



# Market consistent value, risk neutral measure

Concepts and examples  
for life insurance liabilities

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# Agenda

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## Motivation

### Concepts and examples

- risks and markets
- MCV, risk neutral measure, replication
- risk margin, MCEV

### Illustrations and highlights

- Behind market prices
- Bond CF adjustment
- RN Monte Carlo limitations
- Residual discretion in MCEV

## Wrap-up

## For a presentation

### For MCEV

- legal, professional
- peers, analysts
- portfolio

# Objectives of the presentation

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- ✓ Review and clarification of concepts
- ✓ Illustrations
- ✓ Understanding for usage and validation of
  - o MCEV calculation models
  - o risk neutral scenario generation
- ✓ Reveal replication behind risk neutral measure
- ✓ Spot simple ideas buried in complicated methods
- ✗ Knowledge to build
  - o MCEV models
  - o RNS generation tools
- ✓ Challenges, limitations
- ✗ Illiquidity adjustment

# Backgrounds – why market consistency?



- It's nice...
  - ✓ comparable (insurance, finance sector), objective, less room for mgmt discretion, internal consistency, group aggregation
  - ✗ volatile, procyclical, complex, increases and hides model risk
- Analysts like it
- We have to
  - MCEV targeted to replace [E]EV in disclosure
  - IFRS fair value
  - Solvency II technical provision and risk capital based on MC valuation
    - in particular Art. 75.1 (b), 76, 77, 79 of Directive 2009/138/EC
  - In the presentation we take this as an objective **requirement**.

# Example liabilities (cash flow patterns) 1

The most important reason for MCEV calculation is the presence of a portfolio.

Here we present a few very basic liability examples to start with. Importantly, in these examples the world will be as simple as the product – two possible outcomes at all for the policy, so be it for the universe. This aid in talking about unambiguity.

| <b>Payout</b> | <b>T</b> | <b>Condition</b> |                      |
|---------------|----------|------------------|----------------------|
| 10200         | 1        |                  |                      |
| 30400         | 1        | D                | (DH @ t=1)           |
| 10000         |          | M                | (MA @ t=1)           |
| 30400         | 1        | D                |                      |
| 30400         | 2        | ID               | (IF @ t=1, DH @ t=2) |
| 10000         | 2        | IM               | (IF @ t=1, MA @ t=2) |

# Example liabilities

| Payout                               | T | Condition                |                                |
|--------------------------------------|---|--------------------------|--------------------------------|
| 11000<br>9000                        | 1 | $u_{10\%}$<br>$d_{10\%}$ | (EQ +10% @ 1)<br>(EQ -10% @ 1) |
| 33000 / 11000<br>27000 / 9000        | 1 | $u_{10\%}$<br>$d_{10\%}$ | D / M<br>D / M                 |
| 33000 / 11000<br>27000 / <b>9510</b> | 1 | $u_{10\%}$<br>$d_{10\%}$ | D / M<br>D / M                 |
| 33000                                | 1 | $u_{10\%}$               | D                              |
| 36300 / 12100                        | 2 | $uu_{10\%}$              | ID / IM                        |
| 29700 / 9900                         | 2 | $ud_{10\%}$              | ID / IM                        |
| 27000                                | 1 | $d_{10\%}$               | D                              |
| 29700 / 9900                         | 2 | $du_{10\%}$              | ID/IM                          |
| 24300 / 8100                         | 2 | $dd_{10\%}$              | ID/IM                          |

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Wrap-up

Risk factors list

- identification
- relevant markets
- sources and appearance of data

examples, examples, examples

# Mortality risk

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- Death / survival of the insured person
  - Affects the cash flows.
  - In our simple world, timing within a year does not matter.
- Not a traded risk, because...
  - Can *only* be covered with reinsurance, coinsurance, limited level of securitization.
  - There is no market where:
    - short and long positions can be opened and closed,
    - with small margins and incurring low frictional costs,
    - quickly (though for mortality this is not very important),
    - both in small and large quantities (relative to our exposure).
- Data representation
  - best estimate, confidence ranges, ad hoc scenaria

# Time value of money

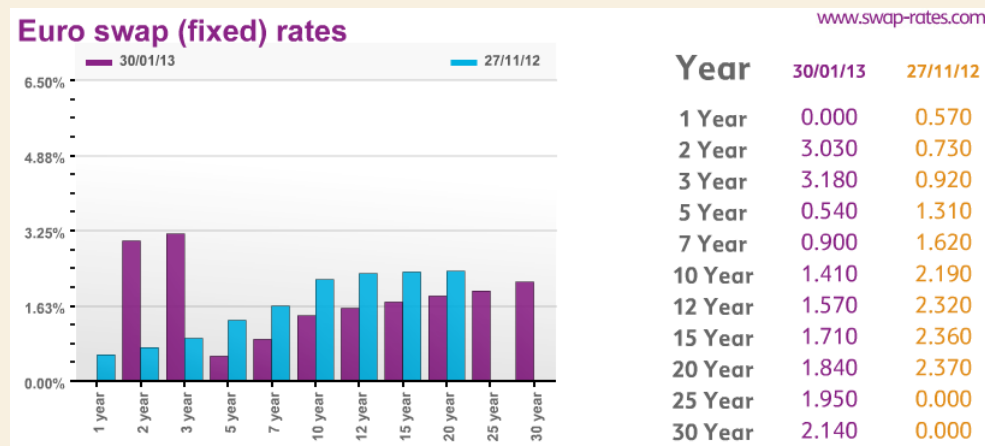


- Not a 'risk', but treated similarly
  - Affects the current value of future cash flows.
  - Does have a market.
  - We use the same methods as for market risk quantification.
- Available markets and prices
  - swap transactions, FRAs
  - secondary market of sovereign bonds, other low risk fixed income securities
  - primary issues of these instruments
  - interpolation patterns, adjustments, spreads from other markets (e.g. more liquid currencies)
  - yield curves prepared by and purchased from a provider
  - EIOPA official rates and spreads

# Time value of money



- Data
  - yield curve for the entire duration of the CF
  - per currency
  - per risk class
- Data examples
  - risk free zero coupon bond, 100 @ t=1 trades at 98.04  
⇒ annual effective risk free rate for 1y is 2.00%
  - swap mid prices  
+ interpolation  
⇒ ZCB yield curve



# Interest rate variation



- Chance for future interest rates going up / down
  - ... relative to 'expected' (implied by current forward rates).
  - Affects the value of assets and liabilities if those involve or imply interest rate.
  - options and guarantees attached to interest rate.
- Available markets and prices
  - swaptions
  - historical volatility, adjustments based on more liquid markets (currencies)
  - (historical) correlations
- Data
  - volatility parameter(s) to yield curve model
  - tenor correlations (within a currency)
  - cross-currency correlations, link(s) with FX rate model

## Swaption

The right to optionally enter a swap:

- on a future date,
- at a preset fixed rate (not *in par*).

Note: if the option is taken:

- the swapped coupons are not optional any more,
- however the position can be closed (cashed in).

# FX rates



- Movements in foreign exchange rates
  - ... relative to 'expected' (implied by current interest rates).
  - May affect the cash flows.
  - Affect the value of cash flows if those involve or imply options and guarantees attached to FX rates.
  - Important for group aggregation of value and risk.
- Market and prices
  - FX spot and forward
  - FX options
  - cross-currency swaps
  - historical correlations
- Data
  - volatility and correlation parameters (also with IR!)

## Impact of future FX rates to liabilities

Most common: UL fund indirectly invests abroad.

- Real liability will depend on FX.
- Without options we may model directly the redenominated price process.

Market prices of FX derivatives needed if:

- Optionality involved.
- FX risk reported separately.
- Multi-currency portfolio.

- Risk in movement of equity and index prices

**(Ir)relevance of equity spot prices**

If the liabilities are defined in nominal terms (to the actuarial valuation),  
then the spot prices do not directly impact the cash flows (only set the scale, e.g. for projected EQ prices).

- risk attached to UL
- traditional with profit

○ Affects the value of options and guarantees

- Market and prices

- spot prices...
- forward prices...
- equity options, index options, basket options, cross FX options etc.

**Relevance of equity forward prices**

Forward equity prices depend on interest rates, not on EQ price process attributes – irrelevant for EQ risk.

However, EQ derivatives that are *not* adjusted for dividend gains *do* provide pricing information on the dividend flow – relevant for interpretation of other unadjusted instrument prices, possibly options.

- Data
  - volatility parameters to EQ projection model
  - (historical) correlations between EQ, FX, IR

- Data example

- Annualised volatility  $x\%$ , as implied by market prices
  - of ATM European options
  - for 1y tenor
  - based on a static interest rate
  - using  $y\%$  risk free rate
  - assuming  $z\%$  (annualized) dividend rate

### Equity model parameters

- Standard Black-Scholes has only a single, constant volatility parameter (drift will be tied for MC).
- More complex models contain (G)ARCH terms, jumps, ...
- The more parameters a model uses, the harder it is to calibrate – the more we may need historical data to supplement market prices.

