance of the Structural Liquidity Risk

The understanding of liquidity is multidimensional. In the time dimension, short-term and structural (often known as "funding" or long-term) liquidity can be distinguished. The management of short term liquidity includes the traditional interpretation of liquidity as the ability of the institution to meet its financial obligations as they come due. It focuses on the balancing of day-to-day payments (Bartetzky, 2010; Zeranski, 2005). The objective of the structural liquidity management is to balance the medium- and long-term liquidity structure of the balance sheet. It includes the maintenance of possibilities for a good market access, also called market liquidity, ensuring an appropriate funding with the focus on mitigation of losses due to a change in refinancing costs or of an institute's own refinancing curve (spread risk). The Liquidity Maturity Transformation (LMT) risk represents the risk of loss arising from changes in the bank's own refinancing curve, i.e., the liquidity spread curve, resulting from the LMT within a given time period at a certain security level (Bartetzky, 2010; Pohl, 2008, pp. 23, 25; Matz, 2011, p. 56).

Over the past years, measuring of structural liquidity risk has not received as much attention as it desires. The re-structuring of portfolios containing of financial instruments with middle to long maturities cannot be met rapidly. There are also no possibilities for hedging strategies because the necessary liquidity derivative does not exist. The adjustment is possible by taking balance-sheet-related arrangements only (Bartetzky, 2010). The expenses connected to the funding changes vary in dependence on the market conditions and liquidity as well as on the institute's own rating.

The crisis has showed that an insufficient control of structural liquidity risk leads to the shortage in refinancing possibilities. Due to an insufficient stock of securities for the purpose of a collateralized financing, for many institutions, the only way to prevent the bankruptcy was the balance sheet contraction. This has led straightly to credit crunch and yield reduction. Following, the institute's credit rating decreased. The downward spiral of a fall in value was triggered (Dietz, 2010; Brunnermeier & Pedersen, 2009).

The mutual interaction of the short-term and the structural liquidity risk is another significant reason to

intensify the attention to this topic (Pohl, 2008, p. 27; Bartetzky, 2010). To reach a desired outcome on the asset side, the liability side of the balance sheet has to be steered to reach a stable and reasonably priced financing. The widening of credit spreads, as in the crisis occurred, has impact to both sides of the balance sheet. On the active side, the prices deteriorate and on the passive side, the costs of borrowings on the money and capital markets increase. Hence, a simultaneous monitoring of both sides is necessary. Usually, the asset side risk is measured within the market risk management. Even when the LMT risk has similar yield effects as the other price risks, it was often neglected.

The impact of an unfavorable development of the institute's own liquidity spread to refinancing conditions is examined within the structural liquidity risk management. The reasons for liquidity spread switches can be different. They are affected by market conditions or by widening of credit spreads (Gann, 2010, pp. 34-40). They also can enlarge independently of the institute's own creditworthiness. If the spread widening lasts for longer time horizons, the profits from the LMT will decline, the sense of funding transactions will change, and consequently the business strategy will be negatively affected. Hence, a forward-looking approach to measuring this risk, especially under stressed conditions, by using modern methods, is a considerable step to improve the liquidity risk management.

Complying With the Regulatory Requirements

Banks are also facing the excessively increased liquidity risk regulatory requirements of Basel III and SREP as ICAAP/ILAAP. They are expected to implement risk quantification methods, for both Pillar 1 and Pillar 2 risks, fitting to their business models and risk profiles. Alongside the supervisory stress tests, they should use wide information on historic stress events and assume hypothetical scenarios of different level of severities and various time horizons (EBA, 2016; 2017). Even risks which are not easy to quantify have to be assessed. It should be possible to integrate the methodologies to the overall risk management process. As required by Article 73 of Directive 2013/36/EU, banks have i.e., to take a forward-looking view to their risk management, capital and liquidity planning. One of the appropriate tools for this purpose is stress testing.

For middle-sized banks by adopting internal liquidity stress tests, a proportionality rule is applicable (EBA, 2017, p. 4). They usually have a business structure for that copious and complex models are unsuitable, particularly regarding the limited possibility to maintain the required mathematical and methodological know-how and information technology. They often lack appropriate methods and IT infrastructures, in many cases they use vendors' model solutions (BCBS, 2013, pp. 34-35). Most banks focus on liquidity gaps analysis for different time horizons in a qualitative manner; some use risk quantification for the short-term liquidity risk. Measuring the LMT risk by using modern methods still is not common.

Hence, the previous methods require improvements in several aspects. In particular, the combination of scenario analysis and risk measurement of structural liquidity risk, is computing liquidity costs arising from shifts in refinancing conditions as well as considering of longer time horizons. To satisfy the EBA requirements and generate scenarios flexibly, an application of simulation method appears to be beneficial. To be able to include these risks to the overall risk management process, stochastic risk quantification and modern risk measures should be used.

For this type of banks, the approach for LMT stress testing has to be comprehensible and should base on known and in practice proven methodologies which should be enhanced by the individual demands of the respective institution. For this purpose, the present paper shows a forward-looking approach which meets these

criteria. The present case study, based on a hypothetical middle-sized German bank, intends to show in a simplified way: (1) how the present approach can be practically applied, and (2) how the expected shortfall contributes to the analysis of the outcomes.

Alongside the richness of regulatory papers and guidelines regarding liquidity risk, its measurement and stress testing, there are a few research papers written on similar topic.

Berkowitz (1999) provides a formal definition of stress tests and investigates the possibility to integrate stress testing into a basis risk model of a bank. This definition of stress test will be used here as a fundament for the liquidity risk measurement. Schmaltz, Pokutta, Heidorn, and Andrae (2013) develop a framework to achieve a Basel III compliance, an optimal strategy for a bank planning and combine it with the internal stress tests.

The present paper leans on Acerbi (2004) who shows the boundaries of VaR in liquidity risk measurement and underlines possibilities and problems for using of Expected Shortfall (ES). Yamai and Yoshiba (2002) compare VaR and ES and draw practical implication for the use in financial risk management by illustrating of some serious problems. There are some studies which derive mathematical proofs and results for measuring liquidity risk using coherent measures: Bangia, Diebold, Schuermann, & Stroughair (1999) study market liquidity and classify it in two categories: the exogenous and the endogenous illiquidity, and build a liquidity adjusted VaR using the distribution of the bid-ask spreads. Acerbi and Scandolo (2007) define a coherent standard risk measure on the liquidity-adjusted value of the portfolio. Weber, Anderson, Hamm, Knispel, Liese, and Salfeld (2013) extend this approach and construct cash-invariant liquidity-adjusted risk measure. Allaj (2017) presents a theoretical framework for incorporating of liquidity risk, arising from a bank's trading activities in securities, into the standard risk measures and discusses the VaR measure. Schmielewski (2010) and Muela, Martín, and Sanz (2017), use extreme value theory EVT by focusing on market liquidity risks.

