1 Risk in perspective

1.1 Risk

- The Concise Oxford English Dictionary: "hazard, a chance of bad consequences, loss or exposure to mischance"
- McNeil et al. (2005): "any event or action that may adversely affect an organization's ability to achieve its objectives and execute its strategies"
- No single one-sentence definition captures all aspects of risk (risk means different things to different people).

For us: *risk* = potential/chance for loss $\Rightarrow$ uncertainty $\Rightarrow$ randomness

1.1.1 Risk and randomness

- To put this on solid ground, Kolmogorov (1933) introduced the notion of a *probability space* $(\Omega, \mathcal{F}, \mathbb{P})$, where
  - Ω is a *sample space* and $\omega \in \Omega$ represents a realization of an experiment ("state of nature");

- the *σ-algebra* $\mathcal{F}$ contains all sets to which we can assign probabilities ("events"); and
- $\mathbb{P}(\cdot)$ denotes a *probability measure*.

- We will mostly model situations in which an investor holds today an asset with an uncertain future value. To this end, we model the value of the asset/risky position as a *random variable* $X : \Omega \to \mathbb{R}$. Several risky positions are modeled by a *random vector* $\boldsymbol{X} : \Omega \to \mathbb{R}^d$.
- Most of this modeling concerns the *distribution functions* $F_X(x) = \mathbb{P}(X \leq x)$ and $F_{\boldsymbol{X}}(\boldsymbol{x}) = \mathbb{P}(\boldsymbol{X} \leq \boldsymbol{x})$ of X and $\boldsymbol{X}$, respectively.
- If time matters, one can consider sequences of random variables $(\boldsymbol{X}_t)_{t \geq 0}$, so-called *stochastic processes*.
- Our modeling tools will mainly come from probability and statistics (so *stochastics*; Greek "Stohastikos" = art of guessing, skilled at aiming)

1.1.2 Financial Risk

There are various types of risks. We focus on (statistical methods for)

Market risk The risk of losses in financial positions due to changes in the underlying components (e.g., stock and bond[1] prices, exchange rates, commodity prices)

Credit risk The risk of a counterparty failing to meet its obligations (default), i.e., the risk of not receiving promised repayments (e.g., loans or bonds).

Operational risk (OpRisk) The risk of loss resulting from inadequate or failed internal processes, people and systems or from external events (e.g., fraud, fat-finger trades, earthquakes).

[1] The bond issuer owes the bond holder a debt and is obliged to pay at maturity T the principal and a coupon (interest; typically payed at fixed time points).

There are many other types of risks (not discussed in detail here):

Liquidity risk

(Market) liquidity risk is the risk stemming from the lack of marketability of an investment that cannot be bought or sold quickly enough to prevent or minimize a loss. Liquidity is "oxygen for a healthy market": one is not aware of its presence; its absence, however, is recognized immediately.

Funding liquidity risk refers to the ease with which institutions can raise funding. The two often interact in stress periods.

Underwriting risk

In insurance, underwriting risk is the risk inherent in insurance policies sold (related, e.g., to natural catastrophes, political changes, changes in demographic tables).

Model risk The risk of using a misspecified (inappropriate) model for measuring risk. This is always present to some degree! (e.g., heavily in OpRisk modeling)

Good risk management (RM) has to follow a *holistic approach*, i.e., all (possibly influential) types of risks and their interactions should be considered.

1.1.3 Measurement and management

Risk measurement

- Suppose we hold a portfolio of d investments with weights $w_1, \dots, w_d$. Let X_j denote the change in value of the jth investment. The change in value (*profit and loss (P&L)*) of the portfolio over a given holding period is then $X = \sum_{j=1}^{d} w_j X_j$. Measuring the risk now consists of determining the *distribution function* F (or functionals of it, e.g., mean, variance, α-quantiles $F^-(\alpha) = \inf\{x \in \mathbb{R} : F(x) \geq \alpha\}$).

- We need a properly calibrated joint model for $\boldsymbol{X} = (X_1, \dots, X_d)$ (statistical estimates of F or one of its functionals are obtained based on historical observations of this model). Not an easy (or unique) task!
- Good risk measurement is essential (for good RM). For any product sold, the underlying risks need to be properly quantified and openly communicated to a client to decide whether or not the product matches her/his risk appetite. The 2007–2009 crisis saw numerous violations of this principle (e.g., through collateralizded debt obligations).

Risk management

What is RM? Kloman (1990) writes:

> "To many analysts, politicians, and academics it is the management of environmental and nuclear risks, those technology-generated macro-risks that appear to threaten our existence. To bankers and financial officers it is the sophisticated use of such techniques as

currency hedging and interest-rate swaps. To insurance buyers or sellers it is coordination of insurable risks and the reduction of insurance costs. To hospital administrators it may mean "quality assurance". To safety professionals it is reducing accidents and injuries. In summary, RM is a discipline for living with the possibility that future events may cause adverse effects."

$\Rightarrow$ It is about ensuring resilience to future events.

