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Measuring and managing

# Liquidity risk

ANTONIO CASTAGNA  
FRANCESCO FEDE



# Measuring and Managing Liquidity Risk

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Measuring and Managing  
Liquidity Risk

**Antonio Castagna and Francesco Fede**

**WILEY**

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*AC: To Tatiana, for the patience she almost never lost*

*FF: To my wife, Gabriella, for her love, patience and support*





# Contents

<b>Preface</b>	xiii
<b>About the authors</b>	xvii
<b>Abbreviations and acronyms</b>	xix
<b>PART I LIQUIDITY AND BANKING ACTIVITY</b>	<b>1</b>
<b>1 Banks as lemons?</b>	<b>3</b>
1.1 Introduction	3
1.2 The first wave	4
1.3 Banks as lemons?	7
1.4 The response	9
1.5 The second wave	13
1.6 Conclusion	15
<b>2 A journey into liquidity</b>	<b>17</b>
2.1 Introduction	17
2.2 Central bank liquidity	18
2.3 Funding liquidity	19
2.4 Market liquidity	22
2.5 The virtuous circle	24
2.6 The vicious circle	24
2.8 The role of the central bank, supervision and regulation	28
2.9 Conclusions	31
<b>3 Too big to fail</b>	<b>33</b>
3.1 Introduction	33
3.2 When giants fall	34
3.3 A hard lesson	36
3.4 Closer supervision	37
3.5 G-SIFI regulations	39
3.6 The next steps	41
3.7 Conclusion	44

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<b>4</b>	<b>The new framework</b>	47
4.1	Introduction	47
4.2	Some basic liquidity risk measures	48
4.3	The first mover	50
4.4	Basel III: The new framework for liquidity risk measurement and monitoring	53
4.4.1	The liquidity coverage ratio	55
4.5	Inside the liquidity coverage ratio	63
4.6	The other metrics	66
4.7	Intraday liquidity risk	69
4.8	Beyond the ratios	72
4.9	Conclusion	74
<b>5</b>	<b>Know thyself!</b>	75
5.1	Introduction	75
5.2	Some changes on the liabilities side	75
5.3	The role of leverage	79
5.4	The originate-to-distribute business model	82
5.5	The liquidity framework	84
5.6	Stress-testing and contingency funding plan	89
5.7	The CEBS identity card	95
5.8	Conclusions	97
5.9	Appendix: The CEBS Identity Card Annex (CEBS)	98
<b>PART II TOOLS TO MANAGE LIQUIDITY RISK</b>		<b>109</b>
<b>6</b>	<b>Monitoring liquidity</b>	111
6.1	A taxonomy of cash flows	111
6.2	Liquidity options	114
6.3	Liquidity risk	115
6.4	Quantitative liquidity risk measures	118
6.4.1	The term structure of expected cash flows and the term structure of expected cumulated cash flows	119
6.4.2	Liquidity generation capacity	123
6.4.3	The term structure of available assets	127
6.5	The term structure of expected liquidity	134
6.6	Cash flows at risk and the term structure of liquidity at risk	135
<b>7</b>	<b>Liquidity buffer and term structure of funding</b>	143
7.1	Introduction	143
7.2	Liquidity buffer and counterbalancing capacity	143
7.3	The first cause of the need for a liquidity buffer: Maturity mismatch	145
7.3.1	Some or all stressed scenarios do not occur	149
7.3.2	The cost of the liquidity buffer for maturity mismatch	152
7.3.3	Liquidity buffer costs when stressed scenarios do not occur	158