Bartetzky (2008) defines the liquidity risks in two dimensions: as the inability to pay risks as they come due and as LMT risks. Zeranski (2005) provides a liquidity risk measurement approach for the first type of liquidity risks. For the measure of the second type of liquidity risks, Bartetzky (2008) proposes the VaR measure but he doesn't develop a closed valuation model. Until now, there is (to author's knowledge) no approach that would describe the combination of liquidity assets and the spread movement in a closed framework. The present article closes this gap and extends the suggested idea by developing a VaR/ES stress testing framework.

Pohl (2008) modifies the present value approach of the interest rate book management for the liquidity risk on the basis of the Liquidity Gap Report (LGR) focusing the entire time horizon of the business activities. He does not calculate VaR or ES. Schmitt (2017) extends the determination of the LGR by considering of non-contractual and behavioral CF and the Counterbalancing Capacity (CBC) and proposes a comprehensive liquidity gap report which is an appropriate base for liquidity and wealth evaluation and stress testing, as e.g., in the present study.

The present paper relies on research associated to Matz (2011) and Neu (2007) who view the liquidity risk as a consequential risk. It is increased in the wake of one or more spikes in other financial risks. Drehmann and Nikolau (2009) define the funding liquidity as a flow concept and differentiate two components: the future random cash flows and prices of obtaining funding from different sources. Neu (2007) sets on two principles for liquidity costs: (i) dependence on scenario, market conditions, bank balance sheet, and the bank's positioning in the market, and (ii) liquidity reserve reduces liquidity risks but increases liquidity costs. Gann

(2010) discusses different risk factors which influence the credit spreads amount in varying market phases.

Khan, Scheule, and Wu (11/2015) show that bank size and capital buffers may also affect the relation between liquidity risk taking and cost of funds. Dietrich, Hess, and Wanzenried (2014) found that banks with lower NSFR benefit from lower funding costs as a result of using less costly short-term funding.

Kapinos and Mitnik (2015) provide an overview of the stress testing practice in banks and review several critiques. Galiay and Maurin (2015) analyze the long-term view to the post crisis regulatory package by synthetic estimation of risk and show: (i) that regulatory changes affect bank's market funding costs, and (ii) a dampening effect of capital for funding and liquidity regulation. Schupp and Silbermann (2017) answer the questions of whether a stable funding makes German banks safer and reduces the probability of financial distress. The present paper complements the previous research by the possibility to quantify LMT risk in the selected time bucket.

The main aim of the present work is to present a new approach to stress testing structural liquidity risk, especially of measuring liquidity costs arising following the bank's own liquidity spread shifts, focusing the German middle-sized banks.

The risk measure should suit the pre-existing risk measures. It should be possible to integrate the structural liquidity risk into the overall risk management and allow for the aggregation of different kind of risks within the bank to achieve a comprehensive view to the overall risk situation. The present approach uses the well-known methods as VaR and historical simulation and enhances them by following methodical elements:

- Possibility to include different, complementary, or interacting stress tests.
- Enhancement of the liquidity gap with two important features:
    o including the CBC into the liquidity gap report which enables to control the really exposure to potential liquidity needs, after the balancing possibilities were absorbed,
    o procedure of prospective gaps closing, to make the calculation of the present value of liquidity costs possible—in each time bucket and not only through the entire time horizon.
- Simulation of the institute's own liquidity spread in each time bucket using historical simulation, for business as usual and stress scenarios.
- VaR based risk measurement, which usually is well known and used e.g., in market risk measurement.
- Extension of the classical VaR calculation by including the coherent risk measure Expected Shortfall. These measures can be aggregated on the bank-wide basis.
- Risk quantification for varying liquidity horizons.

The advantage of this approach is that it combines the liquidity assets (from the LGR) with the liquidity spread movements and measures the LMT risk which can be included into the risk management landscape of the focused bank group with not much additional effort and expenses. Thus, it allows for both: the forward-looking liquidity and the wealth estimation. Scenario analysis can be combined with quantitative risk measure. Hence, the risk manager can take necessary steps in a timely manner to prevent a possible financial distress.

Methodology and Data

The Quantitative Framework

To establish a stress testing of the LMT risk, a series of steps have to be implemented, as illustrated in Figure 1:
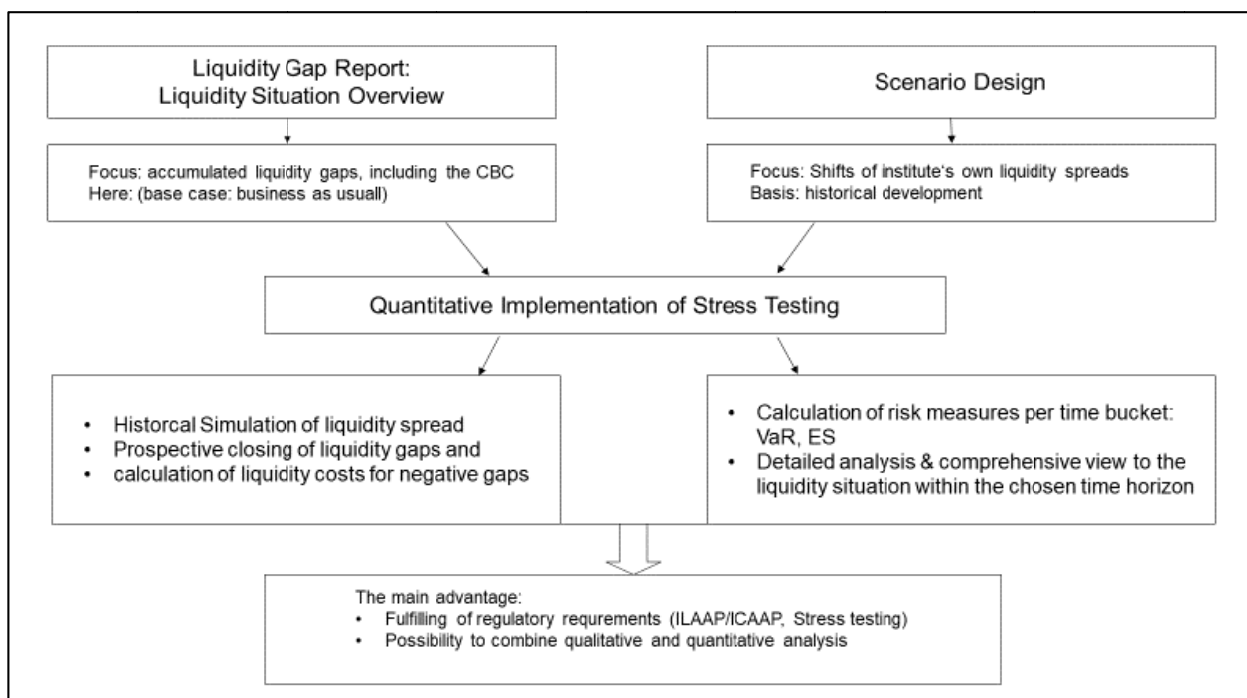
Figure 1. Construction of the stress testing approach—an overview.