- Note that financial firms are not passive/defensive towards risk, banks and insurers actively/willingly take risks because they seek a return. RM thus belongs to the core competence of an insurance company or bank.
- What does managing risks involve?
  - Determine the capital to hold to absorb losses, both for *regulatory capital* (to please regulators) and *economic capital* purposes (to survive as a company).

- Ensuring portfolios are well diversified.
- Optimizing portfolios according to risk-return considerations (e.g., via derivatives to hedge exposures to risks, or *securitization*, i.e., repackaging risks and selling them to investors).

1.2 A brief history of risk management

1.2.1 From Babylon to Wall Street

The ancient world to the the 20th century

- A *derivative* is a financial instrument derived from an underlying asset, e.g., stocks, bonds, commodities, currencies, interest rates etc. Examples are
  - *Options* (right, but not the obligation, to buy (*call*) or sell (*put*) an asset at an agreed-upon price (the *strike price* K) during a predetermined period (*American*) or date (*exercise date* T; *European*);
  - *Futures* (obligation for the buyer (seller) to purchase (sell) an asset at a predetermined date and price);
  - *Swaps* (any exchange of an asset for another to change the maturity (e.g., of a bond) or because investment objectives have changed; include currency swaps, interest rate swaps).

- Babylon of 1800 BC: early evidence for options to provide financial cover against crop failure.

Academic innovation in the 20th century

- Before 1950: Desirability of an investment was measured in terms of its return.
- Markowitz (1952): Theory of portfolio selection; Desirability of an investment was decided upon a risk-return diagram (x-axis: risk, i.e., standard deviation; y-axis: expected return). An *efficient frontier* determined the optimal return for a given risk level.
- Late 20th century: Theory of valuation for derivatives (important milestone for quantifying and managing financial risk)
- Black and Scholes (1973): Black–Scholes–Merton formula for the price of a European call option (Nobel Prize 1997)

- Harrison and Kreps (1979), Harrison and Pliska (1981): Fundamental theorems of asset pricing

  1) A (model for) a market is arbitrage free if and only if there exists a (risk-neutral) probability measure Q equivalent to $\mathbb{P}$;

  2) A market is complete (i.e., every contingent claim can be replicated) if and only if Q is unique.

- By 1995: Nominal values outstanding in derivatives markets: tens of trillions.

Disasters of the 1990s

- Growing volume of derivatives in banks' trading books (often not appearing as assets/liabilities in the balance sheet).
- 1995 Barings Bank: OpRisk losses + *straddle position* on the Nikkei (short in a call and put with the same strike; allows for a gain if Nikkei

does not move too far up or down) + Kobe earthquake = ruin due to loss of $1.3 billion

- 1998 Long-Term Capital Management (LTCM): hedge fund; losses due to derivatives trading, required a $3.5 billion payout to prevent collapse; M. Scholes and R. Merton were principles
- Life insurer Equitable Life: Prior to 1988 Equitable Life had sold pension products which offered the option of a guaranteed annuity rate of 7% at maturity. In 1993, current annuity rate fell below the guarantee rate and policyholders exercised their options. Equitable Life faced an enormous increase in their liabilities (not properly hedged). Around 2001, Equitable Life was underfunded by around £4.5 billion.

The turn of the century

- 1996–2000: *dot-com bubble*; Nasdaq index climbed from around 1000 to around 5400; many firms contributing to this rise belong to the internet

sector. Within one year, the Nasdaq falls by 50% (the bubble burst).

- During this time, financial engineers discovered *securitization* (bundling and repackaging of risks into securities with defined risk profiles that can be sold to investors).
- Different types of assets were transformed into *collateralized debt obligations (CDOs)*; boom to lend to borrowers with low credit ratings; CDO issuance volume by 2008 was around \$3 trillion; for *credit default swaps (CDS)*[2] around \$30 trillion. *Netting* considered (i.e., compensation of long versus short positions on the same underlying), the economic value of CDS and CDO markets was much smaller.
- CDSs were being increasingly used by investors to speculate on the changing credit outlook.

[2] Credit derivative which allows the (protection) buyer (pays premiums) to transfer credit risk inherent in a reference entity to a seller (investor; pays in case of default).

- The consensus was that all this activity was a good thing!

  Alan Greenspan (Chairman Federal Reserve), November 2002:

  > "... instruments ... such as credit default swaps, collateralized debt obligations... have been developed and their use has grown rapidly in recent years. The result? Improved credit RM together with more and better risk-management tools appear to have significantly reduced ... stress on banks and other financial institutions. ... Obviously this market is still too new to have been tested in a widespread down-cycle for credit, but, to date, it appears to have functioned well."

  International Monetary Fund (IMF), April 2006:

  > "... dispersion of credit risk by banks to ... investors, rather than warehousing such risks on their balance sheets, has helped to make the banking and overall financial system more resilient."

(but also warned about possible vulnerabilities)
CEO of AIG Financial Products, August 2007:

> "It is hard for us, without being flippant, to even see a scenario within any kind of realm of reason that would see us losing one dollar in any of these transactions."