*Mind the clauses!*

# Real estate

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- Stochastic behaviour of RE indices or direct investment
  - Often reported separately from EQ.
  - Models and methods quite the same.
  - Out of our scope.

# Other risks

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- Persistency, health, P&C, operation, ...
  - Non-traded just as mortality.
  - Out of our scope.
- Macroeconomic indicators (inflation), 'fancy' financial measures (volatility, correlation), dynamic behaviour
  - Usually no direct market and no standalone risk dimension.
  - Modelling decision whether and how split between market and non-market (also consider model risk).
  - Not in our focus.

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Wrap-up

Rules of the game

Evaluation methods

- abstract replication
- matrix algebra
- risk neutral measure

Discretion in

- model layout, parameter rules
- calibration

Continuous models

- risk neutral measure
- dynamic and static replication

examples, examples, examples

# Market Consistent Value



Result from a **valuation method / system** which is:

- internally **consistent**,
  - Homogeneous linear – same rules that we demand from the expected value operation.
- **consistent** with calibration prices obtained from **markets**
  - The valuation method can be applied to the (cash flows of) calibration instruments.
  - The recalculated value reconciles – in theory, and up to acceptable statistical and other technical error.
- positive / monotonous
  - $CF \geq 0$  has value  $\geq 0$ , and if also  $CF > 0$  is possible,  $V > 0$ .
  - *This is usually trivial, or implied by calibration.*

Result from a **valuation method / system** which is...

- unambiguous

In the selected model  
result is uniquely determined

**Mind the steps!** 

- Real portfolio mapped to model portfolio intentionally lose information
- Running the model unambiguity OK in granularity of the valuation system (!)
- The valuation mechanics may also require us to lose or invent information in the extrapolation).

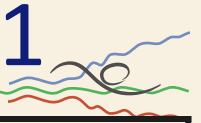
## Granularity and ambiguity – example

- Inflation in reality is not determined by yield curve.
- In lack of inflation linked instruments, market calibration is not possible.
- Linking inflation to risk free rate is a model design simplification.
- This ties the value of inflation dependent cash flows to FI instruments and removes ambiguity.
- This simplification is not a part of the market consistent machinery but a **prerequisite** to its applicability.
- Appropriateness of the simplification is a **requirement** for market consistency and not an implication of it – document and validate as expert judgement!

Observed prices for our examples

- ZCB with tenors 1, 2, 3, 4, ... (nominal 100, risk free)  
98.04, 96.12, 94.23, 92.38, ...
- spot price of the equity we'll use  
 $S = 100$
- European call/put options on  $S$  at  $t=1$ , various strikes  
for simplicity, we don't allow for realized gains
  - $C_{t=1}(100) = 2.94$        $P_{t=1}(100) = 0.98$        $P_{t=1}(95) = 0.37$
  - Enough for our examples. In reality we would see infinite different pieces of even the plain vanilla options – and this can be annoying as we'll see.

# MCV examples





| Liability  | Payout  | T | Condition | MCV                               |
|------------|---------|---|-----------|-----------------------------------|
|            | -10 200 | 1 | –         | <input type="text" value="?"/> 10 |
| Instrument | Payout  | T | Condition | Market price                      |
| ZCB(n=1)   | 100     | 1 | –         | 98.04                             |

- Valuation method, result
  - set discount rate (annual effective) to 2%
  - value = deterministic PV@t=0 of the future (unconditional) CF  
-MCV =  $10\,200 / 102\% = 10\,000$
- Consistency
  - internal – trivial (deterministic PV is a linear operation)
  - external – ZCB price OK (because of discount rate **calibration**)
- Uniqueness
  - liability CF is identical to -102 ZCB, value **must** be -102 V(ZCB)

# MCV examples

2a 

| Liability  | Payout          | T | Condition  | -MCV   |
|--|-----------------|---|--|--|
|  | 11 000<br>9 000 | 1 | $u_{10\%}$<br>$d_{10\%}$  | <input style="border: 1px solid black; display: inline-block; width: 40px; height: 20px; vertical-align: middle;" type="text" value="?"/> 10 |
| Instrument   | Payout          | T | Condition  | Market price   |
| ZCB(n=1)   | 100             | 1 | —  | 98.04  |
| Equity(0..1)  | 110<br>90       | 1 | $u_{10\%}$<br>$d_{10\%}$   | 100  |

- Valuation method: **abstract replication**

- $CF(\text{liability}) = w_1 \text{ CF}(\text{ZCB}) + w_2 \text{ CF}(\text{EQ}_{0..1})$

- $-\text{MCV}(\text{L}) = w_1 \text{ Price}(\text{ZCB}) + w_2 \text{ V}(\text{EQ})$

- unique solution:**  $w_1=0, w_2=-100, -\text{MCV}(\text{L}) = 10\ 000$


- Consistency, uniqueness

- trivial as long as the calibration prices are consistent and appropriate weights can be found

# MCV examples


2b 

| Instrument   | Payout   | T | Condition             | Market price |
|--------------|----------|---|-----------------------|--------------|
| ZCB(n=1)     | 100      | 1 | —                     | 98.04        |
| Equity(0..1) | 110 / 90 | 1 | $u_{10\%} / d_{10\%}$ | 100          |

- Valuation method: **state prices**
  - Invest 1 to risk free asset (bank account) at  $t=0$ .
  - For each possible outcome  $\omega$  the instrument  $B_\omega$  pays out the accumulated investment ( $B(t)$ , 'bank account process') **if and only if**  $\omega$  does happen: 
    - $B_u$  pays **1.02** at  $t=1$  **on up** and pays 0 on down.
    - $B_d$  pays 0 on up and pays **1.02** at  $t=1$  **on down**.
  - Calculate the value  $V_\omega$  for each of these imaginary instruments via abstract replication.
    - $B_u = -0.0459 \text{ ZCB} + 0.051 \text{ E}$        $V_u = 60\%$
    - $B_d = 0.0561 \text{ ZCB} - 0.051 \text{ E}$        $V_d = 40\%$
  - Replicate the liabilities with the  $\{B_\omega\}$  instrument set.
- Consistency, uniqueness – same as previous (same calculation)

# MCV examples

| Instrument | Payout          | T | Condition                | Market price |
|------------|-----------------|---|--------------------------|--------------|
| $B_u$      | B(T)            | 1 | $u_{10\%}$               | 60%          |
| $B_d$      |                 |   | $d_{10\%}$               | 40%          |
| Liability  | Payout          | T | Condition                | -MCV         |
|            | 11 000<br>9 000 | 1 | $u_{10\%}$<br>$d_{10\%}$ | 10 000       |

- Calculation is simple:  $-MCV(L) =$ 
  - $\sum_{\omega} (CF(T) / B(T) | \omega) V_{\omega} = \sum_{\omega} (PV_0(CF) | \omega) V_{\omega}$
  - $(11\ 000 / 1.02) \cdot 60\% + (9\ 000 / 1.02) \cdot 40\% = 10\ 000$
- $Q(A) = \sum_{\omega \in A} V_{\omega}$  defines a prob. measure on the outcomes
  - $\sum_{\omega} V_{\omega} = 100\%$  Price of the instrument that surely pays B(T).
  - $V_{\omega} > 0$  Must be, or calibration is impossible. 
  - $-MCV(L) = E_Q(PV_0(CF))$  **Q** turns MCV into an expected present value.

| Instrument      | Payout   | T | Condition             | Market price |
|-----------------|----------|---|-----------------------|--------------|
| B(1) (from ZCB) | 1.02     | 1 | –                     | 1            |
| Equity(0..1)    | 110 / 90 | 1 | $u_{10\%} / d_{10\%}$ | 100          |

- Valuation method: **implied probability measure**
  - Define model structure (possible outcomes).
  - Assume calibration prices are calculated as  $E_Q(PV_0(CF))$  and solve on  $Q$ .
    - Technically, we can do this **before** even looking at the liabilities to value. This is useful for splitting operation in time and staffing.
    - However, model structure and calibration instruments **should be** selected with consent for the target scope (granularity, relevance, appropriateness).
    - Consistency of models **creating**  $Q$  and models **using**  $Q$  is key – **easy to miss**.
  - $110 / 1.02 \cdot Q(u) + 90 / 1.02 \cdot (1 - Q(u)) = 100$  yields  $Q(u) = 60\%$
- Consistency, uniqueness – same as abstract replication
  - The calculation is literally the same, just we have split it to steps.
  - Hidden it may be – we **do use** replication and no arbitrage argumentation.

# MCV examples

| Instrument    | CF(1)   $u_{10\%}$ | CF(1)   $d_{10\%}$ | Value      |
|---------------|--------------------|--------------------|------------|
| ZCB(n=1)      | 100                | 100                | 98.04      |
| Equity(0..1)  | 110                | 90                 | 100        |
| $B_u$         | 1.02               | –                  | $Q(u)$ 60% |
| $B_d$         | –                  | 1.02               | $Q(d)$ 40% |
| UL plain      | 11 000             | 9 000              | 10 000     |
| UL guaranteed | 11 000             | 9 510              | 10 200     |

- Plain and guaranteed UL pricing require the same information set.
  - We only need interest rate and (for scale) spot price.
  - This is specific to the model (binary, fixed step EQ process) – volatility and value are linked together through the single free parameter  $Q(u)$ .  
Of course, this does not happen in proper models.
  - Model is **not valid** for pricing UL guarantees.