Liquidity risks are based on scenarios (Matz, 2011). But analyzing of qualitative scenarios only does not satisfy policymakers who need to derive future action strategies in case of a possible distress. For that reason, they need to know, how high the occurrence probability of the respective adverse event is. Hence, the present approach builds upon statistical methods: on the present value based calculation of the liquidity wealth (Pohl, 2010) and the VaR framework (Bartetzky, 2008) enhanced by the calculation of expected shortfall (Acerbi, 2004; Uryasev, 2004). Scenarios for liquidity spreads shifts are modeled on a historical basis by applying the historical simulation method.

The first step is to determine a comprehensive LGR, including the CBC.

For the risk quantification a comprehensive exposition of the liquidity situation, the LGR is needed[1]. The LGR and CBC have to be modeled for business as usual as well as for stress view. In each time bucket, where a negative accumulated liquidity gap appears, an additional funding is needed. As the amount of the counterbalancing capacity is already included in the gap, the bank has to enter into the capital markets to gain the corresponding amount of funds. Its liquidity spread has a determining influence on the funding expenses.

The second step is to determine the liquidity spread and define scenarios.

For the calculation of the institute's own liquidity spread of the banks focused in the present study, covered bonds, called "Pfandbriefe" and the asset swap curve financials are appropriate (For the choice of credit spreads confer Schlecker (2009), Gann (2010), Schmitt (2015, pp. 77-80).

To obtain a comprehensive view about the amount of possible liquidity costs in a distress situation, two categories of scenarios should be investigated: institute-specific and market-wide scenarios which should base on historical, market and hypothetical events (Matz, 2011, pp. 111-118; EBA, 2017; CEBS, 2009, p. 3). As the

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[1] Modeling of cash flows and methods for drawing up of LGR does not belong to the scope of this article. For more details confer Zeranski (2005), Pohl (2008), CEBS (2009), Matz (2011), Schmitt (2015), and Schmitt (2017).

risk factors to be stressed upon are an interest rate and a spread curve, their characteristics have to be taken into account as well:

1. A sensitivity scenario should be modeled as a parallel shift, where the value at every grid point of the liquidity spread curve at the observation time point will be shifted by the same absolute amount. It induces a level-movement of the curve. Such scenarios often are used as "worst-case" scenarios.

2. Structure changing shifts, where different absolute shifts are applied to the respective grid point of the liquidity spread curve. Compared to the business as usual, the shape of the curve can completely change in case of a stress event.

Here, historic changes of the liquidity spreads are calculated as follows:

Consider $LS_{t,hist,1}, \dots, LS_{t,hist,N}$ the time series of $n = 1, \dots, N$ historical liquidity spreads LS on the grid point t. The $LS_{t,hist,N}$ is the current liquidity spread, N is the observation time point. The delta spread, or liquidity spread shift, is computed as a "historical change" at the grid point t:

$$\Delta LS_{t,hist,n} = LS_{t,hist,n} - LS_{t,hist,n-1} \text{ for } n = 2, \dots, N \tag{1}$$

In the present study, exemplary, four scenarios are calculated:

The basis scenario: Interest rates and spreads development under normal circumstances, as in business as usual. This scenario is a comparative basis for the analysis of the stress events.

Market scenario—imitation of an actually occurred historical event: For the time period of the chosen event, the delta spread values on the given grid points of the spread curve have to be computed. The result is a new time series of delta liquidity spreads.

$$\Delta LS_{t,hist,m}; \ m = 1, \dots, M \tag{2}$$

These "deltas" are added to the liquidity spread of the base case at the observation time point. Hence, a new time series for the chosen scenario is created under the assumption that the historical crisis will repeat in the future.

In the present approach, the scenario values are calculated by using the historical simulation method. For this purpose, four factors have to be determined:

1. The length of the simulation time horizon: Here, it is the length of the crisis period. It is important to choose a crisis where enough historical data are available. If the period of time is too short, unwanted distortion of the risk measure can occur.

2. Choice of holding period: It is the time period between the respective liquidity spread value changes, here one month.

3. Choice of confidence level: It determines the significance of the VaR result. Here it is 95%.

4. Choice of the type of value changes: Here, absolute differences of the spread values are chosen.

The third step is the historical simulation of liquidity spreads under business as usual and stressed conditions.

The bank's own liquidity spread is the Risk Factor (RF) which has to be modeled in the historical simulation, basing on the chosen scenario. According to Huschens (2000), the procedure can be schematically shown as follows:

The development of the RF $r_1, \dots, r_j$ is observed in historic time series at different time points.

$t = \dots - 1, 0, 1, \dots, h$ where $t = 0$ is the current time point, $t = h$ is the future time point. The current

portfolio value depends on the J risk factors by a valuation function.

$$g: w_0 = g_0(r_{0,1}, \ldots, r_{0,j}). \tag{3}$$

where $r_{t,j}$ is the j-th RF at the time point t.

For $j = 1, \ldots, J$ RF, the differences are simulated to generate n future values.

$$r_n^i, i = 1, \ldots, n: \tag{4}$$

$$\Delta_h r_{t,j} = r_{t,j} - r_{t-h,j} \tag{5}$$

where t = -(n – 1), …, -1, 0

$$r_{h,j}^i = r_{0,j} + \Delta_h r_{-(n-i),j} \tag{6}$$

Hence, by using these historically changed RF, the future portfolio value can be prognosticated as:

$$W_h^i = g_h(r_{h,j}^i) \tag{7}$$

The potential change in the portfolio value from the time point $t = 0$ to $t = h$ is calculated as:

$$W_{0,h} = \Delta W_{0,h} = W_h - w_0 \tag{8}$$

These n prognosticated values $W_{0,h}^1, \ldots, W_{0,h}^n$ depict the historic based distribution of the future portfolio values.