7.3.4	A more general formula for liquidity buffer costs	163
7.4	Funding assets with several liabilities	168
7.5	Actual scenarios severer than predicted	169
7.6	The term structure of available funding and the liquidity buffer	171
7.6.1	The term structure of forward cumulated funding and how to use it	175
7.7	Non-maturing liabilities	179
7.7.1	Pricing of NML and cost of the liquidity buffer	182
7.8	The second cause of the liquidity buffer: Collateral margining	186
7.8.1	A method to set the liquidity buffer for derivative collateral	186
7.8.2	The cost of the liquidity buffer for derivative collateral	188
7.9	The third cause of the liquidity buffer: Off-balance-sheet commitments	192
7.10	Basel III regulation and liquidity buffer	194
<b>8</b>	<b>Models for market risk factors</b>	199
8.1	Introduction	199
8.2	Stock prices and FX rates	199
8.3	Interest rate models	201
8.3.1	One-factor models for the zero rate	201
8.3.2	Vasicek model	202
8.3.3	The CIR model	202
8.3.4	The CIR++ model	209
8.3.5	The basic affine jump diffusion model	211
8.3.6	Numerical implementations	212
8.3.7	Discrete version of the CIR model	212
8.3.8	Monte Carlo methods	214
8.3.9	Libor market model	215
8.4	Default probabilities and credit spreads	219
8.4.1	Structural models	219
8.4.2	Reduced models	221
8.4.3	Credit spreads	223
8.5	Expected and minimum liquidity generation capacity of available bonds	224
8.5.1	Value of the position in a defaultable coupon bond	225
8.5.2	Expected value of the position in a coupon bond	226
8.5.3	Haircut modelling	227
8.5.4	Future value of a bond portfolio	228
8.5.5	Calculating the quantile: a $\Delta - \Gamma$ approximation of the portfolio	228
8.5.6	Estimation of the CIR++ model for interest rates	231
8.5.7	Estimation of the CIR++ model for default intensities	233
8.5.8	Future liquidity from a single bond	239
8.5.9	Future liquidity from more bonds	240
8.6	Fair haircut for repo transactions and collateralized loans	247
8.7	Adjustments to the value of illiquid bonds	256
8.7.1	Liquid equivalent adjustment	258

8.7.2	Price volatility adjustment	261
8.A	Expectation value of the bond with selling probability and spread	270
<b>9</b>	<b>Behavioural models</b>	277
9.1	Introduction	277
9.2	Prepayment modelling	277
9.2.1	Common approaches to modelling prepayments	277
9.2.2	Hedging with an empirical model	278
9.2.3	Effective hedging strategies of prepayment risk	285
9.2.4	Conclusions on prepayment models	288
9.2.5	Modelling prepayment decisions	288
9.2.6	Modelling the losses upon prepayment	290
9.2.7	Analytical approximation for ELoP <sub>1</sub>	296
9.2.8	Valuing the ELoP using a VaR approach	299
9.2.9	Extension to double rational prepayment	303
9.2.10	Total prepayment cost	305
9.2.11	Expected cash flows	306
9.2.12	Mortgage pricing including prepayment costs	308
9.3	Sight deposit and non-maturing liability modelling	316
9.3.1	Modelling approaches	317
9.3.2	The stochastic factor approach	319
9.3.3	Economic evaluation and risk management of deposits	324
9.3.4	Inclusion of bank runs	334
9.4	Credit line modelling	337
9.4.1	Measures to monitor usage of credit lines	339
9.4.2	Modelling withdrawal intensity	340
9.4.3	Liquidity management of credit lines	341
9.4.4	Pricing of credit lines	360
9.4.5	Commitment fee	362
9.4.6	Adding the probability of default	364
9.4.7	Spread option	365
9.4.8	Incremental pricing	368
9.A	General decomposition of hedging swaps	371
9.B	Accuracy of mortgage rate approximation	373
9.B.1	Internal model simulation engine	373
9.B.2	Results	374
9.C	Accuracy of the approximated formula for correlated mortgage rate and prepayment intensity	379
9.D	Characteristic function of the integral $\Lambda_i^D(s, T) = \int_s^T \lambda_i^D(u) du$	382
<b>PART III PRICING LIQUIDITY RISK</b>		383
<b>10</b>	<b>The links between credit risk and funding cost</b>	385
10.1	Introduction	385
10.2	The axiom	385
10.3	Cash flow fair values and discounting	386