- Not all of the risk from CDOs was dispersed, large banks held alot of it themselves (see Acharya et al. (2009)):

> "Starting in 2006, the CDO group at UBS noticed that their risk-management systems treated AAA securities as essentially riskless even though they yielded a premium (the proverbial free lunch). So they decided to hold onto them rather than sell them! After holding less that $5 billion of them in 02/06, the CDO desk was warehousing a staggering $50 billion in 09/07. ... Similarly, by late summer of 2007, Citigroup had accumulated over $55 billion of AAA-rated CDOs."

The financial crisis of 2007–2009

- US house prices began to decline in 2006 and 2007.
- Subprime mortgage holders (having difficulties in refinancing their loans due to higher interest rates) defaulted on their payments. Starting in late 2007, this led to a rapid reassessment of the riskiness of securitization and losses in the value of CDOs. Banks were forced into write downs of the value of these assets on their balance sheets.
- The most serious crisis since the 1920s resulted:
  - March 2008: Bear Stearns collapsed and was sold to JP Morgan Chase
  - September 2008: Lehman Brothers filed for bankruptcy ($\Rightarrow$ worldwide panic, markets tumbled, liquidity fanished, many banks were near collapse)

- September 2008: AIG (insuring the default risk in securitized products by selling CDS protection) got into difficulty when many of the underlying securities defaulted $\Rightarrow$ emergency loan of $85 billion from the Federal Reserve Bank of New York.

Governments had to bail companies out by injecting capital or acquiring their distressed assets in arrangements such as the US TARP (Troubled Asset Relief Program).

- J. E. Stiglitz (Nobel Prize 2001) on securitization and the housing market in 1992:

  "The question is, has the growth of securitization been a result of more efficient transaction technologies, or an unfounded reduction in concern about the importance of screening loan applicants? It is perhaps too early to tell, but we should at least entertain the possibilty that it is the latter rather than the former. . . . At the very least, the banks have demonstrated ignorance of two very

basic aspects of risk: (a) the importance of correlation ... (b) the possibility of price declines."

- In parts, mathematicians/financial engineers were also blamed due to the failure of valuation/pricing models for complex securitized products, e.g., by F. Salmon (Wired Magazine, 2009-02-23, "Recipe for disaster: the formula that killed Wall Street"). The formula was the Gauss copula model and its application to credit risk was attributed to David Li.
- The reliance on mathematics was only one factor in the crisis, and certainly not the most important. Mathematicians had also warned well beforehand about securitization (see, e.g., Frey et al. (2001)). Political shortsightedness, the greed of market participants and the slow reaction of regulators had all contributed.

Recent developments and concerns

- The financial crisis led to recession and sovereign debt crises.

- High Frequency Trading (HFT) has raised concerns among regulators, triggered by such events as the Flash Crash of 2010-05-06 (United States trillion-dollar stock market crash; in about 36 minutes the S&P 500, the Nasdaq 100, and the Russell 2000 collapsed; the Dow Jones Industrial Average had its biggest intraday loss of about 9%; 2015-04-21 US Department of Justice: 22 criminal counts, including fraud and market manipulation).
- Trades are executed by computer (algorithms) in fractions of a second (no testing), computer centers are build near stock markets for faster trading. One notable casualty of algorithmic trading: Knight Capital lost $460 million due to trading errors on 2012-08-01 (acquired by Getco LLC in December 2012).
- Ongoing concern: *System risk*, i.e., the risk of the collapse of the entire financial system due to the propagation of financial stress through a network of participants. The networks are complex. Besides banks

and insurance companies they contain largely unregulated hedge funds and structured investment vehicles ("shadow banking system"). One important theme is the identification of *systemically important financial institutions (SIFIs)* whose failure might cause a systemic crisis.

1.2.2 The road to regulation

- Main aim of regulation: Ensure that financial institutions have enough capital to remain solvent.
- Robert Jenkin (member of the Financial Policy Committee of the Bank of England, 2012-04-27):

  "Capital is there to absorb losses from risks we understand and risks we may not understand. Evidence suggests that neither risk-takers nor their regulators fully understand the risks that banks sometimes take. That's why banks need an appropriate level of loss absorbing equity."

- *Basel Committee of Banking Supervision (BCBS)*: Committee established by the Central-Bank Governors of the Group of Ten (G-10) in 1974. The Basel Committee's secretariat is located at the Bank for International Settlements (BIS) in Basel (CH). The Basel Committee does not have legal force but it formulates broad supervisory standards, guidelines and statements of best practice, the *Basel Accords*, in the expectation that individual authorities will take steps to implement them.

The first Basel Accord (Basel I)

- Issued in 1988
- Only addressed credit risk
- Fairly coarse (measured risk in an insufficiently differentiated way)
  - Claimes were divided into 3 categories only, counterparties being governments, regulated banks or others;

- Risk weighting identical for all corporate borrowers, independent of their credit rating;
- Unsatisfactory treatment of derivatives.