The fourth step is the prospective closing of the accumulated liquidity gaps to gain the view to the funding needs

The accumulated liquidity gaps have to be closed using money and capital market transactions (Thereby, the other risk types and the balance sheet structure should not be influenced). Here, fictitious transactions are used which generate interest rate costs or returns depending on the sign of the gap. To close a negative gap which shows a financing shortfall FL_t, as focused in the present study, the corresponding amount of liquidity must be gained. The bank pays then a refinancing price RZ which is expressed by its own liquidity spread:

$$RZ = Swap_t + LS_t + \Delta LS_t \tag{9}$$

ΔLS_t is the difference between the base LS and the scenario LS in the time bucket t.

The fifth step is to calculate the present values of liquidity costs in each time bucket of a chosen scenario.

The historical present value of the refinancing costs caused by the closing of the financial shortfall FL_t in the time bucket t and derived from a liquidity spread scenario x, is calculated by discounting of the FL_t using the discount factor $DF_{t,x}$ of the refinancing costs in the time bucket t, derived in the scenario x:

$$BW_{t,x} = FL_t.DF_{t,x}. \tag{10}$$

To estimate the impacts of the stress scenario on the current conditions, in each time bucket t, the present value differences of liquidity costs $BW_{t,x}$ (derived by x scenarios of the liquidity spread changes, $x = 1, \ldots, X$) and the current present value $BW_{t,0}$ in the time bucket t are calculated as follows:

$$\Delta BW_{t,x} = BW_{t,x} - BW_{t,0} \tag{11}$$

for every time bucket $t = 1, \ldots, T$.

The sixth step is to calculate VaR and ES based on the present values (as in step five).

The VaR as the measure of the LMT risk is calculated on the basis of two dimensions: possible future portfolio value changes calculated as the present value of the potential loss in the respective time bucket and based on price changes of the bank's own liquidity spreads.

This VaR is the value of the maximal loss which will not be exceeded with a chosen probability, here 95%, when the liquidity gaps are prospective closed and by the application of changes in liquidity spreads in the respective time bucket (Acerbi & Scandolo, 2007; Bartetzky, 2008, p. 18; Schmielewski, 2010, p. 158). Hence, the present values of the liquidity costs arise out of (maturity matching and fictive) closing transactions of the negative gaps.

In the output time series of the historical simulation in each time bucket, the portfolio value changes are sorted in ascending order. Then the VaR is the value which is to be found on the place number $a = ((1 - confidencelevel.n+1$, where n is the number of simulated time points. This place corresponds to the chosen confidence level (Schmitt 2015, pp. 123-124).

$$\Delta BW_1 \leq \Delta BW_2 \leq \cdots \leq \Delta BW_{a-1} \leq \Delta BW_a \leq \cdots \leq \Delta BW_n \tag{12}$$

$$VaR_a = \min_{i=1,\dots,n} \{\Delta BW_i | \Delta BW_i \geq \Delta BW_{a-1}\} = \Delta BW_a \tag{13}$$

There are usually some larger losses in the time series than the VaR value. An appropriate measure for such tail risk is the ES, because it considers the conditional expectation of loss beyond the VaR level (Acerbi, 2004; Uryasev, 2004). Formally, the ES is defined as follows (Yamai & Yoshiba, 2002, p. 60):

$$ES_a(X) = E(X|X \geq VaR_a(X)) \tag{14}$$

That means, the ES is composed of the maximal loss of 100(1-α)% losses and the average contingent excess:

$$ES_a(X) = VaR_a(X) + E(X - VaR_a(X)|X > VaR_a(X)) \tag{15}$$

The Choice of the Example Bank, Data Sample, and Input Parameters

In order to derive conclusive stress tests, the strategic direction of the respective bank and its economic environment has to be considered. For the present case study, a simplified hypothetical structure of a middle-sized German bank is chosen, which has a hypothetical balance-sheet total of approximately 35 Billion Euro, as shown in Table 1.

Table 1

Balance Sheet of the Hypothetical German Bank (In Mio. Euro)

Assets	Mio. €	Liabilities	Mio. €
Cash	700.00	-	350.00
Stocks	0.00	Liabilities due to central bank	1,750.00
Bonds	5,250.00	Deposits by banks	7,000.00
Lending to banks	2,800.00	Deposits by non-banks	10,500.00
Lending to non-banks	25,900.00	Debt securities (bank bonds)	14,000.00
Participations	350.00	Equity Capital	1,400.00
Total	35,000.00	Total	35,000.00

Notes. The hypothetical bank was prepared on the basis of the current schedule (http://www.die-bank.de/fileadmin/pdf/diebank_8_2016_TOP 100_web.pdf) and of annual reports for the year 2016 of selected banks with the range of balance-sheet total from 31 to 43 Billion Euro.

Such banks are typically mortgage banks and some saving banks. This kind of banks uses capital markets for their refinancing in addition to the retail or wholesale funding. For funding purposes, they issue covered bonds named "Pfandbriefe".

For the construction of the hypothetical LGR, it is assumed that the balance sheet is constant and the business model remains stable (Schmitt, 2017). Hence, the following assumptions were made (according to EBA, 2017, p. 14, point 5):

- the cash flow structure bases on the business as usual;
- it will stay constant in the future;
- the payment structure is static;
- fixed interest rate positions are hold until the final maturity date;
- the expiring transaction will be replaced by positions with the same maturity structure.

The time bucket structure is oriented on the calendar days and is structured as follows: two time buckets within the first year, eight time buckets for the second to ninth year, and one time bucket for all businesses with maturities 10 years and longer. In the time bucket of 6 M, the liquidity gap is positive. Table 2 shows the hypothetical accumulated liquidity gap, starting by year one, because there the first negative gap appears:

Table 2

Total Accumulated Liquidity Gap, $TGap_{acc}$, Consisting of the Accumulated Gap and Accumulated CBC-Gap (In Mio. Eur)

Maturity	1Y	2Y	3Y	4Y	5Y	6Y	7Y	8Y	9Y	10Y
$TGap_{acc}$	-195	-455	-845	-1,300	-2,275	-2,340	-2,145	-2,340	-2,275	-1,495

Source: Own processing based on the balance sheet structure and LGR of a hypothetical German bank.