10.4	Critique of debit value adjustment	389
10.4.1	Single-period case	389
10.4.2	Multi-period case	391
10.4.3	DVA as a funding benefit	394
10.5	DVA for derivative contracts	397
10.6	Extension to positive recovery and liquidity risk	402
10.7	Dynamic replication of DVA	404
10.7.1	The gain process	404
10.7.2	Dynamic replication of a defaultable claim	405
10.7.3	Objections to the statement “no long position in a bank’s own bonds is possible”	409
10.7.4	DVA replication by the funding benefit	410
10.7.5	DVA replication and bank’s franchise	415
10.8	Recapitulation of results	419
10.9	Accounting standard and DVA	419
10.10	Distinction between price and value	421
<b>11</b>	<b>Cost of liquidity and fund transfer pricing</b>	<b>425</b>
11.1	Introduction	425
11.2	Principles of transfer pricing	425
11.2.1	Balance sheet	425
11.2.2	Bank’s profits and losses	426
11.3	Funding and banking activity	431
11.4	Building a funding curve	432
11.5	Including the funding cost in loan pricing	446
11.5.1	Pricing of a fixed rate bullet loan	450
11.6	Monitoring funding costs and risk control of refunding risk	452
11.7	Funding costs and asset/liability management	456
11.8	Internal fund transfer pricing system	457
11.8.1	Multiple curves	459
11.8.2	Single curve	461
11.8.3	Implementation of funding policies	465
11.9	Best practices and regulation	468
<b>12</b>	<b>Liquidity risk and the cost of funding in derivative contracts</b>	<b>473</b>
12.1	Pricing of derivative contracts under collateral agreements	473
12.1.1	Pricing in a simple discrete setting	475
12.1.2	The replicating portfolio in continuous time	480
12.1.3	Pricing with a funding rate different from the investment rate	483
12.1.4	Funding rate different from investment rate and repo rate	489
12.1.5	Interest rate derivatives	491
12.2	Pricing of collateralized derivative contracts when more than one currency is involved	499
12.2.1	Contracts collateralized in a currency other than the payoff currency	499
12.2.2	FX derivatives	505

12.2.3	Interest rate derivatives	511
	12.2.4 Cross-currency swaps	514
12.3	Valuation of non-collateralized interest rate swaps including funding costs	518
	12.3.1 The basic setup	518
	12.3.2 Hedging swap exposures and cash flows	519
	12.3.3 Funding spread modelling	521
	12.3.4 Strategy 1: Funding all cash flows at inception	522
	12.3.5 Strategy 2: Funding negative cash flows when they occur	524
	12.3.6 Including counterparty credit risk	528
	12.3.7 Practical examples	531
<b>13</b>	<b>A sort of conclusion: towards a new treasury?</b>	<b>539</b>
	13.1 Introduction	539
	13.2 Organization of the treasury and the dealing room	539
	13.3 Banking vs trading book	542
	13.3.1 Collateralization	542
	13.3.2 Links amongst risks	543
	13.3.3 Production costs	545
	<b>References</b>	<b>547</b>
	<b>Index</b>	<b>553</b>

## Preface

The outbreak of the financial crisis in 2007/2008 brought liquidity risk measurement and management to the attention of practitioners, regulators and, to some degree, academicians.

Up until then, liquidity risk was not considered a serious problem and was almost disregarded by risk control systems within banks and by international and national regulations. Liquidity management and fundraising was seen as routine activity, simply a part of more complex banking activity, deserving little attention or effort.

Although the savvy approach would always be to forecast and devise scenarios under which extreme conditions occur, it was barely conceivable that such a difficult economic environment like the financial crisis of 2007 could ever occur. In the economic and financial environment in which banks used to run their business before 2007, liquidity risk simply did not exist. Moreover, it was never considered a problem that could possibly extend beyond the limits of organizational issues and the development of basic monitoring tools. The design of procedures and systems were believed to cope with the small effects that banks suffered from liquidity risks.

As a consequence of these general considerations, the theory of liquidity risk was vague and restricted typically to market liquidity risk, which is the risk that assets cannot be sold swiftly in the market at a price close to the theoretical value. Although this is an important aspect of the broader liquidity risk notion, nonetheless it is just a small part of the full story, and in most cases not one strongly impacting banking activity. The only literature available on the aspects of liquidity risk concerning banking activity was mainly written by practitioners working in the industry and by a few academics. A notable example, among a few others, is the book edited by Matz and Peter, *Liquidity Risk Measurement and Management: A Practitioner's Guide to Global Best Practices* [87], which presents an excellent overview of the most relevant issues in liquidity risk management.

We felt there was a gap, though, between the need for improved practices after the events of 2007/2008, and what was proposed in the available research. The above-mentioned book by Matz and Peter was published in 2007 and, of course, could not deal with the increased requirements for risk liquidity practices.

This book tries to cover this gap: it should be seen as an attempt to introduce new tools and methods to liquidity risk measurement and management. We do not dwell on every facet of the subject; in particular, problems that are more related to organization

and mechanisms that involve higher levels of management to cope with specific liquidity crises, are only briefly analysed for modifications that could be made to existing best practices in the current financial environment.