The birth of VaR

- 1993: G-30 published a seminal report addressing for the first time so-called off-balance-sheet products, e.g., derivatives. The banking industry saw the need for proper measurement of these risks.
- At JPMorgan the famous Weatherstone 4.15 report asked for a one-day, one-page summary of the bank's market risk to be delivered to the CEO in the late afternoon (hence the "4.15").
- Value-at-Risk (VaR) as a market risk measure was born and the JP-Morgan methodology (which became known as *RiskMetrics*), set an industry-wide standard.

- Banks pushed to be allowed to use *netting* effects (compensation of long versus short positions on the same underlying)
- Amendment to Basel 1 in 1996 $\Rightarrow$ *standardized model* for market risk and internal Value-at-Risk-based model for more sophisticated banks
- Coarseness problem for credit risk remained (not enough incentives to diversify credit portfolios; regulatory capital rules too risk insensitive). Because of overcharging on the regulatory capital side, banks started shifting business away from certain market segments.

The second Basel Accord (Basel II)

- Initiated in 2001, document published in June 2004.
- Three pillar concept: 1) Quantification of regulatory capital; 2) Regulatory review of the modeling process; 3) Disclosure requirements.
- Important themes were:

- Under Pillar 1, banks are now allowed to use a more risk-sensitive approach for assessing credit risk of their portfolios (they could opt for an *internal ratings-based* approach which permitted the use of credit-rating systems.
- Operational risk was introduced as a new class of risk.

- Due to the financial crisis of 2007–2009, further amendments to the 2004 version were made (criticism: Basel II is *procyclical*, i.e., forcing firms to increase their capital ratios at exactly the wrong point in the business cycle with negative effects on liquidity), which delayed the implementation of the Basel II guidelines.

Basel 2.5

- CDOs had opened up opportunities for *regulatory arbitrage* (transferring credit risk from the capital-intensive banking book to the less-capitalized trading book).

- Some enhancements to Basel II were proposed in 2009 with the aim of addressing the build up of risk in the trading book. These enhancements, known as *Basel 2.5*, include a *stressed VaR* (calculating VaR from data for a 12-month period of market turmoil) and the *incremental risk charge* (to capture some of the default risk in trading book positions). There were also specific new rules for certain securitizations.

The third Basel Accord (Basel III)

- 2011: Five extensions of Basel II (and 2.5) were proposed:

  1) Measures to increase the quality and amount of capital by changing the definition of key capital ratios and allowing countercyclical adjustments to these ratios in crises;

  2) A strengthening of the framework for counterparty credit risk in derivatives trading with incentives to use central counterparties (exchanges);

3) Introduction of a leverage ratio to prevent excessive leverage;
4) Introduction of various ratios that ensure that banks have sufficient funding liquidity;
5) Measures to force systemically important banks (SIBs) to have even higher risk capital.

- Note: Basel III works alongside Basel II (and 2.5), not replacing it.
- Targeted end date of implementation: 2019

Parallel developments in insurance regulation

- More fragmented, much less international coordination of efforts
- Exception: Solvency II framework in the European Union (EU)
- Overseen by EIOPA (European Insurance and Occupational Pensions Authority), but implementation is a matter for national regulators (e.g., the Prudential Regulatory Authority (PRA) in the UK).

- US: Insurance regulation is a matter for state governments. The National Association of Insurance Commissioners (NAIC) provides support to insurance regulators from the individual states (helps to promote best practices etc.; early 1990s: NAIC promoted the concept of risk-based capital (RBC), a rule-based (rather than model-based) method of measuring the minimum amount of captial appropriate for supporting overall business operations depending on size and profile).
- After the 2007–2009 crisis: 2010 Dodd–Frank Act (creation of a Federal Insurance Office to "monitor all aspects of the insurance sector" and the Financial Stability Oversight Council (FSOC) "charged with identifying risks to the financial stability of the United States")
- The International Association of Insurance Supervisors (IASI) works on more international convergence for regulating the capital adequacy.
- There are also ongoing initiatives to bring about convergence of banking and insurance regulation.

From Solvency I to II

- Solvency I came into force in 2004: Rather coarse rules-based framework calling for companies to have a *minimum guarantee fund* (minimal capital) of €3 million and a solvency margin of 16–18% of non-life premiums together with 4% of the technical provisions for life $\Rightarrow$ Single, robust system, easy to understand, inexpensive to monitor. However, on the negative side, it is mainly volume based and not explicitly risk based.
- Solvency II was initiated in 2001 (publication of the Sharma report): While the Solvency II Directive was adopted by the Council of the European Union and the European Parliament in November 2009, implementation of the framework is not expected until 1 January 2016.
- The process of refinement of the framework is managed by EIOPA (conducts a series of quantitative impact studies (QIS) in which companies

have tried out aspects of the proposals; information about the impact and practicability of the new regulations results).

- Solvency II goals: strengthen the capital adequacy by reducing the possibilities of consumer loss or market disruption in insurance ($\Rightarrow$ policyholder protection and financial stability motives)

Swiss Solvency Test (SST)

- Specific to Switzerland.
- Already developed and in force since 2011-01-01.
- Implements its own principles-based risk-capital regulation for insurers.
- Similar to Solvency II, but differs in its treatment of different types of risk. Also puts more emphasis on the development of internal models.
- The implementation of the SST belongs to the responsibilities of the Swiss Financial Markets Supervisory Authority (FINMA).