# MCV examples

| Instrument            | CF(1)   $u_{10\%}$ | CF(1)   $d_{10\%}$ | Value      |      |
|-----------------------|--------------------|--------------------|------------|------|
| $B_u$                 | 1.02               | –                  | Q(u)       | 60%  |
| $B_d$                 | –                  | 1.02               | Q(d)       | 40%  |
| $C_{t=1}(100) = 2.94$ | 10                 | 0                  | wrong      | 5.88 |
| $P_{t=1}(100) = 0.98$ | 0                  | 10                 | wrong      | 3.92 |
| $P_{t=1}(90)$         | 0                  | 0                  | impossible |      |

- Model could only be calibrated to interest rate and spot equity.
  - Options with strike 100 could not be calibrated properly – calculated MCV is far off from market prices.
  - Option with strike 90 can not exist in this model because it never pays out.
  - These results **could be** valid, but only if the respective options were irrelevant for the product range.

# MCV examples

| Instrument            | $u_{10\%}$ | n      | $d_{10\%}$ | Value   |
|-----------------------|------------|--------|------------|---------|
| ZCB(n=1)              | 100        | 100    | 100        | 98.04   |
| Equity(0..1)          | 110        | 100    | 90         | 100     |
| $C_{t=1}(100)$        | 10         | 0      | 0          | 2.94    |
| $B_u$                 | 1.02       | –      | –          | 30%     |
| $B_n$                 | –          | 1.02   | –          | 60%     |
| $B_d$                 | –          | –      | 1.02       | 10%     |
| UL plain              | 11 000     | 10 000 | 9 000      | 10 000  |
| UL guaranteed         | 11 000     | 10 000 | 9 510      | 10 050  |
| $P_{t=1}(100) = 0.98$ | 0          | 0      | 10         | OK 0.98 |
| $P_{t=1}(95) = 0.37$  | 0          | 0      | 5          | 0.49    |
| $P_{t=1}(90)$         | impossible |        |            |         |

Most relevant for the product: P(95) – model not dumb, but not good enough.

# MCV examples – interpretation

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Discrete models with completely defined outcomes

- Abstract replication is a simple linear problem.
- Risk neutral probabilities  $\mathbf{Q}_0(\omega)$  give a basis solution.

Calculating the risk neutral probabilities means:

- efficiency gain (only one matrix inversion)
- split of process
  - market team produces  $\mathbf{Q}$
  - valuation team uses  $\mathbf{Q}$

# MCV examples – multiple steps

4a 

| Instrument        | $u_{10\%}$ | d     | uu     | ud     | du     | dd     | Value |
|-------------------|------------|-------|--------|--------|--------|--------|-------|
| Bank acct. (0..1) | 1.02       | 1.02  |        |        |        |        | 1     |
| Bank (1..2   u)   | -1.02      |       | 1.02   | 1.02   |        |        | 0     |
| Bank (1..2   d)   |            | -1.02 |        |        | 1.0404 | 1.0404 | 0     |
| Equity(0..1)      | 110        | 90    |        |        |        |        | 100   |
| Equity(1..2   u)  | -110       |       | 121    | 99     |        |        | 0     |
| Equity(1..2   d)  |            | -90   |        |        | 99     | 81     | 0     |
| $B_u$             | 1.02       |       |        |        |        |        | 60%   |
| $B_d$             |            | 1.02  |        |        |        |        | 40%   |
| $B_{uu}$          |            |       | 1.0404 |        |        |        | 36%   |
| $B_{ud}$          |            |       |        | 1.0404 |        |        | 24%   |
| $B_{du}$          |            |       |        |        | 1.0404 |        | 24%   |
| $B_{dd}$          |            |       |        |        |        | 1.0404 | 16%   |

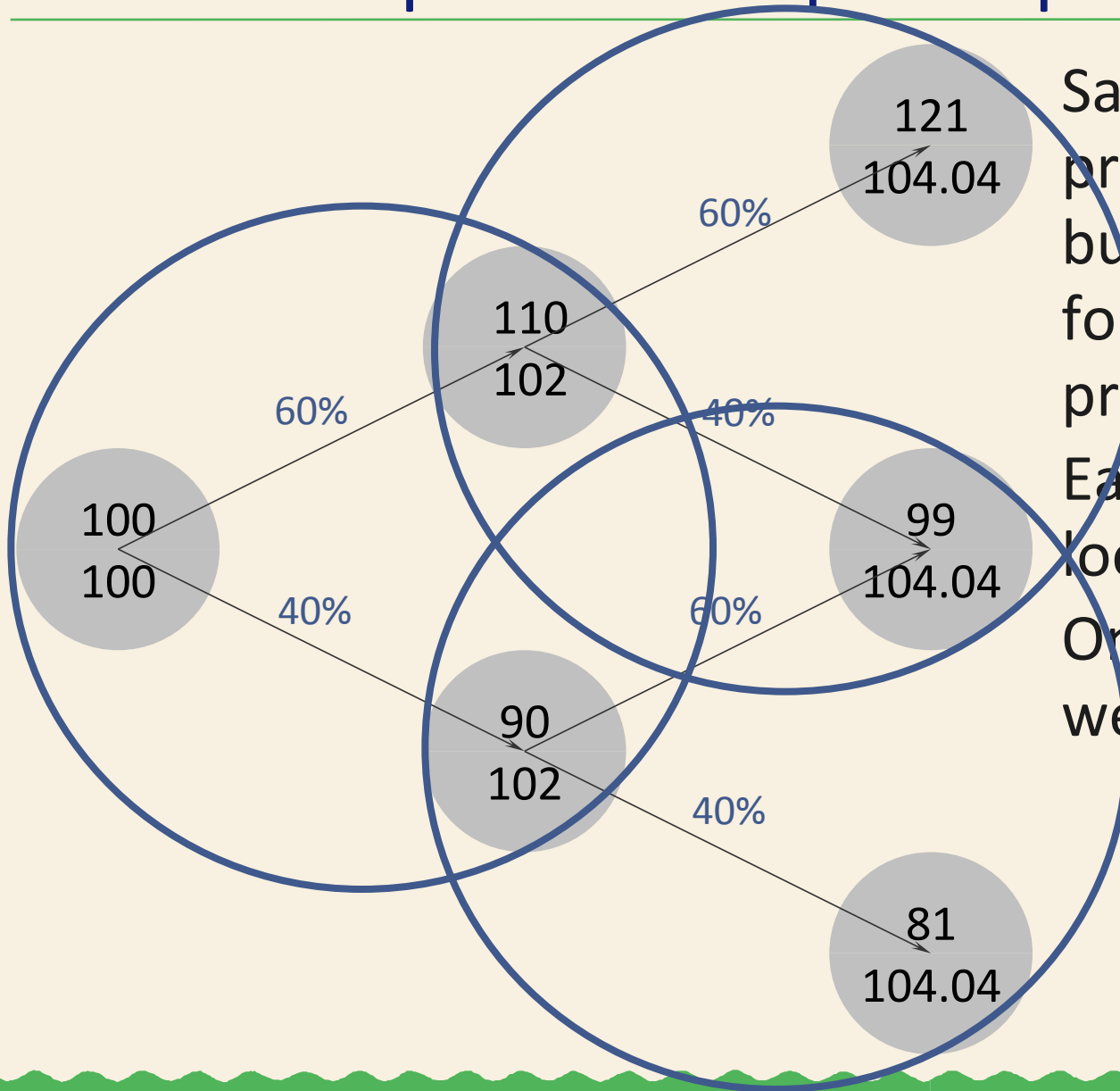
# MCV examples – multiple steps

4b 

| Instrument        | $u_{10\%}$ | d    | uu   | ud   | du   | dd   | Value |
|-------------------|------------|------|------|------|------|------|-------|
| Bank acct. (0..1) | 1.02       | 1.02 |      |      |      |      | 1     |
| Bank acct. (1..2) | -1         |      | 1.02 | 1.02 |      |      | 0     |
| Bank acct. (1..2) |            | -1   |      |      | 1.02 | 1.02 | 0     |
| Equity(0..1)      | 110        | 90   |      |      |      |      | 100   |
| Equity(1..2)      | -100       |      | 110  | 90   |      |      | 0     |
| Equity(1..2)      |            | -100 |      |      | 110  | 90   | 0     |
| $B_u$             | 1.02       |      |      |      |      |      | 60%   |
| $B_d$             |            | 1.02 |      |      |      |      | 40%   |
| $B_{uu} / B_u$    | -1         |      | 1.02 |      |      |      | 60%   |
| $B_{ud} / B_u$    | -1         |      |      | 1.02 |      |      | 40%   |
| $B_{du} / B_d$    |            | -1   |      |      | 1.02 |      | 60%   |
| $B_{dd} / B_d$    |            | -1   |      |      |      | 1.02 | 40%   |