The book is organized in three parts. Part I is an overview of the crisis in 2007 and describes how it became globalized from the US economy to the rest of the world and how it altered its form during the subsequent years, up until 2013 (when this book was written). In Part I we also show how the banking business is changing (or will be forced to change) in response to the dramatic events that occurred. These triggered a regulatory overshoot the traits of which are extensively investigated towards the end of Part I (Chapters 4 and 5). One of the most challenging tasks was actually updating chapters in the face of (still) continuously evolving regulation, which represents one of the current main drivers of the liquidity framework. For this reason, this will most likely be the part of the book doomed to becoming outdated the quickest and no longer state of the art. The regulations mentioned and studied in this book are accurate at the time of writing in January 2013. Regulations that have been updated since January can be found at the book's website <http://www.wiley.com/go/liquidityrisk>

Moving from a macroeconomic point of view, we analyse the different types of liquidity risk and how they impact on a bank's business activity, in order to find how best to manage it from a microeconomic point of view, based on analysis of the actual structure of the balance sheet and of a comprehensive framework for pricing, monitoring and managing liquidity risk.

In Part II we start quantitative study of liquidity risk, first by introducing standard tools to monitor it: it is here we show how these tools can be enhanced and extended to cope with a substantially more volatile market context. The guiding principle is to draw approaches and models from the robust and thorough theory developed to evaluate financial contracts and to apply them, with a slight shift of perspective, to the measurement and management of liquidity risk. For this reason we stress the importance of concepts such as "cash flow at risk" and "liquidity at risk" that are not new, but have never really been widely adopted in the banking industry.

Starting with Part II, the reader will soon realize that topics are discussed as if there were a sort of pendulum, constantly swinging from fundamental concepts, hinging most of the time on balance sheet analysis and involving basic math (algebraic summation), to complex modelling with stochastic processes, grounded on rather heavy mathematical approaches. We would like to make it clear we have not really created new models to measure the liquidity risk, although in a few cases we actually do so. We only want to show how to apply already available theoretical frameworks and extend their use in the liquidity risk field. For example, we show how to adapt the option pricing theory approach to liquidity risk measurement and management.

Hopefully, our intent will be clear when the chapters devoted to the modelling of market risk factors and behavioural models are read. In these chapters we used a number of instruments, available in the theoretical toolkit prepared for the valuation of derivative contracts, to solve specific problems related to liquidity risk. We left aside our initial fear and opted, like pioneers in unexplored territory, to take routes that eventually may prove not to be optimal or even wrong, but our aim was to show a different mindset when approaching the liquidity risk problem rather than to provide the best solutions.



We must acknowledge that others have tried to adopt a similar approach; namely, Robert Fiedler [89] and, more recently, Christian Schmaltz [109]. Continuing in their footsteps, we applied a bottom-up method by modelling the main items of a bank's balance sheet. In theory, the bank is then able to simulate the entire balance sheet on a very granular basis, allowing for a rich set of information that can be extracted for liquidity risk purposes.

The theoretical apparatus developed for derivative contract evaluation is even more fruitful because modern liquidity risk does not only refer, as typically in the past, to the quantitative dimension of cash flow imbalances. In fact, a new and sometimes even more important dimension is the cost of liquidity that financial institutions can raise in the market. The dramatic increase in the levels and volatility of funding spreads paid over the risk-free rate is a factor that definitely cannot be disregarded in the pricing of contracts dealt with clients and the more general planning of banking activity. This is why we devoted the third and final part of the book to the analysis of this topic.

We start Part III with definitions of funding costs and counterparty risk and the interrelations between them, which demonstrate that banks are ultimately forced to consider the cost to raise liquidity in the market as a business-related factor that cannot be hedged. We present a new framework to model funding costs keeping in mind the multiplicity of sources and the dynamicity of the activity. We introduce a novel measure of risk implicit in the rollover of maturing liabilities and we show how corresponding economic capital should be allocated to cope with it and how corresponding costs should be included in the pricing of products a bank offers to its clients.

The inclusion of funding costs is much more subtle when dealing with derivative contracts; this is why we dwell in the final chapters of the book on possible approaches to dealing with them and point out how the classical results of option pricing theory are modified when these additional factors are taken into account in the evaluation process.

In conclusion, we would like to thank everyone who helped us in elaborating the ideas presented in the book. The list would be so long and would involve so many colleagues, who have analysed and discussed these topics with us over recent years, that not only would many pages be required to name them all, but we would also run the serious risk of forgetting someone.