1.3 The regulatory framework

1.3.1 The Basel framework

The three-pillar concept

This concept is a key feature of the framework starting from Basel II. From Basel Committee on Banking Supervision (2004):

> "The Basel II Framework sets out the details for adopting more risk-sensitive minimum capital requirements [Pillar 1] for banking organizations. The new framework reinforces these risk-sensitive requirements by laying out principles for banks to assess the adequacy of their capital and for supervisors to review such assessments to ensure banks have adequate capital to support their risks [Pillar 2]. It also seeks to strengthen market discipline by enhancing transparency in banks' financial reporting [Pillar 3]."

Pillar 1 *Minimal capital charge*. Requirements for the calculation of the *regulatory capital* to ensure that a bank holds sufficient capital for its market risk in the trading book, credit risk in the banking book and operational risk (main quantifiable risks). For market risk, most banks use internal models based on VaR methodology; for credit risk and operational risk banks may choose between several approaches (see later). We will focus on Pillar 1.

Pillar 2 *Supervisory review process*. Local regulators review the checks and balances put in place for capital adequacy assessments, ensure that banks have adequate regulatory capital and encourage them to use good techniques for monitoring and managing risks. Interest-rate risk in the banking book must be considered and stress tests of a bank's capital adequacy performed. Aim: A bank should hold capital in line with its true economic loss potential (economic capital).

Pillar 3 *Market discipline*. Addresses better public disclosure of risk measures and other RM relevant information (banks are required to provide better insight into the adequacy of their capitalization).

Credit and market risk; banking and trading book

- Banking activities are organized around the *banking book* (assets on the balance sheet held to maturity, at historic costs (*book value*); $\mathrm{VaR}_{0.999}$ is calculated based on a one-year time horizont) and the *trading book* (assets held that are regularly traded; marked-to-market every day; $\mathrm{VaR}_{0.99}$ is calculated based on a 10-day time horizont) reflecting the different accounting practices for different kinds of assets.
- Credit risk is mainly identified with the banking book; market risk with the trading book.
- The distinction is somewhat arbitrary and depends on "available to trade". There can be incentives to move instruments from one book

to the other (often from the banking to the trading book) to benefit from a more favourable capital treatment. Basel Committee on Banking Supervision (2013):

> "... the overall capital framework proved susceptible to arbitrage before and during the crisis ... To reduce the incentives for arbitrage, the Committee is seeking a less permeable boundary with strict limits on switching between books and measures to prevent "capital benefit" in instances where switching is permitted."

The capital charge for the banking book

- The credit risk of the banking-book portfolio is assessed as the sum of *risk-weighted assets (RWAs)* (i.e., linear combination of notional exposures weighted by risk weights reflecting the creditworthiness of the counterparty)

- To calculate risk weights, banks use either the *standardized approach* or one of the more advanced *internal-ratings-based (IRB)* approaches (international banks have to follow the latter).
- The capital charge is determined as a fraction (*capital ratio*) of the sum of risk-weighted assets in the portfolio. The capital ratio was 8% under Basel II, but will be increased for Basel III in 2019.
- In the standardized approach, risk weights are prescribed by the regulator.
- Under the IRB approaches banks may make an *internal* assessment of the riskiness of a credit exposure, expressing this in terms of an estimated annualized *probability of default (PD)* and an estimated *loss-given-default (LGD)*, which are used as inputs in the calculation of risk-weighted assets. The total sum of risk-weighted assets is calculated using formulas specified by the Basel Committee, which also take positive correlation into account.

- IRB approaches allow for increased risk sensitivity in the capital charges compared with the standardized approach. Note, however, that the IRB approaches do not permit fully internal models of credit risk in the banking book (they only permit internal estimation of inputs to a model that has been specified by the regulator).

The capital charge for the trading book

- For market risk in the trading book there is also a standardized approach. However, most major banks use an *internal VaR model approach* ($\mathrm{VaR}_{0.99}$ for a 10-day holding period; a 10-day $\mathrm{VaR}_{0.99}$ of \$20 million means that our market portfolio is estimated to incur a loss of $\geq$ \$20 million with probability 1% by the end of a 10-day holding period, if the portfolio composition remains fixed).
- For the conversion of VaR numbers into an actual capital charge, see later.

- VaR calculation is the main component of risk quantification, but Basel 2.5 added:
  - *Stressed VaR*: Banks are required to carry out VaR calculations based on their models being calibrated to a historical 12-month period of financial stress.
  - *Incremental Risk Charge (IRC)*: Banks must calculate an additional charge based on an estimate of the 99.9% quantile of the one-year loss distribution due to defaults and rating changes (since default and rating migration risk are not considered otherwise).
  - *Securitizations*: Exposures to securitizations in the trading book are subject to new capital charges.

The capital charge for OpRisk

There are three options of increasing sophistication. Under the *basic-indicator* and *standardized approaches* banks may calculate their OpRisk

charge using simple formulas based on gross annual income. Under the *advanced measurement approach* banks may develop internal models (most are based on internal and external historical data).