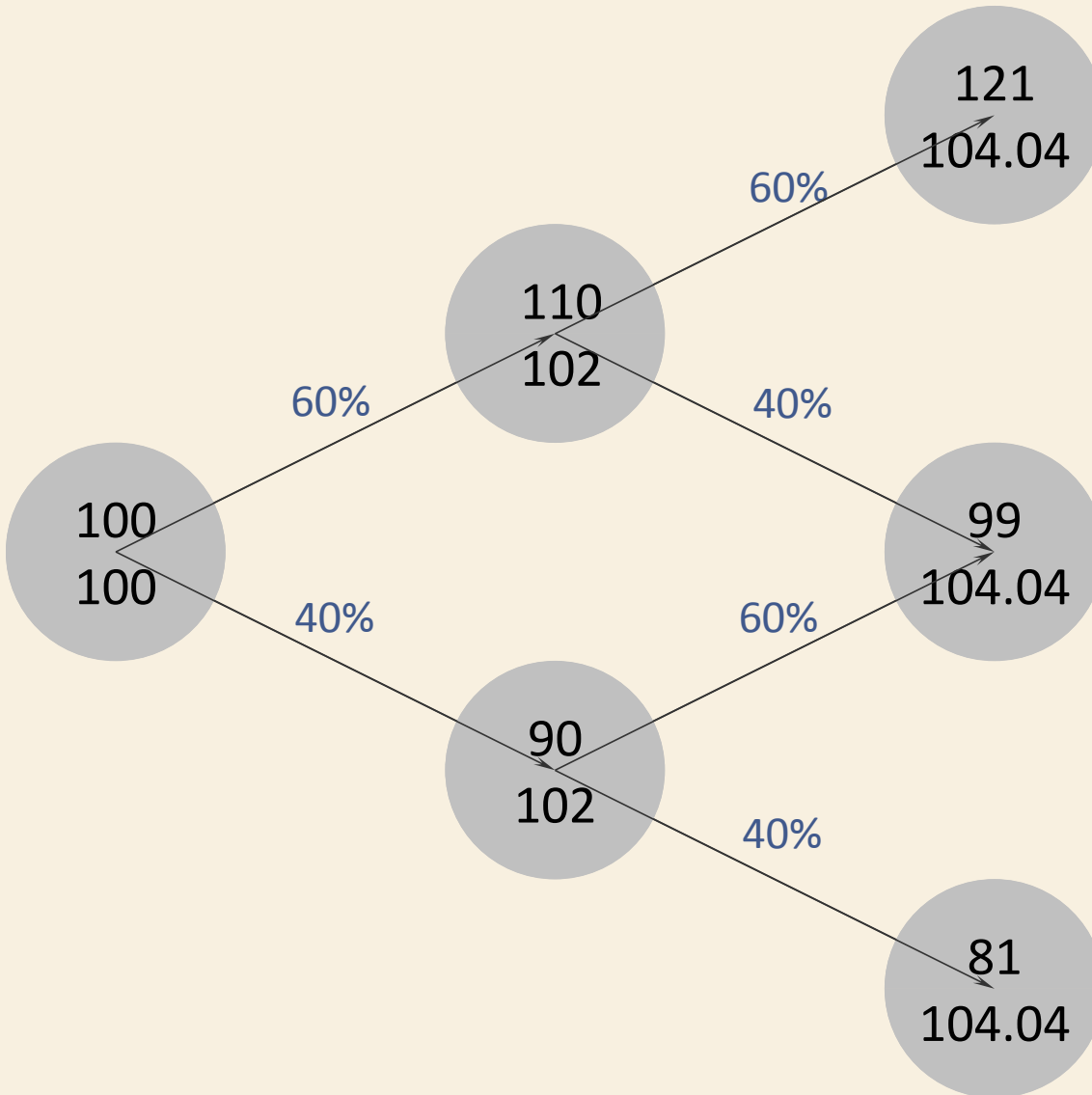
Conditional probabilities

# MCV examples – multiple steps



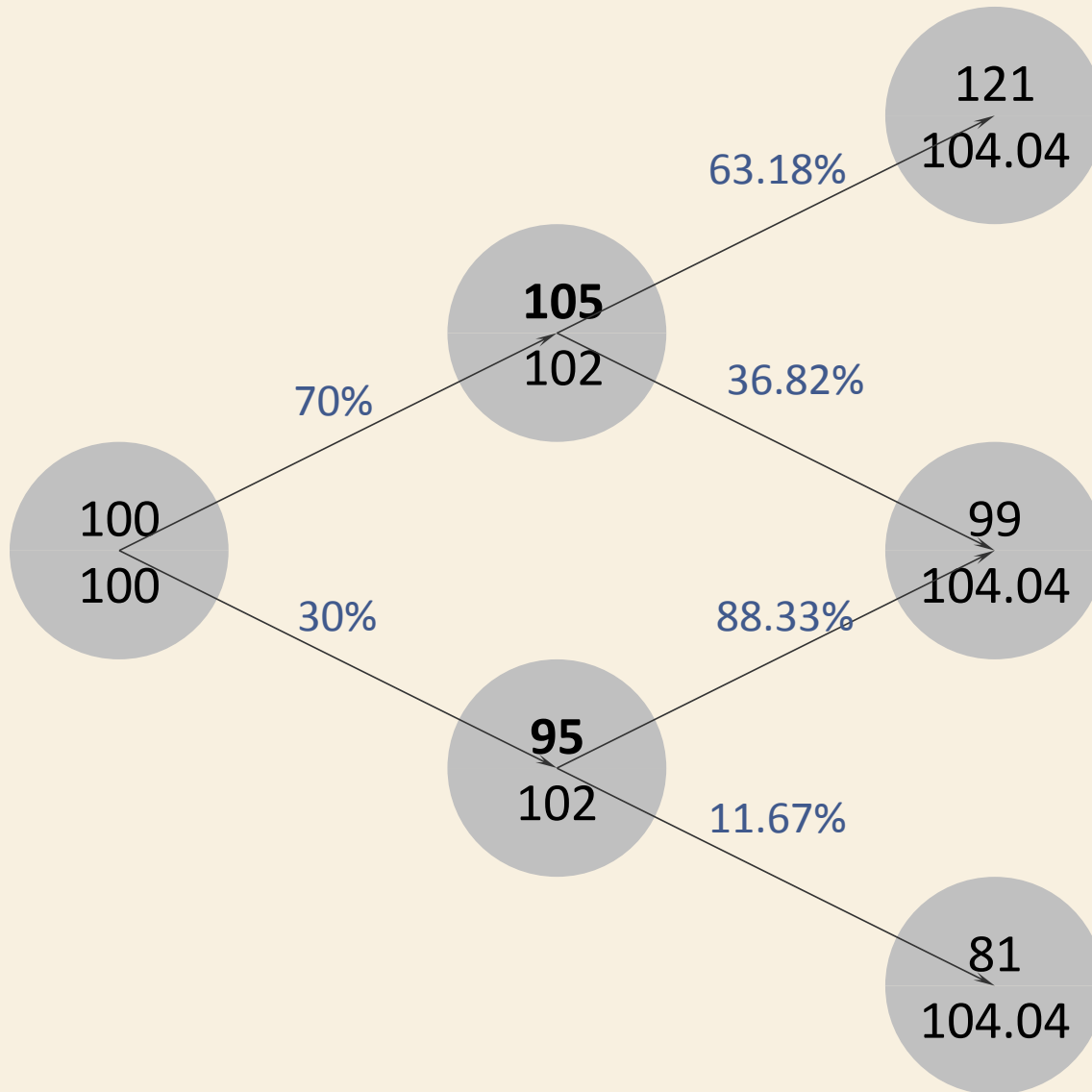
Same setup as previous example, but seeking visually for the conditional probabilities. Each small triangle looks the same. Once we have **Q** we're done.

# MCV examples – multiple steps



If we skip the interim EQ prices but want homogeneous structure...  
we just ask for the same thing differently.

# MCV examples – multiple steps



However, different EQ prices only at t=1... completely change the prices also at t=2 (**Q** moves).

It **does** matter what we prescribe for the inner structure of the model.