However, Francesco would like to thank his employer (Banca IMI) and bosses for creating a conducive and stimulating environment, in which many topics treated in this book have found continuous reference regarding analysis and applicability; many friends and colleagues, within the counterparty risk management desk and financial engineering desk, the Finance & Investments Department and the Capital Market Department of Banca IMI, the risk management desk and treasury desk of Intesa Sanpaolo, who have always been ready to exchange ideas and interesting opinions and contributions about these topics; last but not least, to all colleagues of the market treasury desk, for their friendship, support and constructive example set during their daily activity. Obviously, the book expresses only the views of the authors and does not represent the opinions or models of Francesco's employers (Banca IMI and Iason).

Finally, we want to acknowledge a number of people to whom we owe a special debt of gratitude. In particular, Raffaele Giura, of Banca IMI, who constantly discussed with us many of the issues covered and always gave us insightful and fruitful perspectives to examine in depth. Antonio discussed many of the ideas related to the liquidity of derivative contracts with Fabio Mercurio. Caterina Covacev and Luca Visinelli, of

Iason, contributed massively to refining some of the models presented, to writing the code to test them and to preparing the examples. Finally, Francesco Manenti, of Iason, helped us to estimate and test behavioural models for non-maturing liabilities.

Although the book is a joint work, during its writing we split the tasks so that Francesco mainly dealt with the topics in Part I, whereas Antonio focussed on Parts II and III. We hope the reader will find the text conducive to a better understanding of liquidity risk and perhaps go on to develop and improve the ideas outlined.

*Antonio Castagna*  
*Francesco Fede*  
Milan, January 2013

## About the authors

**Antonio Castagna** is currently partner and co-founder of the consulting company Iason Ltd, focusing on the design of models to price complex derivatives and to measure financial, liquidity and credit risks. Previously he was with Banca IMI Milan, from 1999 to 2006, where he first worked as a market maker of caps/floors and swaptions and then he set up the FX options market-making desk. He started his career in 1997 at IMI Bank Luxembourg, in the Risk Control Department. He graduated in Finance at LUISS University in Rome in 1995. He has written papers on different issues, including credit derivatives, managing exotic options risks and volatility smiles and is also the author of *FX Options and Smile Risk*, Wiley.



**Francesco Fede** is a graduate of the LUISS University of Rome. He has worked for IMI Bank Luxembourg as financial controller and risk manager since 1996. In 1998 he moved to Banca IMI Milan, where he started his career as short-term interest derivative trader in 2001. Since then, he has covered many tasks in Treasury and ALM activities. Currently he is the head of the Market Treasury desk of Banca IMI. Over the last couple of years he has focused on the pricing of liquidity risk for structured loans and derivative products, and on the impact of liquidity risk on both the trading book and banking book.





## Abbreviations and acronyms

ABCP	Asset Backed Commercial Paper
ABS	Asset Backed Security
AFS	Available For Sale
AIG	American International Group
ALM	Asset Liability Management
ASF	Available Stable Funding
bAJD	basic Affine Jump Diffusion
BBA	British Bankers' Association
BCBS	Basel Committee on Banking Supervision
BSL	Balance Sheet Liquidity
c.l.	confidence level
CBC	CounterBalancing Capacity
CC	Central Clearing
CCS	Cross Currency Swap
CD	Certificate of Deposit
CDO	Collateralized Debt Obligation
CDS	Credit Default Swap
CEBS	Committee of European Banking Supervisors
cfAR	cash Flow At Risk
CFP	Contingency Funding Plan
CIR	Cox, Ingersoll and Ross (model)
CM	Clearing Membership
CMBS	Commercial Mortgage Backed Security
CME	Chicago Mercantile Exchange
CP	Commercial Paper
CPR	Constant Prepayment Rate
CRT	Credit Risk Transfer
CSA	Credit Support Annex
CVA	Credit Value Adjustment
DF	Discount Factor
DVA	Debit Value Adjustment
EAD	Exposure At Default
EBF	European Banking Federation