New elements of Basel III

The main changes will be (may change before final implementation):

- Banks will need to hold more and better quality capital (the latter is achieved through a more restrictive definition of eligible capital, the former relates to Basel II's 8% + a capital conservation buffer of 2.5% of risk-weighted assets + a countercyclical buffer of up to 2.5%)
- A *leverage ratio* will be imposed to put a floor under the build-up of excessive leverage (leverage will be measured through the ratio of Tier 1 capital to total assets; a minimum ratio of 3% is currently being tested).
- A charge for *counterparty credit risk* is included. When counterparty credit risk is taken into account in the valuation of an OTC derivative

contract, the default-risk-free value has to be adjusted by an amount known as the *credit valuation adjustment (CVA)*.

- Banks will become subject to *liquidity rules*; this is a completely new direction for the Basel framework which has previously only been concerned with capital adequacy. A *liquidity coverage ratio (LCR)* will be introduced to ensure that banks have enough highly liquid assets to withstand a period of net cash outflow lasting 30 days. A *net stable funding ratio (NSFR)* will ensure that sufficient funding is available in order to cover long-term commitments ($\geq$ one year).

Risk quantification may change from VaR-based to being based on expected shortfall (ES); see later.

1.3.2 The Solvency II Framework

Main features

- As Basel II, Solvency II adopts a three-pillar system (Pillar 1: quantification of regulatory capital; Pillar 2: governance and supervision; Pillar 3: disclosure of information to the public)
- Under Pillar 1, a company calculates its *solvency capital requirement (SCR)* = amount of capital to ensure that the probability of insolvency over a one-year period is no more than 0.5% (referred to as a confidence level of 99.5%).
- The company also calculates a smaller *minimum capital requirement (MCR)* = minimum capital to continue operating without supervisory intervention.
- For calculating capital requirements, a *standard formula* or an *internal model* may be used. Either way, a *total balance sheet approach* is taken

(all risks and their interactions are considered).

- The insurer should have *own funds* (surplus of assets over liabilities) that exceed the SCR and the MCR.
- Under Pillar 2, the company must demonstrate that it has a RM system in place and that this system is integrated into decision making processes.
- An internal model must pass the "use test": It must be an integral part of the RM system and be actively used in the running of the firm. Moreover, a firm must undertake an *ORSA (own risk and solvency assessment)* as described below.

Market-consistent valuation.

- Assets and liabilities of a firm must be valued in a *market-consistent* manner. Where possible, actual market values should be used (*marking-to-market*).

- When no market values exist, models (consistent with market information) have to be calibrated (a process known as *marking-to-model*).
- Market consistent valuation of the liabilities of an insurer is possible if cash flows to policyholders can be replicated by a replicating portfolio of matching assets.
- If this is not possible (e.g., for mortality risk), valuation is done by computing the sum of a *best estimate* of the liabilities (basically an expected value) plus a *risk margin*.

Standard formula approach

- Insurers calculate capital charges for different kinds of risk within a series of *modules* (e.g., for market risk, counterparty default risk, life underwriting risk, non-life underwriting risk and health insurance risk)
- Within each module, capital charges are calculated with respect to fundamental risk factors (e.g., within the market risk module, there

are interest-rate risk, equity risk or credit-spread risk). Capital charges are calculated by considering stress scenarios on the value of net assets (assets − liabilities). The stress scenarios are intended to represent 1 in 200 year events (i.e., events with annual probability 0.5%).

- The capital charges for each risk factor are aggregated to obtain the module risk charge. Again a set of correlations is used to express the regulatory view of dependencies between the fundamental risk factors.
- The risk charges arising from these modules are aggregated to obtain the SCR using a formula that involves a set of prescribed correlation parameters.

Internal model approach.

- On regulatory approval, firms can develop an internal model for the financial and underwriting risk factors.

- An internal model often takes the form of a so-called *economic scenario generator (ESG)* in which risk-factor scenarios for a one-year period are randomly generated and applied to the assets and liabilities to determine the SCR.

ORSA (Own risk and solvency assessment)

- *OSRA* = entirety of processes and procedures to identify, assess, monitor, manage, and report short and long term risks a (re)insurance company may face and to determine the own funds necessary to ensure the company's solvency at all times.
- OSRA (Pillar 2) is different from capital calcuations (Pillar 1):
  - ORSA refers to a *process* (and not just an exercise in regulatory compliance);
  - Each firm's ORSA is its *own* process and likely to be *unique* (not bound by a common set of rules such as the standard-formula ap-

proach in Pillar 1; even firms using internal models under Pillar 1 are bound to similar constraints).

- ORSA goes beyond the one-year time horizon (which is a limitation of Pillar 1); e.g., for life insurance.

1.3.3 Criticism of regulatory frameworks

- Benefits of regulation: Customer protection, responsible corporate governance, fair and comparable accounting rules, transparent information on risk, capital and solvency for shareholders etc.
- The following aspects have raised criticsm:
  - Costs and complexity for setting up and maintaining a sound risk management system compliant with present regulations (PRA: in the UK, Solvency II compliance costs at least £3 billion. Regulation becomes more and more complex.