# MCV examples – many steps



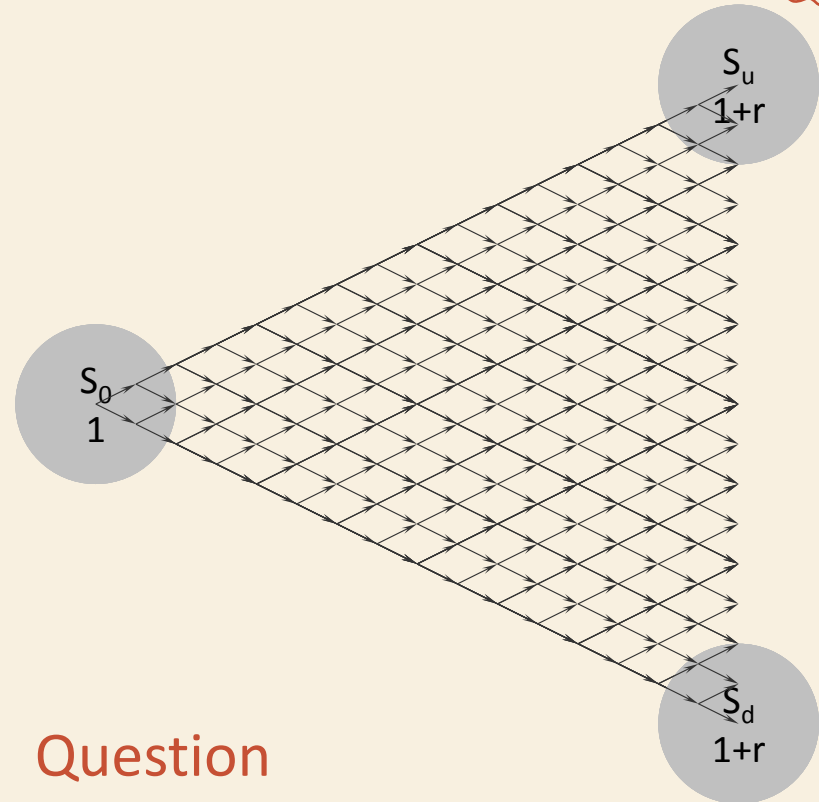
If we want a homogeneous model,  $Q$  for any of these binary-step models is locked by just:

- $r$  risk free return
- $S_u / S_d$  sort of volatility
- $S_d / S_0$  sort of skewness

In such restrictive setups we “can” price (replicate) options **without** calibrating on any option price.

Alternative **calibration** method:

- $r$  from swaps
- $S_u, S_d$  fix somewhere
- $S_u / S_d$  fit last free param to the market price of an option



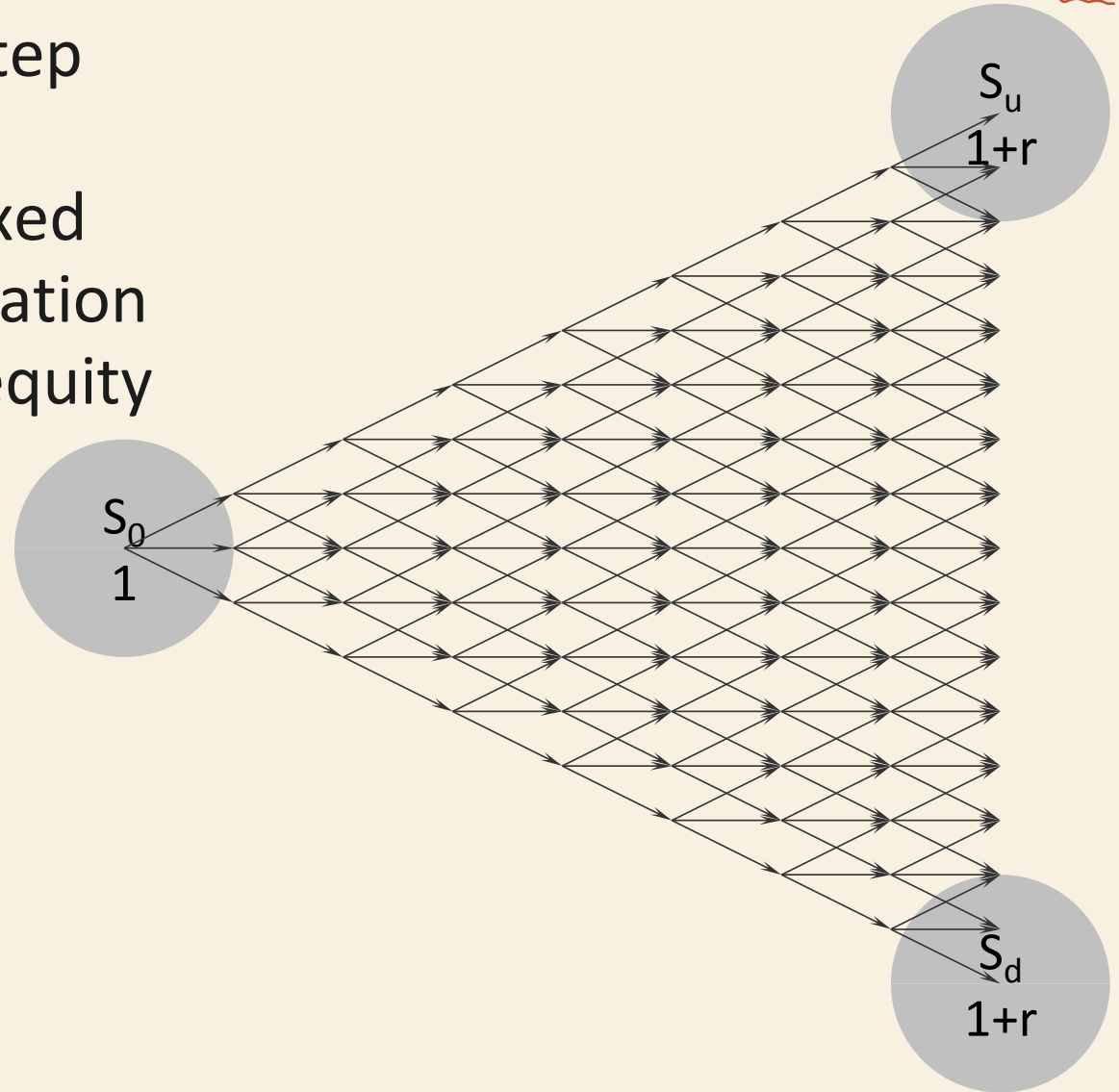
## Question

What happens here for  $\Delta t \rightarrow 0$  using the second calibration method?

The Black–Scholes model 😊

# MCV examples – many steps

By the way, trinary-step models don't invent options. Even with fixed grid shape, the calibration requires a bond, an equity and an option.



# MCV – summary of discrete models



- Risk neutral valuation
  - $MCV = E_Q(PV(CF))$  for some artificial  $Q$
  - $Q$  is implied by calibration prices
  - fully equivalent to abstract replication – result is definitive
  - realistic distribution serves possible outcomes / paths – defines model
  - realistic probabilities are irrelevant
  - allows for easy split in the process
- Observed prices vs. model
  - prices may conflict each other
  - prices may conflict model design
  - internal inconsistency – error in calibration or model use, unacceptable
  - external inconsistency – acceptable if irrelevant
- Different models or parameter restrictions
  - enable different calibration
  - produce different results
  - selection of calibration input, choice of model – expert judgement

# RNM vs. replication: continuous models 1

For continuous models the two are still close – but the link is far less clear than for discrete ones. We touch upon the line of thought.

- Model structure
  - Select reference assets and the realistic price processes to set the granularity.
  - MCV can be implied for instruments that depend only on (the risk dimensions represented by the price processes of) these.
    - plus technical conditions (finite and continuous, in some fancy senses)
- Calibration consistency
  - Price processes  $\{X_i(t)\}$  of reference assets must be martingales by  $\mathbf{Q}$  adjusted by discounting at the risk free rate.
- Liability valuation in theory
  - Let all cash flows run off by  $T$  and be  $Y(T)$  the accumulated CF.
  - Define  $Y(t) = \mathbf{E}_{\mathbf{Q}}( Y(T)B^{-1}(T)B(t) \mid \mathcal{F}_t ) = \mathbf{E}_{(\mathbf{Q}|\mathcal{F}_t)}PV_t(Y(T))$ .
  - Then also  $Y(t)^{-1}B(t)$  will be a martingale wrt.  $\mathbf{Q}$  and  $\text{MCV} = Y(0)$ .

# RNM vs. replication: continuous models 2

- Liability valuation via abstract replication
  - ‘Dynamic delta hedging’ strategy – ‘nice’ weight processes  $\{-w_i(t)\}$ 
    - $Y(T) \equiv \sum w_i(T)X_i(T)$  – replicates payoff
    - $w$  is foreseeable – no jumps in trading positions
    - self-financing – buying and selling is always in balance
    - exists – because smart mathematicians proved that
  - Then  $MCV = Y(0) = \sum w_i(0)X_i(0)$ .
- Link with risk neutral measure
  - $\mathbf{Q}$  exists  $\Leftrightarrow \{w_i\}$  exists for any valid payout
  - Being able to **calculate**  $\mathbf{Q}$  sort of implies being able to calculate  $w$ 
    - The fully theoretical construction of  $\mathbf{Q}$  from the martingale properties is a ‘broader’ problem than the construction of  $\{w_i\}$  – the latter is a linear function of  $\mathbf{Q}$  (some fancy integral).
    - When  $\mathbf{Q}$  is fitted to the prices via parameter selection, we don’t calculate it and calculating  $w$ .
  - Valuation via dynamic replication or via risk neutral measure are **conceptually equivalent** – technically not.