EC	Economic Capital
EEA	European Economic Area
EFC	Expected Funding Cost
EL	Expected Loss
ELoP	Expected Loss on Prepayment
EM	Empirical Model
ENE	Expected Negative Exposure
Eonia	Euro overnight index average
FAS	Financial Accounting Standards
FASB	Financial Accounting Standards Board
FC	Funding Cost
FCAVL	Forward Cumulated AVailable Liquidity
FFT	Fast Fourier Transform
FO	Financial Option
forex, FX	Foreign eXchange
FRA	Forward Rate Agreement
FSA	Financial Services Authority
FSB	Federation of Small Businesses
FSB	Financial Stability Board
FTO	Fine-Tuning Operations
FTP	Fund Transfer Pricing
FVA	Funding Value Adjustment
FX	Foreign eXchange
(G)CDS	Global Credit Default Swap
G-SIFI	Global-Systemically Important Financial Institution
GDP	Gross Domestic Product
HLA	High Liquidity Asset
HQLA	High Quality Liquid Asset
IAS	International Accounting Standards
IASC	International Accounting Standards Committee
IFRS	International Financial Reporting Standards
ILAA	Individual Liquidity Adequacy Assessment
ILAS	Individual Liquidity Adequacy Standard
ILG	Individual Liquidity Guidance
IMF	International Monetary Fund
IRS	Interest Rate Swap
ISP	Intesa SanPaolo
ITA	ITAlian Treasury
LA	Liquidity Adjustment
LB	Liquidity Buffer
LBC	Liquidity Buffer Cost
LCH	London Clearing House
LCR	Liquidity Coverage Ratio
LEA	Liquid Equivalent Adjustment
LGC	Liquidity Generation Capacity
Liffe	London International Financial Futures and Options Exchange

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LLR	Lender of Last Resort
LMM	Libor Market Model
LO	Liquidity (Behavioural) Option
LTRO	Long Term Refinancing Operation
LVA	Liquidity Value Adjustment
LVA	Liquidity Value Adjustment
MBS	Mortgage Backed Security
MRO	Main Refinancing Operation
MTA	Minimum Transfer Amount
MTM	Mark To Market
MTN	Medium Term Note
MVAR	Market Value At Risk
NCB	National Central Bank
NCO	Net Cash Outflow
NINJA	No Income No Job (or) Asset
NML	Non-Maturing Liability
NPV	Net Present Value
NSFR	Net Stable Funding Ratio
OAS	Option Adjusted Spread
OBS	Off Balance Sheet
ODE	Ordinary Differential Equation
OIS	Overnight Indexed Swap
OLS	Orthogonal Least Square
OMO	Open Market Operation
OMT	Outright Monetary Transaction
ON	Over Night
OTC	Over The Counter
OTD	Originate To Distribute
P&L	Profit and Loss
PD	Probability of Default
PDCF	Primary Dealer Credit Facility
PDE	Partial Differential Equation
PDF	Probability Density Function
PFE	Potential Future Exposure
PL	Probability of Loss
PSE	Public Sector Entity
PVA	Price Volatility Adjustment
PVECF	Present Value of the sum of Expected Capital Cash Flow
RFV	Recovery of Face Value
RAROC	Risk-Adjusted Return On Capital
RBS	Royal Bank of Scotland
RI	Refinance Incentive
RMBS	Residential Mortgage Backed Security
RMV	Recovery of Market Value
ROE	Return On Equity
RPM	Rational Prepayment Models
RSF	Required Stable Funding

RTGS	Real Time Gross Settlement
SDE	Stochastic Differential Equation
SF	Standing Facility
SF	Stochastic Factor
SIFI	Systemically Important Financial Institution
SIV	Structured Investment Vehicle
SLRP	Supervisory Liquidity Review Process
SMP	Securities Market Programme
SP	Survival Probability
SPV	Special Purpose Vehicle
TA	Total Asset
TAF	Term Auction Facility
TARGET2	Trans-European Automated Real-time Gross-settlement Express Transfer
TARP	Troubled Asset Relief Program
TLA	Targeted Liquidity Assistance
TN	TurNover
TPC	Total Prepayment Cost
TRS	Total Return Swap
TSECCF	Term Structure of Cumulated Expected Cash Flow
TSECF	Term Structure of Expected Cash Flow
TSFCFu	Term Structure of Forward Cumulated Funding
TSFu	Term Structure of available Funding
TSL_e	Term Structure of expected Liquidity
TSLaR	Term Structure of Liquidity at Risk
USG	USaGe metric
VA	Value Added
VaR	Value at Risk
ZC	Zero Coupon



Part I

Liquidity and banking activity



# Banks as lemons?

## 1.1 INTRODUCTION

It was a sunny and warm Thursday of midsummer. Some dark clouds in the previous days suggested that sudden showers had been expected to fall in the short term, but no one would have forecast the magnitude of the incoming financial tsunami.

But, citing L. McDonald [87], Wall Street's most sinister troubles occasionally arrive without the thunder of the guns and the clash of mounted cavalry on the trading floor. Some deadly problems come creeping in unannounced and often unnoticed, when financial players unobtrusively arrive at a single conclusion at around the same time. No one can say anything about collective changes: suddenly there is a lightning bolt of fear crackling through the market, and the consequences are there.