The currency used is Euro. The following market data were used for the calculation.

The hypothetical liquidity spread is derived from two interest rate curves:

- the historical rates of "Pfandbrief" as a proxy for the institute's own financing curve, on the monthly closing base, as in the time series statistics of Deutsche Bundesbank (Notes, Table 3).

- the asset swap curve which is used as a risk-free reference (Schlecker, 2009; Gann, 2010; Schmitt, 2015, p. 157).

The zero curve is computed from the asset swap curve, by using the bootstrapping method. It is used for the calculation of the present value, for the determination of the discount factor. Table 3 shows the rates for the basis case:

Table 3

Market Data: Swap Rates, Zero Rates and Liquidity Spread, the Basis Case

Maturity	1Y	2Y	3Y	4Y	5Y	6Y	7Y	8Y	9Y	10Y
Swap in %	-0.27	-0.20	-0.08	0.06	0.20	0.34	0.47	0.59	0.73	0.84
Zero in %	-0.27	-0.20	-0.08	0.06	0.20	0.34	0.48	0.60	0.74	0.85
Liqui-spread in %	15.59	10.75	6.8	4.2	3.1	4.4	4.8	6.61	7.4	8.45

Notes. Swap rates: Bloomberg; Zero rates: own processing by bootstrapping method; Liquidity spread: own processing on the base of the "Pfandbrief" rates from Deutsche Bundesbank. Retrieved from http://www.bundesbank.de/Navigation/DE/Statistiken/ Zeitreihen_Datenbanken/Geld_und_Kapitalmaerkte/geld_und_kapitalmaerkte_list_node.html?listId=www_skms_it04b.

In the banking practice, the application of spread curves for covered and uncovered refinancing businesses can be useful. If they would be applied, the gap has to be determined correspondingly, which can bear some problems by the appropriate mapping of the positions.

Results and Discussion

The Choice of Stress Scenarios

To show the impact of different scenarios on the bank's refinancing costs, the shifts of the liquidity spreads in the respective time-period are examined. Figure 2 shows the movement of three liquidity spread curves, for the maturities of one year, five years, and 10 years, over the last seven years. As can be seen, the widening differs considerably over the last seven years. A desired time period can be selected for the modeling of stress scenarios. Due to the course of the spread developments, the following four different scenarios have been chosen.

Figure 2. Historical liquidity spreads development, in the time period 2000-2017, for the maturities one year, five years and 10 years.

(1) Crisis 1: February 2000-April 2004: This market turmoil was caused by the bursting of the "dotcom bubble" and the terror attacks in 09/2001 in New York. In this time period, some other distress situations were observed: Argentina Crisis (1998-2002), Brasilia crisis, breaking down of the New Economy and Enron bankruptcy. A high frequency of large spread widenings is apparent.

(2) Crisis 2: January 2007-April 2011: In this time-period, the subprime crisis and its expansion to the global liquidity crisis, the widening of spreads in the EU-zone in 2009 as well as financial disturbances in Greece occurred (Rudolph, 2011). Liquidity spreads widened considerably.

After the financial turmoil of the years 2007-2008, the monetary policy instruments of the European Central Bank have undergone some changes (Benoît, 2012; Praet, 2017). Notably, the interest rates were pulled down targeting two central arguments: to mitigate the risk of the deflation and the fragmentation of the financial market (Randow & Kennedy, 2017). Both, a prolonged time-period of low interest rates and a sudden increase in interest rates bear risks. Hence, as a base case, two time-periods are chosen.

(3) Base Case (BC): May 2004-July 2008: In this time period, the interest rates development is "normal". Though, a downward tendency of long term interest rates in OECD countries is observable for a long time

(OECD, 2006).

(4) Current Market circumstances (CM): January 2012-October 2017: This time period is characterized by a substantial interest rate reduction in Europe. Since 2012, the main refinancing and deposit rates decreased, the first negative rate was set in June 2014. The financial markets were distorted when some central banks in Europe cut interest rates below zero which provide a benchmark for borrowing costs (Randow & Kennedy, 2017). Negative interest rates spread also to the corporate bonds and securitized debt. They reached their peak in middle 2016, when even "Pfandbrief" rates (with maturities 1Y-4Y) fell below zero. The idea behind these actions is to reduce the borrowing costs and boost the economy by making credit taking cheaper.

Scenario Results for the VaR and ES Measures

To estimate the costs of funding, the total liquidity needs of a LGR's and CBC's base case are used. The hypothetical bank has no negative gaps within the first year. As shown in Table 2, the first negative gap appears in the time bucket of one year. After that, it is not possible to cover the liquidity needs by using the assumed planned CBC. It means that the liquidity needs which appear by the prospective closing of the negative gaps bear the risk of the level of financing costs. It is measured using the calculation of the VaR and ES measures as described in section 2. The following Table 1 shows the VaR and ES results in the respective time bucket for each scenario.

Table 4

Scenario-Results: VaR and ES for Base Case and Crisis Scenarios (In Mio. €)

Maturity	1Y	2Y	3Y	4Y	5Y	6Y	7Y	8Y	9Y	10Y
Base Case: 5/2004 to 7/2008										
VaR	-0.19	-0.46	-1.77	-2.33	-7.84	-4.77	-10.51	-6.53	-9.26	-1.89
Es	-0.28	-0.76	-2.90	-4.10	-12.99	-7.29	-13.33	-10.41	-14.64	-2.33
Current Market: 1/2012 to 10/2017										
VaR	-0.14	-0.33	-0.85	-1.04	-4.56	-3.18	-6.63	-4.61	-6.85	-1.07
ES	-0.25	-0.43	-1.22	-1.48	-6.43	-3.47	-8.00	-6.87	-10.38	-1.85
Crisis 1: 2/2000 to 4/2004										
VaR	-0.46	-1.40	-5.25	-6.08	-19.56	-10.80	-20.63	-14.85	-20.40	-2.91
ES	-0.48	-1.56	-5.72	-7.70	-24.64	-13.66	-24.83	-18.52	-24.63	-3.59
Crisis 2: 1/2007 to 4/2011										
VaR	-0.19	-0.78	-2.45	-3.66	-11.75	-7,06	-13.66	-11.30	-16.35	-2.63
ES	-0.59	-0.95	-3.56	-4.91	-16.35	-9,20	-17.20	-13.39	-19.66	-3.18

Source: Own processing.