# Dynamic vs. static replication



- ‘Dynamic’ – weights **change** stochastically
  - $\{X_i(t)\}$  is insufficient to replicate  $Y(T)$  with **constant** weights
  - with **more instruments** weight can get closer to constant
- Plain Black-Scholes examples (B deterministic, X log-normal)
  - replication  $\{B, X\} \Rightarrow Y$  – continuous repositioning
  - static strategy  $w_{X,0} \cdot X(t) + w_{B,0} \cdot B(t)$  – serves  $MCV_0$  but **residual** is risky
  - $\{B, X, \text{Put}_T(K) \text{ for all finite decimal } K\} \Rightarrow Y$   
Can use constant weights for path independent payoffs at T, no residual.
  - $\{B, X, \text{some selected put options}\} \Rightarrow Y$   
Can use constant weights (or infrequent repositioning) for options and much less varying  $w_B$  and  $w_X$ .
  - $\{B, X, \text{some selected put options}\} \Rightarrow Y$  with **constant** w and **optimized** for minimal residual variance at T
    - Theoretical solution provides proper  $MCV_0$  and **possibly** low residual risk.
    - Numerical approximation on simulated scenarios **possibly** provides low residual variance – small  $MCV_0$  bias, **risk profile** well captured.
    - We term this as **numerical replicating portfolio (NRP)** for internal use.

# RNM vs. replication: continuous models 3

## Liability valuation in practice

- $w$  not in focus
  - $\mathbf{Q}$  ( $\underline{X}$  by  $\mathbf{Q}$ ) selected from a parameterized family
    - $\mathbf{Q}$  calibrated to (not calculated from) market prices
    - We can generate samples from  $\mathbf{Q}$  without knowing the liability.
    - We can perform simulations without calculating  $w$  (or anything close to that).
  - $MCV_0 \approx \text{average } PV_0(\text{CF})$  from Monte Carlo simulation
- $w$  matters in the background
  - average  $PVCF \approx \mathbf{E}_{\mathbf{Q}}PV(\text{CF}) = MCV_0$  because  $\{w_i\}$  exists
  - $\{w_i\}$  drives accuracy and statistical stability
    - volatile weights, offsetting positions could signal model risk
    - but  $w$  is invisible
  - NRP can inform on model quality
    - build from simple instruments – reliably priced by Monte Carlo, preferably by closed formula
    - large residual variance, offsetting positions  $\Rightarrow$  model risk, simulation noise
    - simulation noise on NRP value  $\approx$  simulation noise on MCV

# Agenda



Motivation

Concepts and examples

- risks and markets
- MCV, risk neutral measure, replication
- risk margin, MCEV

Illustrations and highlights

- Behind market prices
- Bond CF adjustment
- RN Monte Carlo limitations
- Residual discretion in MCEV

Wrap-up

Margin for pure non-market risk

- key concept
- formalization
- examples

Combining market and non-mkt

- example
- conditional expected value
- actually we can explain the term 'risk neutral' now...
- building blocks, unite!

Control points

# MCEV – key idea

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Non traded risks incorporated in the valuation method / system on a cost of capital basis.

- To responsibly take these risks we need to hold a capital buffer.
- We can only finance this from capital markets in return for expected risk premium (in excess of the risk free rate).
- A buyer in an arm's length transaction would also account for this. ▷

# MCEV – idea formalized



Portfolio (CF stream) exposed **only** to non-market risks

- Need **1-year** ruin probability  $\leq .5\%$   $\Rightarrow$  surplus capital at start  $\geq RC_0$ .
  - Out of our scope: calculation and projection of  $E_0$ .
- Shareholders provide this buffer for an expected excess return of **6%** annual over the risk free rate.
- Within the year's result (net cash flow):
  - $E_0$   $r_{free}$  is not value creation  
*return expected on **any** investment, unwinding of interest rate*
  - $E_0$  6% is not value creation  
*return expected on **risky** investment, capital cost of safe operation*
- Applies to all future years
  - $E(PV(CF)) = E(\sum_i CF_i DF_{0...t(i)})$
  - $MCEV(CF) = E(PVCF - \sum_k RC_k CoC\% DF_{0...k+1})$
  - $MCEV(CF) = E(PVCF) - E(PVCoC) = -(BEL + Risk\ Margin)$

$E()$  by **best estimate** (no market risk)

parameters, naming from Solvency II

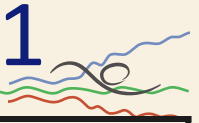
# MCEV examples



| Liability | Payout | T | Condition     | -MCEV  |
|-----------|--------|---|---------------|--------|
| Endowment | 30000  | 1 | Death         | ?      |
|           | 10000  |   | In force      |        |
| BEL       | 10200  | 1 | 1% DH, 99% IF | 10000  |
| $RC_0$    | 2000   | 0 | —             | n/a    |
| CoC       | 120    | 1 | —             | 117.65 |

- Valuation method: **for each** market outcome
  - take the average along the non-market risk using BE
  - attach CoC based on preceding (start of year...) risk capital allocated to this risk piece (this also involves BE averaging)
  - this conditional expected value only depends on market risk
  - so calculate its MCV

# MCEV examples



| Instrument   | At start | Death                      | In force | Value |
|--|----------|----------------------------|----------|-------|
| Liability (-1): endowment  |          | 30000                      | 10000    | ?     |
| ZCB(1)   |          | 100                        |          | 98.04 |
| -L averaged out to granularity of market risk<br><i>conditional expected value</i> |          | BE: 1% DH, 99% IF<br>10200 |          | 10000 |
| Risk capital allocated for mortality<br><i>assume ≈ 15% accounting SaR</i>         | 3000     |                            |          |       |
| RM (cost of mortality risk capital)  |          | 180                        |          | 176   |

Valuation method: **for each** market outcome

- take the average along the non-market risk using BE
- attach CoC based on preceding (start of year...) risk capital allocated to this risk piece (this also involves BE averaging)
- the conditional expected values only depends on market risk
- so calculate MCV of (-simplified liability -CoC)

# MCEV examples

2a 


| Instrument   | T=0  | $u_{10\%}$<br>$D_{1\%}$ | $u$<br>$I_{99\%}$ | $d$<br>$D_{1\%}$ | $d$<br>$I_{99\%}$ | Value |
|--------------|------|-------------------------|-------------------|------------------|-------------------|-------|
| -L: UL+risk  |      | 32352                   | 10784             | 26472            | 8824              | ?     |
| ZCB(1)       |      | 100                     |                   | 100              |                   | 98.04 |
| EQ(0..1)     |      | 110                     |                   | 90               |                   | 100   |
| -BEL         |      | 11000                   |                   | 9000             |                   | 10000 |
| RC allocated | 3000 |                         |                   |                  |                   |       |
| CoC          |      | 180                     |                   | 180              |                   | 176   |

- $E_{\text{best estimate}}(CF_t | \text{market}_t)$  is a **stochastic process**
  - just less granular: **adapted** to  $\mathbf{Q}$
  - in matrix arithmetics: no exact replication with the market instruments, but a weighted regression (WLS)
  - fully abstract: orthogonal projection of the CF process to the plane of  $\mathbf{Q}$ -adapted processes in  $\mathcal{L}^2(\mathbf{Q}, \mathbf{BE}_{\text{non/mkt}})$
  - closest match with respect to **residual variance**
  - **does not depend on  $\mathbf{Q}$**  (only on the set of possible outcomes)

# MCEV examples

2b 

| Instrument   | T=0  | $u_{10\%}$<br>$D_{1\%}$ | $u$<br>$l_{99\%}$ | $d$<br>$D_{2\%}$ | $d$<br>$l_{98\%}$ | Value |
|--------------|------|-------------------------|-------------------|------------------|-------------------|-------|
| -L: UL+risk  |      | 32352                   | 10784             | 26472            | 8824              | 10353 |
| ZCB(1)       |      | 100                     |                   | 100              |                   | 98.04 |
| EQ(0..1)     |      | 110                     |                   | 90               |                   | 100   |
| -BEL         |      | 11000                   |                   | 9177             |                   | 10177 |
| RC allocated | 3000 |                         |                   |                  |                   |       |
| CoC          |      | 180                     |                   | 180              |                   | 176   |

- no problem if markets influence BE incidence rates
  - in this example: mortality shock on economy downturn
  - more relevant: dynamic behaviour
- creates nonlinearity though
  - **now** the replication of the BEL contains nonzero ZCB (check!)
  - sorry, some cheating to fit on screen 

# MCEV exercise

| Instrument | $u_{10\%}$<br>$D_{1\%}$ | $u$<br>$I_{99\%}$ | $d$<br>$D_{2\%}$ | $d$<br>$I_{98\%}$ | Value |
|------------|-------------------------|-------------------|------------------|-------------------|-------|
| ZCB(1)     |                         | 100               |                  | 100               | 98.04 |
| EQ(0..1)   |                         | 110               |                  | 90                | 100   |
| $B_u$      |                         | 1.02              |                  |                   | ?     |
| $B_d$      |                         |                   |                  | 1.02              | ?     |
| $B_{uD}$   | 1.02                    |                   |                  |                   | ?     |
| $B_{uI}$   |                         | 1.02              |                  |                   | ?     |
| $B_{dD}$   |                         |                   | 1.02             |                   | ?     |
| $B_{dI}$   |                         |                   |                  | 1.02              | ?     |

- Calculate the values for the elementary payouts that are in line with the BEL calculation
- This is **not** a risk neutral distribution because it does not provide the proper value as  $E()$  – we need to add RM.