That day was August 9, 2007. Some years later, that day be referred to as the dawn of the worst crisis to hit financial markets in the last two decades. It begun with newswires reporting the announcement by some BNP Paribas funds to freeze redemptions, citing difficulties in valuing their assets due to the lack of liquidity in subprime mortgage markets. In a few hours the international money market had been seriously deadlocked: central banks had to inject an enormous and unprecedented amount of liquidity into the system to settle its daily payment obligations (e.g., the special refinancing operation conducted by the ECB with overnight maturity registered a request record for EUR95 billion; on the same day the Fed injected USD24 billion). The day of reckoning had eventually come: the financial market started the long-awaited process of risk

### **Box 1.1.** Some dark clouds

On July 24 the major US home loan lender, Countrywide Financial Corp., announced an earnings drop. The market rumoured that almost one in four of all Countrywide's subprime loans were delinquent (10% of those were 90 days delinquent or more). With the ABCP market finally faltering, there was no easy access to cheap, fast money for this shadow bank that was going to be in a deadly situation.

On July 30 German bank IKB warned of losses related to subprime mortgage fail-out: as a consequence the five-year European iTraxx Crossover index reached a peak of 500 bp and liquidity in the European government bond market declined sharply.

On July 31 American Home Mortgage Investment Corp. announced its inability to fund lending obligations, and it subsequently declared bankruptcy on August 6.

reappreciation, which had been evoked by regulators and supervisors several times in previous months.

What was going to happen?

## 1.2 THE FIRST WAVE

During the previous years the combination of (i) large financial market liquidity; (ii) increasing risk appetite; (iii) rising leverage in market strategies and derivative products led to an aggressive search for higher yield by investors. This process was suddenly reversed when the number of delinquencies in the US hugely increased from early 2007. The related sharp decline in the credit quality in the subprime mortgage market impacted on the fundamentals of structured credit products. It ignited rising concerns that the delinquency rate could have risen to unprecedented levels and led some rating agencies to downgrade several issues of ABS, backed by pools of subprime mortgages. Moreover, they announced a revision of their methodologies for assigning new ratings.

At this point investors realized that (i) risk assessment and (ii) pricing methods for a large proportion of complex instruments were definitely inadequate. These factors produced great uncertainty about the fundamentals of the ABS market and increased trading frictions. At last, they translated to bid-ask spreads that grew wider and wider up to the point where all the ABS markets dried up.

Why did the announcement of these downgrades and methodology revisions impact so heavily on the market and spread far beyond a risk reappraisal and a simple shock related to the subprime sector?

First, claims on the cash flows generated by subprime loans used to be embedded by the financial industry in a broad array of structured credit products (starting with RMBS, followed by CDOs containing some exposure to these RMBS, and ultimately by CDO squared). This partly explained why indirect exposures to US subprime loans through ABS had been widespread much more than initially forecast by regulators and financial firms.

### **Box 1.2.** The phantom menace

On the May 4 UBS shut down its internal hedge fund, Dillon Read, after suffering about USD 125 million of subprime-related losses. In mid-June two hedge funds run by Bear Stearns and involved in the subprime market experienced serious trouble in fulfilling their margin calls, leading the bank to inject USD 3.2 billion in order to protect its reputation. These were not the first episodes about a possible spill-over from the US mortgage market: on the February 27, 2007 global equity markets dropped on fears about Asian equity markets and growing concerns over further deterioration in the US subprime mortgage sector. The relatively small correction (Dow Jones Euro STOXX  $-8\%$ , S&P 500  $-6\%$ ) ended on March 14 when equity markets resumed their upward trend.

**Box 1.3.** The warning of Cassandra

According to Homer, the princess Cassandra was gifted a prophecy by Apollo; but afterwards the god, offended with her, rendered the gift unavailing by ordaining that her predictions should never be believed. Like the Trojan Cassandra, not listened, the former ECB president Jean-Claude Trichet often warned the financial community about the reassessment of risk.

From the Q&A session of the ECB press conference on March 8, 2007:

Question: “When we were all in Madrid last year and the financial markets were doing their gymnastics then, you stressed that an appropriate assessment of risk was not the worst thing in the world and that perhaps some valuable lessons were being learnt. We have a similar situation now, albeit with different kinds of contours, and I wanted to see if you might be of a similar sentiment today?”