VaR results of the crises scenarios. As can be seen in Figure 2 and Table 4, the risk patterns in the two crises scenarios show different pictures. For the hypothetical bank, the crisis 1 is more threatening than the crisis 2, even if it may not seem so at first glance when looking at the spread swings. These differences can be explained by the nature of liquidity spread deflections. In the crisis 1, the total magnitude of the range of liquidity spreads is high, and additionally, various consecutives spread widenings occur during the observation time period. In contrast, the crisis 2 involves some much larger spontaneous spread widenings.

Even if in the crisis 2 the maximum and minimum of the liquidity spread widenings is almost 2 times larger than in the crisis 1, the liquidity-spread differences within the selected time horizon (here one month) in the chosen (observation) time periods are about 1.5 times larger in the crisis 1 across all time buckets. Hence, the VaR values of the crisis 1 are almost as double as high as the VaR values of the crisis 2 in the time buckets

1Y to 5Y. In the following time buckets 6Y to 9Y, the difference in the VaR values drop from about 30% and 20%. In the last time bucket 10Y, the risk measures of both crises are almost equal, because the deviation of the liquidity spread differences is small and similar in both crises.

In comparison of the crisis scenarios and the base case, the VaR of crisis 1 is about 2.5 times higher than the VaR of the BC. The VaR of the crisis 2 arose about 1.5 times. That means if one of the crises occurs, the maximum expected loss in the 95% best cases will increase by the factor mentioned above.

ES results of the crises scenarios. The ES values in the crisis 1 are higher than ES values of the crisis 2. That means, in the data of the crisis 1, serious risks were "hidden" beyond the VaR, in the tail of the distribution, which have a larger amount as the "hidden" risks of the crisis 2.

In the crisis 1, the differences between the VaR and the ES values in the time buckets 1Y to 3Y are moderate (3% to 10%) and increase in the time bucket 4Y to 6Y by 25% and in 7Y to 10Y by 20%.

In the crisis 2, the amounts of ES values are smaller than in the crisis 1 but differences between the VaR and ES values in this crisis are greater than in the crisis 1. That means that here, higher losses from the tail of the distribution are not intercepted by the VaR. Especially in the time bucket 1Y where the ES value is 3 time as high as the VaR value. In the time buckets 3Y to 6Y, the increase of the VaR-ES-difference is about 40%. In such events, the underestimation of risk due the VaR may lead to delay in balancing actions.

The ES of the crisis 1 is about 1.8 higher; ES of the crisis 2 is about 1.2 higher in average compared to the ES of the BC. The crisis 1 can be interpreted as a worst-case scenario of the calculated scenarios and the bank should bear in mind that the maximum loss in the 95% best cases can be about 2.5 times higher as under the business as usual conditions (in case of BC). As an additional insurance against losses beyond the VaR, the bank has to count with a 1.8 higher additional amount of money to pay.

At this point, the relevance of the ES is apparent. This measure shows the value which will be needed in average; if in a given scenario, the liquidity costs exceed the estimated VaR value. Hence, the amount of ES can serve as an insurance against extreme events. The risks which are sorted out by VaR are involved in the ES measure. Hence, the risk precaution under ES is more conservative.

Impacts of the Current Market Conditions and the Choice of the Base Case

In the current market circumstances, when the interest rates drop to a historical low level, this special situation has to be analyzed as well. These market conditions are, admittedly, "the business as usual" at the current moment, but it is to be expected that the interest rates will go up in the near future.

At first glance, low interest rates imply low liquidity costs. It can be seen by comparison of the BC and the CM. All VaR and ES values of liquidity costs are significantly lower in the CM scenario. VaR decreases about 28% in 1Y-2Y following 53% in 3Y-5Y, 34% in 6Y-7Y, 27% in 8Y-9Y, and 44% in 10Y. But low interest rates within prolonged periods of time can cause building-up of financial risks. E.g., risks come up when a source of funding will disappear if depositors will not be willing to bring their savings to the bank. Even when the bank does not charge their customers, profit margins between deposit and lending rates will diminish so that the willingness to lend will possibly lessen. The favour to enter into risk positions increases. All these changes and especially the funding costs which arise out of them have to be monitored carefully. Additionally, the risk can suddenly arise if the market situation changes rapidly.

As the results show, in comparison to the crisis situations and the CM scenario, the differences between

the risk in the "current business as usual" and stress scenarios increase significantly. E.g., compared to CM, in the case the crisis 1 occurs, the VaR will increase in the average about 3.9 times and ES about 3.3 times. The increase of the VaR of the crisis 1 is on average 2.4 and ES 1.8 times higher compared to the BC.

Implications of the Results for the Scenario Based Calculation of VaR and ES

These results illustrate the fact that no general estimates for the extent of risk on a basis of standardized scenarios should be made. This hypothetical case study also showed that the distinction of the VaR and ES values under stressed conditions can be remarkably high. According to Matz (2011), the present study shows that historical VaR cannot avoid the "black swan" problem. The availability of extreme data is a deciding factor for the accuracy of the stress-VaR and ES (Yamai & Yoshiba, 2002; Theiler, 2004). The fact that some users tend to postpone the quantile to bring more losses from the tail of the distribution into the VaR measure does not bring a satisfying result either. It does not avoid the problem mentioned above. For that reason, the creation of combined or hypothetical scenarios of different severities where structural changes are involved is necessary. On this fundament, the present approach enables to combine qualitative and quantitative risk assessment. The calculation of VaR and ES enables the bank to include this risk to its overall liquidity risk or the institute's risk in general.

The total amount of liquidity costs (VaR) across all time buckets in the crisis 1 would be 102.34 million €, in the crisis 2 it would be 69.83 million €, and in the BC 45.56 million €. To hold enough cash or high liquid assets for all contingencies is not possible (Matz, 2011, p. 105). The calculation of the ES, even if not enough data are available, provides additional information about possible serious risks in the tail of the distribution[2]. The ES value should be reflected for planning purposes.

The current market conditions of low interest rates cause an ample liquidity on the markets and decrease of liquidity costs. But the small- and medium-sized banks can encounter problems if the extremely low interest rate levels change too quickly. The present approach helps the banks to prove easily for each time bucket what impacts bear they strategies for managing of returns in the low interest rate environment. E.g., if the bank plans refinancing on a short-term base (because the financing costs are very low at the moment), although it lends money in the long-term perspective. It can face difficulties if the interest rates go up, then the long-term market valued assets will lose value and the refinancing costs on the liability side of the balance sheet will rise.