# Why 'risk neutral'?




- We call  $\mathbf{Q}$  risk neutral if...
  - wrt. some risk dimensions represented by instruments  $\{X_i\}$
  - $\mathbf{Q}$  can evaluate  $X_i$ :  $\mathbf{E}_{\mathbf{Q}}$ (PV of payouts of  $X_i$ ) is meaningful
  - the valuation rule  $\mathbf{E}_{\mathbf{Q}}$ (PVCF) reconciles  $\{\text{MV of } X_i\}$ .
- Then...
  - $\mathbf{E}_{\mathbf{Q}}$ (PVCF) = MV on all instruments depending *only* on the selected risk dimensions (if the market is nice enough).
  - It's **neutral to the valuation** rule if such a CF is **risky or not**.
    - cash flows with same expected PV by  $\mathbf{Q}$  are worth the same
    - all necessary adjustment is within  $\mathbf{Q}$
    - no risk margin for risks covered in  $\mathbf{Q}$
    - this sets it apart from realistic expectations
  - Risk margin applies for risks not covered by  $\mathbf{Q}$ . 'Not covered':
    - residual of the conditional expected value:  $\text{CF} - \mathbf{E}_{\text{other factors}}(\text{CF} | \mathbf{Q})$
    - **part of the CF that can not be replicated** from  $\{X_i\}$  & friends

# Market Consistent Embedded Value



Portfolio (CF stream) exposed to both market and non-market risks

- calculate  $CF^*(t) = E_{\text{non-mkt BE}}(CF(t) \mid \text{market information up to } t)$ 
  - denotes a stochastic process that only depends on market risk factors
  - is meaningful (well defined) without picking measure for the market risks 
  - BE probabilities (e.g. lapse rate) are allowed to depend on market (though we rarely need this)
  - amounts that BE acts on (e.g. surrender benefit) are allowed to depend on market (typical)

CF model design

- define a projection (approximation) of risk capital  $RC_{\text{non-mkt}}(k)$ 
  - covers for / allocated on the non-market risk just dropped:  $CF(t) - CF^*(t)$
  - again a stochastic process that can depend on many factors
  - gives rise to  $CoC(k+1)$ , limit to market risk:  $CoC^*(k+1)$

CF model add-on

- calculate the risk neutral measure  $Q$  for market risks

ESG

- calculate  $MCEV = -(BEL + \text{Risk Margin})$

model run

- $MCEV(CF) = MV(CF^*) - RM(CF) = E_Q(PV CF^*) - E_Q(PV CoC^*)$

# Market Consistent Embedded Value



Portfolio (CF stream) exposed to both market and non-market risks

- calculate  $CF^*(t) = E_{\text{non-mkt BE}}(CF(t) \mid \text{market information up to } t)$

benefit  $CF^*(t) =$

(probability of survival from start to previous step) [

death benefit based on current SA relative prob. of death this step

surrender benefit based on current AV r. prob. surrender this step

maturity benefit maturity prob.

]

- define a projection (approximation) of risk capital  $RC_{\text{non-mkt}}(k)$

$RC(k) = \text{if in force, } 1.5 \times \text{accounting sum at risk based on current SA and AV}$

$CoC(k+1) = RC(k) \times 6\%$

$CoC^*(k+1) = (\text{probability of survival to } k) \times [CoC(k+1) \text{ in the in force case}]$

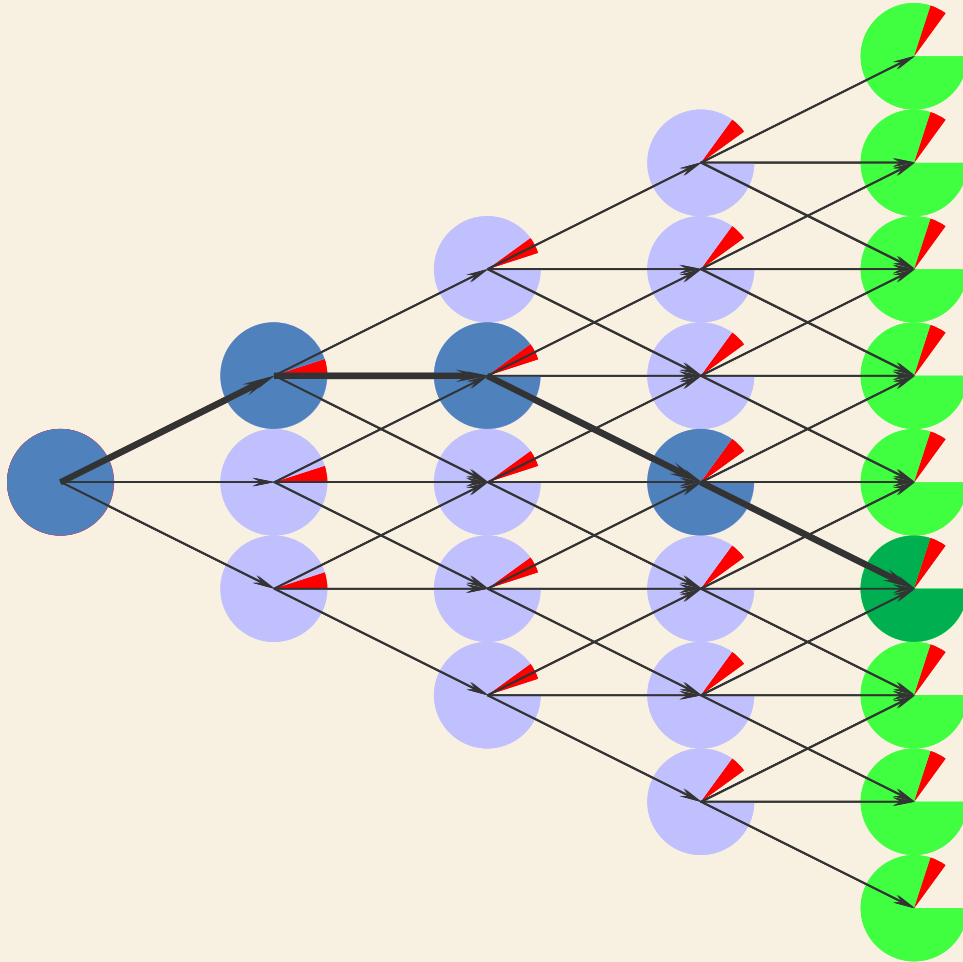
- generate economic scenario set (sample from  $\mathbf{Q}$ )

ESG

- calculate  $MCEV = -(BEL + \text{Risk Margin})$

◦  $MCEV(CF) \approx \text{average PV}(CF^* - CoC^*)$  from stochastic run

# Market Consistent Embedded Value



Build scenario model

Build CF model, add CoC

Calibrate RNS

- Get economic scenario

- Evaluate PV on path

Repeat, take average

Test quality

Done

# MCEV figure flow control points

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*Whiteboard exercise*

# Agenda



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Illustrations and highlights

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Wrap-up

Primary issuers ↔ followers

- no Münchhausen pricing

Multiple vendors ↔ one price

- manufacturing costs
- diversification
- risk profile, risk appetite

Consequences

- no uniform BE + RM split
- final diversification blurred

# Primary issuers vs. followers

- All parties fixing to observed prices...  
is **Baron Münchhausen pulling himself out of the swamp by his own hair.**
- For the 'large' players, market prices are **output** from
  - realistic model of liability,
  - expenses (marginal, OpEx)
  - capital cost, expected profitsSame logic as MCEV!