Mr Trichet’s answer: “Concerning the recent events that we have observed, it is true that the Governing Council of the ECB widely felt—and I would say that it was very largely a consensus, a consensus that I myself have expressed on a number of occasions as the chairman of the G10 group of central bank governors—that we were perhaps in a phase in global finance where risks in general were not necessarily assessed at their real price. This was materializing in the levels of spreads and risk premia and in a number of other considerations, perhaps including low real interest rates. This was our diagnosis. What we have been observing for a number of days has been a certain reassessment of risks on the upside and across the board and a higher level of volatility. This is a phenomenon that we are following very carefully. It has positive aspects, obviously. It represents a more realistic appreciation of risks in general. It must also of course be monitored very carefully because what is of the essence in our view is that such corrections are orderly and smooth and are not abrupt.

On July 10 Chuck Prince, the former Citigroup’s CEO, by referring to Keynes’ analogy between bubbles and musical chairs, said: “When the music stops, in terms of liquidity, things will be complicated. But as long as the music is playing, you’ve got to get up and dance. We’re still dancing” (see Brunnermeier [38]).

From the Q&A session of the ECB press conference on August 2, 2007:

Question: “The current phase of market movements that we see, is that something that you would characterise as a smooth reappraisal of risk or is that something that is abrupt and undesirable?”

Mr Trichet’s answer: “We are in an episode where prices that were under-assessing an element of risk in a number of markets are normalising. I will not give any other qualification to the situation: it is a process of normalisation. The first quality to be demonstrated in circumstances when we see significant increases in measures of volatility in a large range of markets and asset classes by market participants and investors, and of course by authorities is to keep their composure. That is something important and it would permit the evolution of the market to be as effective as possible in terms of going back to a normal assessment of risks in general.”

Second, questioning the methodology to assign ratings to these products implied questioning underlying assumptions about the distribution of returns on a wider variety of ABS products. ABS secured by pools of different assets, such as corporate bonds, bank loans, automobile loans and credit cards, were structured, rated and priced by using a similar methodology. Investors abruptly realized that similar properties could no longer be used for both corporate bonds and structured credit products. Without essential data about rating transition probabilities and market liquidity risk, they could no longer quantify the risk in these structured products with any degree of confidence. Many of these instruments, tailor-made to the risk–reward profile of investors and illiquid by definition, were valued by models. These models no longer worked when input data, such as market prices for ABS indices, were either not available or unreliable. Then the calculation of the fair value for most products became simply impossible.

Other market sectors were already negatively influenced: the issuance volumes of CDOs/CLOs registered a sharp decline. Growing uncertainties toward those products led to widespread refusal by financial investors to maintain their ABCP when they matured. Some ABCP issuers had to roll their debt into issues of only a few days' maturity: as a result, the average maturity of new issued paper significantly lowered. The weekly figures published by the Fed, unknown until then by a large part of market players, became one of the principal market drivers. Going on, this risk reappraisal process hit the refinancing strategies of SPV/SIV: with their usual funding channels dried up, they had to draw on their committed credit lines from their sponsoring banks. In the first half of August two German banks, IKB and Sachsen LB, were unable to honour their liquidity and credit commitments. Given the aggregate large exposures relative to the size of the sponsoring banks' balance sheets, after hectic negotiations, emergency rescues from a number of other financial institutions had to be arranged.

Under the ongoing pressure of the turmoil, financial firms finally began to wonder about the soundness of their liquidity policies. Some of them were targeted by bank runs and heavily hit by the growing credit crunch. As a result a number of small credit institutions failed, others were saved by the public sector (Northern Rock in the UK) or the private sector (Bear Stearns).

More enterprises received capital injections from governments (i.e., Citigroup, Royal Bank of Scotland, Fannie Mae, Freddie Mac, Indie Mac). A lot of them recorded profit warnings and credit losses. Spreads in interbank funding and other credit-related products rose sharply and funding strains were experienced in the secured financing market.

In mid-September 2008 the financial turmoil reached its peak. After pre-announcing its disappointing third-quarter figures, Lehman Brothers, one of the four major US investment banks, was unable to raise capital or find strategic investors: it experienced a destructive run on its liquid assets and was forced to file for creditor protection under Chapter 11 on September 15, 2008. On the same day Merrill Lynch accepted being taken over by Bank of America and, only two days later, the giant insurer AIG was rescued by the US government as it teetered on the edge of collapse due to rising requests for post-collateral payments on derivatives trades after its rating downgrading. Eventually, Morgan Stanley and Goldman Sachs decided to transform themselves from investment banks into commercial bank holding companies to gain advantage from lender-of-last-