- *Endogenous risk* (i.e., the risk generated within a system and amplified by the system due to feedback effects): Regulation may amplify shocks. It can lead to *risk-management herding* (institutions all run for the same exit by following the same (perhaps VaR-based) rules in times of crisis and thus further destabilize the whole system).
- Market-consistent valuation (at the core of the Basel rules for the trading book and Solvency II) implies that capital requirements are closely coupled to volatile financial markets. An insurer may appear to have insufficient solvency funds. However, if assets and liabilities are matched and contractual obligations can be met, this may not be a problem (insurance is a long-term business; no short-term need to sell assets or offload liabilities; a loss of capital need not be realised unless some of the bonds actually default).
- Highly quantitative nature of regulation: Extensive use of mathematical and statistical methods. Lord Turner (2009) (Turner Review of

the global banking crisis):

> "The very complexity of the mathematics used to measure and manage risk, moreover, made it increasingly difficult for top management and boards to assess and exercise judgement over the risk being taken. Mathematical sophistication ended up not containing risk, but providing false assurances that other prima facie indicators of increasing risk (e.g. rapid credit extension and balance sheet growth) could be safely ignored."

Overconfidence in the quality of risk measure estimates is a weakness. Quantitative modeling of OpRisk has been controversial: How can we measure human risk (e.g., incompetence, fraud), process risk (e.g., model risk, transaction risk), technology risk (e.g., system failure, programming and numerical errors) or legal risk?

- Can tighter regulation prevent a crisis such as that of 2007–2009? Rules are constantly overtaken by financial innovation.

1.4 Why manage financial risk?

1.4.1 A societal view

- Society relies on the stability of the banking and insurance system. The regulatory process (from which Basel II and Solvency II resulted) was motivated by the desire to prevent insolvency of individual institutions and thus protect customers (*microprudential perspective*).
- However, the reduction of systemic risk has become an important secondary focus since the 2007–2009 crisis (*macroprudential perspective*).
- Most would agree that the protection of customers and the promotion of financial stability are vital, but it is not always clear whether the two aims are well aligned (e.g., might be good to let a company go bankrupt to teach other companies a lesson).
- This is related to *systemic importance* of the company in question (size and connectivity to other firms). Considering some firms as too big to

fail creates a moral hazard (should be avoided!) since the management of such a firm may take more risk knowing that it would be bailed out in a crisis. Also, some companies are too big to save.

- Before the crisis, it was initially believed that the growth in securitization was dispersing credit risk throughout the system and was beneficial to financial stability. But inadequately valued credit risk (through CDOs) in the trading book, combined with the interconnectedness of banks through derivatives and interbank lending activities, meant that quite the opposite was true.
- Society suffered next. The world economy went into recession, households defaulted on their debts, and savings and pensions were hit hard. The crisis moved from "Wall Street into Main Street".
- It seemed that the government-sponsored bail-outs had allowed banks "to privatize the gains and socialize the losses".

- The interests of society are served by enforcing the discipline of risk management in financial firms, through the use of regulation. Better risk management can reduce the risk of company failure and protect customers and policyholders. However, regulation must be designed with care and should not promote herding, procyclical behaviour or other forms of endogenous risk that could result in a systemic crisis. Individual firms need to be allowed to fail on occasion, provided customers can be shielded from the worst consequences through appropriate compensation schemes.

1.4.2 The shareholder's view

- It is widely believed that proper financial RM can increase the value of a corporation and hence shareholder value. Questions to be answered include:
  - When does RM increase the value of a firm, and which risks should be managed?

- How should RM concerns factor into investment policy and capital budgeting?

- While *individual* investors are typically risk averse and should therefore manage the risk in their portfolios, it is not clear that risk management at the *corporate level* (e.g., hedging a foreign-currency exposure or holding a certain amount of risk capital) increases the value of a corporation and thus enhances shareholder value. The rationale for this is simple: If investors have access to perfect capital markets, they can do the RM transactions via their *own* trading and diversification.
- The famous *Modigliani–Miller Theorem*, which marks the beginning of modern corporate finance theory, states that, in an ideal world without taxes, bankruptcy costs and informational asymmetries, and with frictionless and arbitrage-free capital markets, the financial structure of a firm (thus its RM decisions) is irrelevant for the firm's value. In order to find reasons for corporate RM, one has to "turn the Modigliani–Miller

Theorem upside down":

- RM can reduce *tax costs*.
- RM can be beneficial, since a company may have better access to capital markets than individual investors.
- RM can increase the firm value in the presence of *bankruptcy costs* (e.g., cost of lawsuits or liquidation costs), as it makes bankruptcy less likely; this often has a positive effect on key employees or businesses (e.g., few customers would want to enter into a life insurance contract with an insurance company which is known to be close to bankruptcy; or banks might be faced with a bank run if close to bankruptcy).
- RM can reduce the impact of *costly external financing*, as it helps achieving optimal investment (external funds are more costly to obtain than internal funds; without RM the increased variability of a company's cash flow will be translated either into an increased

variability of external funds or to an increased variability in the amount of investment, both lead to decreasing (expected) profits).