## Option quotes for EQ calibration

- drivers for provider's pricing approach
  - **active hedging** in reality (maybe partly with other options, callable bonds etc.)
  - can not rely on more liquid and efficient reference market
  - **core profit** largely depends on hedging cost and residual risk
- implications to methodology
  - realistic model(s) of cash flows (no alternative): option payout, hedge transactions' balance, marginal costs, opex, profit targets
  - need to adjust for risk – MCEV-like decomposition to BE + risk margin is (sort of) necessary


## Swap quotes for IR calibration

- mid rate
  - clean book policy – balance demand for payer / receiver
  - can not set the price arbitrarily
  - not aiming to make profit on it
  - excess cost (exposure, closing loss) on mispricing – this is why **we trust** the quote for calibration
- b/o spread
  - income source and key factor for competition
  - so this is the pricing output (plus deposit rules...)
  - we **disregard** the spread in assuming **efficient** markets – OK as long as FI repositioning weighs low in our replicating strategy (valuation should not assume to trade as actively as a bank)

## Swap quotes for IR calibration ...

- pricing factors and risks for spread
  - transactional costs, allocated opex
  - counterparty default risk (deposit rules)
  - operation speed and volumes (standard time to clean book)
  - illiquidity / mispricing risk (can not clean quickly)

## non-traded risks – must use **risk margin**

- expected profit / capital cost
- calibrating on the quote
  - insurer can trade swaps and other IR-driven instruments
    - ⇒ OK to use mid rate
  - insurer has different risk profile, operation
    - ⇒ b/o spread maybe a CF item but not calibration input 

# Many vendors, one price

---



Primary issuers use realistic models – prices could vary

- BE value of payout ← model choice, assumptions
- opex ← company profile, scale
- risk margin ← ...
  - residual risk implied by hedging approach and operation
  - diversification method / matrix
  - **proportion** of the respective risk in the company totals:  
diversification benefit **decays** as exposure grows

Natural **balancing** effect through risk appetite

- low raw price (pre-diversification) – can expose more
- high raw price – provider will expose little to this risk
- builds up ‘nice’ aggregate supply from different curves

- **Can not** decompose the market price to BE + RM  
Built up from different risk profiles and splits per provider.
- **Need not** decompose

*Directive 2009/138/EC, Article 77 (4)*

“Insurance and reinsurance undertakings shall value the best estimate and the risk margin separately.

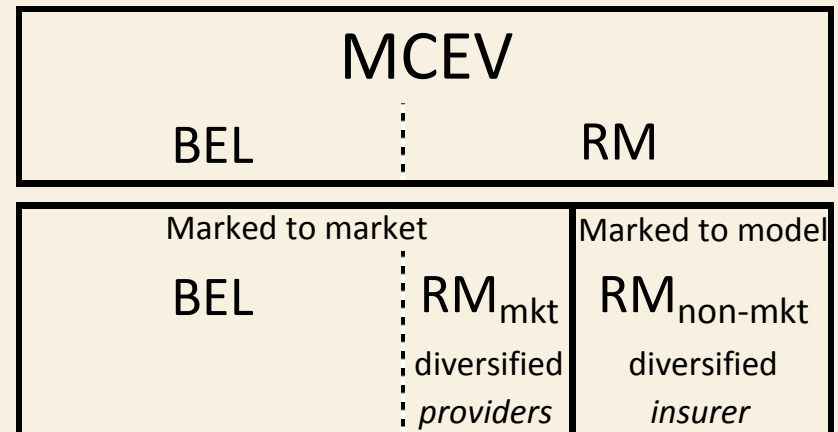
However, where future cash flows associated with insurance or reinsurance obligations can be replicated reliably using financial instruments for which a reliable market value is observable, the value of technical provisions associated with those future cash flows shall be determined on the basis of the market value of those financial instruments. In this case, separate calculations of the best estimate and the risk margin shall not be required.”

# Consequences



Overall diversification in RM is a hybrid

- for market risks
  - **black box**: all we know is that it aggregates from different risk classes, different providers – limited consistency
  - **hopefully** relevant for us (no alternative though)
    - we can not run hedge operation as efficiently as priced in
    - we budget expenses on a different line – gives an edge
- for non-market risks
  - our methods
  - applied to our profile
- across mkt and non-mkt
  - not allowed in QIS5
  - if applied, mind the inherent inconsistency



# Agenda



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## Wrap-up

## Problem statement

- bonds  $MV \neq PV$  notional CF
- profit sharing  $\sim$  bond CF

## Backgrounds

- credit risk (and others)
- model cut, lack of market

## Resolution and its effect

- adjust CFs technically
- aligns A/L in balance sheet
- some convexity concerns
- alternative (?)

# Problem statement

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Risky bond in projection (just credit for simplicity)

- risk is beyond model **granularity**
- **same** notional CF stream  $\leftrightarrow$  **lower** MV than risk free
- $E_Q(\text{PV}(\text{CF}))$  **incorrect**
- bond CF  $\rightarrow$  portfolio return  $\rightarrow$  profit sharing  $\rightarrow$  liability

**Add** risk to model and calibration?

- liquid and relevant market
- many dimensions (issuer, rating, ...)
  - complex, intransparent
  - many correlations – unstable, slow convergence
- tail risks – slooow convergence

# Standard solution



- CFO Forum MCEV Principles

**G14.4** Where a company invests in fixed-income assets which have a yield different to the reference rates, the company should make appropriate **adjustments** to the projected asset **cash flows** to ensure that the asset cash flows, discounted at the reference rates, equal the market value of the assets.

- Implementation examples


- $r_{\text{coupon}}$  in projection = true  $r_{\text{coupon}}$  **minus spread**
- **scale down** all bond cash flows by  $MV_{\text{true}} / MV_{\text{risk free}}$

- Interpretation(s)

- most similar CF pattern that, **in our valuation approach**, is worth the proper MV
- spread in the MV = **expected loss** on defaults  
treat **as cash outgo**, add to notional bond CF

# Implications



- How to **account** in the projection?
  - Principle: risk neutral distribution acts on **realistic outcome** – projection must **make sense**.
  - $r_{\text{coupon}}$  minus spread  $\Rightarrow$  deduct also in book value yield
  - cash flow scaling  $\Rightarrow$  scale down the amortization **end point**
- First order effect on liability
  - ✓ Don't give away **in value** to projected profit sharing liability than what's available **in value** of backing assets.
  - ✗ Value impact transferred to PS scheme  $\leftrightarrow$  based on tail risk.
- Do we underestimate guarantee in bonus by cutting returns? No...
  - that's thinking in traditional reserving formulae
  - the guarantee value comes from 0 allocation if return  $<$  TIR 

# An alternative approach



Think MCEV 😊

- spread in MV represents price of a risk
- it's **BE+RM** somewhere, somehow
- BE on eventual credit default losses
  - tail risk – if running to the end, small can pass to PS scheme
  - rating triggers – higher chance, lower loss, better ratio
- RM for running this risk
  - risk not included in the scenario calibration
  - treat like non-market
    - cost on the insurer (for capital or hedge)
    - does not pass into PS (let alone UK discretionary)
    - cf. “RM on unavoidable market risk” in SII parlance

# An alternative approach



Nice on paper – how to implement?

- expert judgement to split spread as BE+RM
- a realistic stochastic model of (credit) spreads
  - can not embed in CF model (would upscale # scenarios)
  - estimates ratio of loss transfer to PS
- decompose CF adjustment in valuation
  - net earning of company: stays  $CF_{\text{bond}} - \text{adj}_{\text{total spread}}$
  - net PS basis:  $CF_{\text{bond}} - \text{adj}_{\text{spread BE}} \cdot \text{transfer ratio} - \text{amortization}$
  - this is a conditional expected value, mapping to **Q**
- ✓ projected earning ~ current **MV**
- ✓ projected PS – reflects **convexity** of guarantee
- ✗ parameterization, modelling, validation – tough

# Agenda – unexpanded section



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Wrap-up

“Unrealistic”

- outcome set is inherited...
- model selection, calibration

Variance, quantiles useless

- use numerical replication

Slow convergence

- limit dimensions
- bias reduction: antithetic sets, control variate adjustment

Control of accuracy, relevance

- numerical replication
- stability across models

# Agenda – unexpanded section



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Wrap-up

Scenario generation

- model selection
- conflict resolution and extrapolation in calibration
- correlations

Risk margin

- level of diversification applied
- allocation of diversification benefit
- EC projection method, drivers
- EC diversification

# Agenda

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Wrap-up

# Takeaways



- MCV via RN Monte Carlo
  - binds input preparation (scenarios)
  - ... not projection model – remains real in its logic
- MCEV: BE + RM
- price of core activity
  - explicit BE + RM
  - can not mark to market if you are market
- price when reused for calibration
  - BE + RM in the background
  - risk neutral measure veils it as BE
  - discretion is not wiped out, but became much more subtle
  - model and calibration must be relevant and aligned – no way without understanding how to reach and control this state

- Risk neutral measure is a technique to decompose abstract dynamic replication.
  - first calibrate measure – allow for ‘all-purpose’ sampling
  - then take  $E$  of PV – allow for Monte Carlo estimate
  - not an anticipation, just fancy packaging of market prices
    - forget quantiles
  - technical testing is fairly possible and very necessary
  - risk of irrelevance – too easy to perform steps remotely
- Static numerical replication is a natural aid in understanding, testing and improving MCEV calculated in other ways.
  - also to produce many of the risk measures that RN valuation never will

# References

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available on Google books for reading
- Wikipedia: *Risk-neutral measure*
- Gisiger, Nicolas: *Risk-Neutral Probabilities Explained*  
available at <http://ssrn.com/abstract=1395390>
- Directive 2009/138/EC
- CFO Forum MCEV Principles

# Outlook

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Knowing to calculate MCEV well is what makes up a smart lemming to a dumb lemming.

How far any lemming can get is a matter of the landscape.

Feedback, questions

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*Lemmings' true behaviour (relevance check)*

<http://en.wikipedia.org/wiki/Lemming>