Conclusion

The present paper introduces an approach for measuring liquidity maturity transformation risk within a stress testing framework. It enables to calculate the risk of increase of liquidity costs arising due to a downturn in refinancing conditions in a prospective manner and for each time bucket separately by using modern risk measures: VaR and ES. The necessary steps for calculation VaR and ES for both, business as usual and stressed conditions are presented. The effects of the increase in financing costs resulting from the stress scenarios and the risk bearing capacity are transparent due to the integration of the CBC and the risk calculation. Hence, the "real" liquidity requirement can be revealed and sound recommendations for the management of the refinancing structure, in line with the risk coverage capacity, can be drawn up. Even when ES is highly dependent on the amount of data available, the results show that ES offers a significantly better risk assessment than VaR in extreme

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[2] Theiler (2004, pp. 407-408) states the confidence that ES may find acceptance in the practice even if the reliability of ES depends on the stability of estimation and the choice of back-testing methods as pointed out by Yamai and Yoshiba (2002).

scenarios. It can be seen as an insurance against extreme losses. The approach combines a scenario-based view to a possible distress with the quantitative risk measurement. Therewith, it contributes to the bank's wide stress testing, as required by the regulatory authorities (BCBS, 2009). The advantage of this method is the possibility to take necessary actions expedient and in a timely manner if some liquidity needs appears.

The present approach also helps the middle-sized banks to fulfill their regulatory requirements. According to the EBA (2017) and CEBS (2010), the principle of proportionality is utilized by using of methods which are understandable and have proved in the practical risk management. It also is possible to apply and compute the VaR and ES for both sensitivity and scenario analysis. The present forward-looking approach over various time horizons and incorporation of funding needs into the analysis fulfills liquidity requirements stemming from ICAAP and ILAAP. A detailed examination of the basic question of the structural liquidity management is also possible: How much is the amount of liquidity needs with which the bank has to count in the selected period of time under the modeled scenario?

References

Acerbi, C. (2004). Coherent representations of subjective risk-aversion. In. G. Szegö (Ed.), *Risk measures for the 21st century* (pp. 147-209). Hoboken, NJ: John Wiley & Sons.

Acerbi, C., & Scandalo, G. (2007). Liquidity risk theory and coherent measures of risk. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1048322

Allaj, E. (2017). Risk measuring under liquidity risk. Retrieved from https://www.researchgate.net/publication/269764433

Bangia, A., Diebold, F. X., Schuermann, T., & Stroughair, J. D. (1998). Modeling liquidity risk with implications for traditional market risk measurement and management. *NYU Working Paper No. FIN-99-062*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1298788

Bartetzky, P. (2008). Liquidität im Fokus-Wiederentdeckung eines Kernrisikos. In P. Bartetzky, W. Gruber, and C. S. Wehn (Eds.), *Handbuch Liquiditätsrisiko* (pp. 2-27). Stuttgart: Schäffer-Poeschel.

Bartetzky. P. (2010). Stresstests im Rahmen des Liquiditätsrisikomanagements-aktueller Stand und Herausforderungen. In W. Gruber, M. R. W. Marcus, and C. S. Wehn (Eds.), *Szenarioanalysen und Stresstests in der Bank- und Versicherungspraxis* (pp. 177-202). Stuttgart: Schäffer-Poeschel Verlag. ISBN 978-3791029535.

BCBS. (2009). *Basel committee on banking supervision (2009). Principles for sound stress testing practices and supervision. BCBS 155*. Retrieved from https://www.bis.org/publ/bcbs155.pdf

BCBS. (2013). Liquidity stress testing: A survey of theory, empirics and current industry and supervisory practices. *Working Paper No. 24*. Retrieved from https://www.bis.org/publ/bcbs_wp24.pdf

Benoît, C. (2012). Central banks and the challenges of the zero lower bound. Intervention by Benoît Cœuré. *Meeting on the Financial Crisis*. European Central Bank. Retrieved from http://www.ecb.europa.eu/press/key/date/2012/html/sp120219.en.html

Berkowitz, J. (1999). A coherent framework for stress-testing. Retrieved from http://www.ssrn.com, ssrn id=181931

Brunnermeier, M. K., & Pedersen, L. H. (2009). Market liquidity and funding liquidity. *The Review of Financial Studies, 22*(6), 2201-2238.

CEBS. (2009). *Guidlines on liquidity buffers & survival periods*. 9 December 2009. Committee of European Banking Supervisors. Retrieved from https://www.eba.europa.eu/documents/10180/16094/Guidelines-on-Liquidity-Buffers.pdf

CEBS. (2010). *Guidelines on stress testing (GL32)*. August 2010. Committee of European Banking Supervisors Guidelines. Retrieved from https://www.eba.europa.eu/documents/10180/16094/ST_Guidelines.pdf

Dietrich, A., Hess, K., & Wanzenried, G. (2014). The good and bad news about the new liquidity rules of Basel III in Western European countries. *Journal of Banking & Finance, 44*, 13-25.

Dietz, T. (2010). Liquiditätsrisikomanagement in Banken und die Finanzkrise aus Sicht der Bankenaufsicht. In S. Zeranski (Ed.), *Ertragsorientiertes Liquiditätsrisikomanagement* (pp. 5-80). Heidelberg: Finanz Colloquium Heidelberg GmbH.

Drehmann, M., & Nikolau, K. (2009). Funding liquidity risk definition and measurement. ECB. *Working Paper Series No. 1024*.