1.5 Quantitative Risk Management

1.5.1 The Q in QRM

- In what follows, we adopt a somewhat narrower view and treat QRM as a quantitative science using the language of mathematics in general, and probability and statistics in particular.
- Mathematics and statistics provide us with with a suitable language and with appropriate concepts for describing financial risks which could otherwise not be done.
- A main theme is also to point out limitations of current methodology used. Furthermore, mathematicians are very well aware that a mathematical result not only has a conclusion, but equally importantly, has assumptions under which it holds. Statisticians are well aware that inductive reasoning on the basis of models relies on the assumption that these assumptions hold in the real world.

- By starting with questionable assumptions, models can be used (or manipulated) to deliver bad answers. The implication is that quantitative risk managers must become more worldly about the ways in which models are used. But equally, the regulatory system needs to be more vigilant about the ways in which models can be gamed.
- The Q in QRM is an essential part of the process. We believe it remains (if applied correctly and honestly) a part of the solution to managing risk (not the problem). See also Shreve (2008):

  "Don't blame the quants. Hire good ones instead and listen to them."

1.5.2 The nature of the challenge

- Our approach to QRM has two main strands:
  - Put current practice onto a firmer mathematical ground;

- Put together techniques and tools which go beyond current practice and address some of the deficiencies.

- In particular, some of the challenges of QRM are:
  - Extremes matter. There is the need to address unexpected, abnormal or extreme outcomes (in contrast to many classical/statistical applications); see also A. Greenspan (Joint Central Bank Research Conference, 1995):

    "... inappropriate use of the normal distribution can lead to an understatement of risk, which must be balanced against the significant advantage of simplification. From the central bank's corner, the consequences are even more serious because we often need to concentrate on the left tail of the distribution in formulating lender-of-last-resort policies. Improving the characterization of the distribution of extreme values is of paramount importance."

Or Lord Turner (2009):

> "Price movements during the crisis have often been of a size whose probability was calculated by models (even using longer term inputs) to be almost infinitesimally small. This suggests that the models systematically underestimated the chances of small probability high impact events ... it is possible that financial market movements are inherenetly characterized by fat-tail distributions. VaR models need to be buttressed by the application of stress test techniques which consider the impact of extreme movements beyond those which the model suggests are at all probable."

- Interdependence and concentration of risks. Risk is multivariate in nature, we are generally interested in some form of aggregate risk that depends on high-dimensional vectors of underlying risk factors. A particular concern is the dependence between extreme outcomes,

when many risk factors move against us simultaneously. In connection with the LTCM case we find the following quote in Business Week, September 1998.

> "Extreme, synchronized rises and falls in financial markets occur infrequently but they do occur. The problem with the models is that they did not assign a high enough chance of occurrence to the scenario in which many things go wrong at the same time–the "perfect storm" scenario."

In a perfect storm scenario, portfolio disversifcation arguments break down and there is much more concentration of risk; this was very much the case with the 2007–2009 crisis when borrowing rates rose, bond markets fell sharply, liquidity disappeared and many other asset classes declined in value.

- The problem of scale. A portfolio may represent the entire position in risky assets of a financial institution. Calibration of detailed

multivariate models for all risk factors is impossible and hence any sensible strategy involves dimension reduction (i.e., identification of key risk drivers/features to be modeled). We are forced to adopt a fairly "broad-brush" approach. E.g., in the context of portfolio credit risk, we are more concerned with finding suitable models for the default dependence of counterparties than with accurately describing the individual default mechanism, since it is our belief that the former is at least as important as the latter in determining the risk of a large diversified portfolio.

- Interdisciplinarity. Ideas and techniques from several existing quantitative disciplines are drawn together. A combined quantitative skillset should include concepts, techniques and tools from mathematical finance, statistics, financial econometrics, financial economics and actuarial mathematics.
- Communication and education. A quantitative risk manager operates

in an environment where additional non-quantitative skills are equally important (communciation, market practice, institutional details, humility). A lesson from the 2007–2009 crisis is that improved education in QRM is essential; from the front office to the back office to the boardroom, users of models and their outputs need to be better trained to understand model assumptions and limitations. This is part of the role of a quantitative risk manager, who should ideally have (or develop) the pedagogical skills to explain methods and conclusions to audiences at different levels of mathematical sophistication.

1.5.3 QRM beyond finance

- Some of the earliest applications of QRM are to be found in the manufacturing industry, where similar concepts and tools exist under names like reliability or total quality control. Industrial companies have recognized the risks associated with bringing faulty products to the market.
- QRM techniques have been adopted in the transport and energy industries (cost of storage and transport of electricity).
- There is an interest in the transfer of risks between industries; this process is known as *alternative risk transfer (ART)*, e.g., the risk transfer between the insurance and banking industries.
- QRM methodology also applies to individuals, e.g., via the risk of unemployment, depreciation in the housing market or the investment in the education of children.