EBA. (2016). EBA/GL/2016/10. Final report: Guidelines on ICAAP and ILAAP information collected for SREP purposes. Retrieved from https://www.eba.europa.eu/documents/10180/1645611/ Final+report+on+Guidelines+on+ICAAP+ILAAP+(EBA-GL-2016-10).pdf

EBA. (2017). EBA/CP/2017/17. Consultation paper: Draft guidelines on institution's stress testing. Retrieved from https://www.eba.europa.eu/documents/10180/2006781/Consultation+Paper+on+Guidelines+on+institution's+stress+testing+(EBA-CP-2017-17).pdf

ECB. (2016). Recent developments in the composition and cost of bank funding in the euro area. *ECB Economic Bulletin, 1*, 26-45. Retrieved from https://www.ecb.europa.eu/pub/pdf/other/eb201601_article01.en.pdf?c039ecb05b81ecfb742002e93c6e9787

Galiay, A., & Maurin, L. (2015). Drivers of banks' cost of debt and long-term benefits of regulation—An empirical analysis based on EU banks. European Central Bank. Eurosystem. *Working Paper Series 9/2015*. Retrieved from https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp1849.en.pdf

Gann, P. (2010). *Der marktphasenabhängige Einfluss der Liquidität auf die Credit Spreads von Corporate Bonds*. Retrieved from http://epub.ub.uni-muenchen.de/11521/3/GESAMT_Dynamischer_Einfluss_Discussion_Paper.pdf

Georgescu, O. M., Gross, M., Kapp, D., & Kok, C. (2017). Do stress tests matter? Evidence from the 2014 and 2016 stress tests. *Working Paper Series*. European Central Bank. Eurosystem. Retrieved from https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2054.en.pdf?e5a9f3e207355d829bdb2d26861b005a

Huschens, S. (2000). Value-at-Risk-Berechnung durch historische Simulation. *Dresdner Beiträge zu Quantitativen Verfahren. No 30/00*. Fakultät für Betriebswirtschaften: Technische Universität Dresden.

Kapinos, P., & Mitnik, O. (2015). Stress testing banks: Whence and whither? Federal deposit insurance corporation. Center for Financial Research. *WP 2015-07*. Retrieved from https://fdic.gov/bank/analytical/CFR/2015/WP_2015/WP2015_07.pdf

Khan, M., Scheule, H., & Wu, E. (07/2015). The impact of bank liquidity on bank risk taking: Do high capital buffers and big banks help or hinder? Retrieved from http://ssrn.com/abstract=2481887

Khan, M. A., Scheule, H., & Wu, E. (11/2015). Will Basel III liquidity measures affect banks' funding costs and financial performance? Evidence from U.S. commercial banks. Retrieved from http://sfm.finance.nsysu.edu.tw/php/Papers/CompletePaper/088-1872147892.pdf

Matz, L. (2011). *Liquidity risk measurement and management*. USA: Xlibris Corp.

Muela, S. B., Martín, C. L., & Sanz, R. A. (2017). An application of extreme value theory in estimating liquidity risk. *European Research on Management and Business Economics*. Retrieved from http://dx.doi.org/10.1016/j.iedeen.2017.05.001

Neu, P. (2007). Liquidity risk measurement. In L. Matz and P. Neu (Eds.), *Liquidity risk measurement and management* (pp. 15-36). Hoboken, NJ: John Wiley & Sons.

OECD. (2006). Factors behind low long-term interest rates. *Financial Market Trends, 2*, 101-141. Retrieved from http://dx.doi.org/10.1787/fmt-v2006-art12-en

Pohl, M. (2008). *Das Liquiditätsrisiko in Banken-Ansätze zur Messung und ertragsorientierten Steuerung*. Frankfurt am Main: Fritz Knapp Verlag.

Pohl, M. (2010). Ansätze zur Ermittlung des erfolgswirksamen Liquiditätsrisikos auf Basis von Liquiditätsablaufbilanzen. *Kredit und Kapital, 43*, 271-302.

Praet, P. (2017). Communicating the complexity of unconventional monetary policy in EMU. Speech by Peter Praet. Member of the Executive Board of the ECB, at the 2017 ECB Central Bank Communications Conference. Frankfurt am Main. Retrieved from http://www.ecb.europa.eu/press/key/date/2017/html/ecb.sp171115.en.html

Randow, J., & Kennedy, S. (2017). Negative interest rates. Bloomberg Quick Take. Retrieved from https://www.bloomberg.com/quicktake/negative-interest-rates

Rudolph, R. (2011). Hintergründe und Verlauf der internationalen Finanzkrise. In B. Rudolf and J. Bähr (Eds.), *1931 Finanzkrisen* (pp. 145-241). München: Piper.

Schlecker, M. (2009). *Credit spreads*. EUL-Verlag.

Schmaltz, C., Sebastian Pokutta, S., Heidorn, T., & Andrae, S. (2013). How to make regulators and shareholders happy under Basel III. Retrieved from http://dx.doi.org/10.2139/ssrn.2179490

Schmielewski, F. (2010). Quantitative Messung der Liquiditätsrisiken eines Kreditinstitutes mittels eines stochastischen Modellansatzes. In *Frühwarnindikatoren und Risikomanagement* (pp. 144-178). Retrieved from http://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/ics/files/FInAL/2010/FINAL-04-2010-3.pdf

Schmitt, E. (2015). Stochastisches Stresstesting des Liquiditätstransformationsrisikos im Rahmen der strukturellen Liquiditätsrisikosteuerung. Unpublished doctoral dissertation. Munich, Germany: Ludwig-Maximilians-University.

Schmitt, E. (2016). Stress-testing model for structural liquidity risk. Proceedings of *13th International Scientific Conference*. *European Financial Systems*. Brno: Masaryk University. June 27-28, 2016.

Schmitt, E. (2017). Liquidity gap report for stress testing structural liquidity risk. *International Journal of Financial Management, 7*(4), 43-53.

Schupp, F., & Silbermann, L. (2017). The role of structural funding for stability in the German banking sector. Deutsche Bundesbank. *Discussion Paper No. 03/2017.*

Theiler, U. (2004). Risk return management approach for the bank portfolio. In G. Szegö (Ed.), *Risk measures for the 21st century* (pp. 403-432). Hoboken, NJ: John Wiley & Sons.

Uryasev, S. (2004). Conditional value-at-risk, methodology and applications: Overview. Risk Management and Financial Engineering Lab University of Florida. Retrieved from http://www.ise.ufl.edu/uryasev/publications

Weber, S., Anderson, W., Hamm, A. M., Knispel, T., Liese, M., & Salfeld, T. (2013). Liquidity-adjusted risk measures. *Mathematics and Financial Economics, 7*(1), 69-91. doi:10.1007/s11579-012-0092-3

Yamai, Y., & Yoshiba, T. (2002). Comparative analyses of expected shortfall and value-at-risk: Their estimation error, decomposition, and optimization. *Monetary and Economic Studies, 20*(1), 87-121.

Zeranksi, S. (2005). *Liquidity at Risk zur Steuerung des liquiditätsmäßig-finanziellen Bereichs von Kreditinstituten.* Chemnitz: GUC-Verlag.