Building a Risk Modelling Framework: Key Choices and the Role of an Expert

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Agenda

- Fundamental assumptions vs. data driven approach
  - Fundamental assumption and structural modelling
  - Examples
  - In-sample and out-of-sample performance
  - Modelling risk and model risk: introducing the role of expert
- Wider view: role of expert in risk modelling
- Imposing of expert's views directly
  - Conditional events
  - Bayesian approach vs. stochastic factor models
- Key choices in other areas:
- Choice of a modelling object and backtesting objects. Model transparency
- Neglected aspects of real world modelling (implied vs. realised)
- Model resilience and system resilience
  - simplified model framework
  - sparse and illiquid data framework. Actual and implied expert's choices

Structural vs. statistical approach

- How to build a model? Two broad schools of thought:
- Start with fundamental assumptions then overlay data driven “specifics”. In practice this translates into **structural approach**
- Alternative is **statistical** approach : everything we know about the financial universe is in the observed data (historic and observed).
- Some pro-structural arguments:
  - if we know causal link between rare (market) events – it is vital knowledge to model risk better (both in systems and stress tests). We should not discard it easily
  - Structural assumption is the result of data/observations, but from wider scope (e.g. macroeconomic arguments), which could be hard to incorporate in model directly, i.e. fundamental assumption imply wider use of observation, not less
  - Pure data driven modelling is an illusion: for statistical model the fundamental choices are hidden, but still exist - once stochastics process (usually CCR) or distributions (usually market risk) and their calibration are chosen
  - Better out-of-sample performance (assuming fundamental assumptions hold in the future, e.g. after regime change)
- Some pro-statistical arguments:
  - Self-adjusting to changing reality (note: assumes ‘correct’ model, data, calibration)
  - Structural modelling introduces expert error into model error

Examples of structural approach

Some examples of structural reasoning for rare events, ‘short’ time series or ‘short’ term returns:

- Extreme scenarios: Credit-Equity link via default. If a name defaults, equity goes to (near) zero, credit is driven by recovery values
- Other examples of extreme scenarios:
  - Sovereign default – FX devaluation, de-pegging
  - Hyper-inflation – FX devaluation
  - Peak oil vs. all-renewables assumptions – oil dependent entities
- Structural approach is natural modelling approach to reflect such links. Examples:
  - Merton (asset value as latent variable)
  - Volatility as a measure of risk
  - Later in presentation we will address an alternative to reflect causal link:
    - Bayesian nets could be intuitively applied to extreme scenarios
- None-extreme (‘normal’) scenarios:
  - Rates tend to mean-revert or at least tend to be pulled back to within a moderate range due economic and social pressure
  - Easier separation of model’s time-scale behaviour: correlation vs. co-integration (e.g. basis dynamics on different scales)

Structural Equity-Credit approaches in detail

See Chorniy & Greenberg, 2015 (http://ssrn.com/abstract=2708143) for a detailed literature review and references used in Equity-Credit discussion

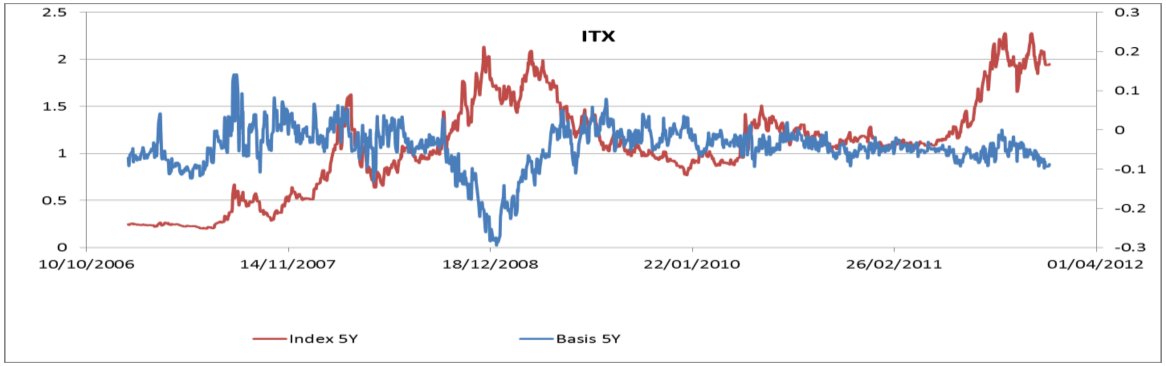
- Structural model: Merton (1974) asset return construction
  - Equity = Call, Debt = Put on asset value of the firm
- Volatility as a risk indicator can affect market prices of equity and debt
- Campbell & Taksler (2003): booming stock market in 1990s accompanied by rising corporate bond yields – counterintuitive?
  - Optimism of equity investors not shared by bond investors
  - Volatility may be the key: more upside for shareholders, more risk for bondholders
- Share prices and volatility of returns
  - "Leverage effect": price growth is less volatile than price drops
  - Historical volatility commonly used as a predictor of future returns distribution
- Cremers et al. (2008) : implied volatility affects credit spreads
  - Both ATM and OTM/skew explain a significant part of CDS spread levels
- Carr & Wu (2009, 2011): economic similarity between CDS and deep OTM equity puts ("Jump to ruin")
- Recall two classical volatility models:
  - Stochastic volatility (Heston, 1993): variance-to-spot return correlation
  - Jump-diffusion (Merton, 1976): size and intensity of jumps

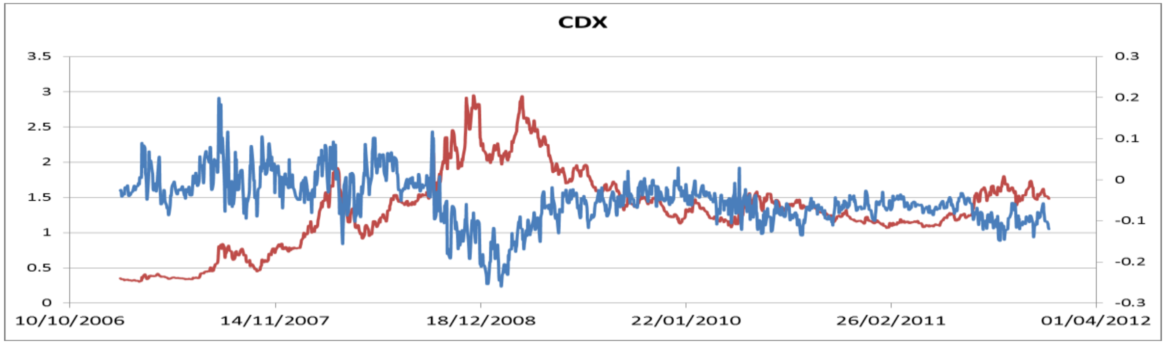
Volatility, Equity and Credit: theoretical models

- Three main interpretations of dependence between CDS spreads and equities, and volatilities
- “Pure” Merton, 1974: link via asset (i.e., firm value) volatility, which is a measure of investment risk
  - Equity = long call, Debt = short put on asset value
- Building on Merton framework, link [all] risk via factors asset behaviour. Actively used in IRC, [CRM], DRC. Allows to superimpose “structure”, by-pass problem of correlation vs. co-integration, but introduces expert/macroeconomic view
- “Leverage”: general term for equity volatility inversely related to equity returns
  - Financial leverage: debt-to-equity ratio of the firm, so drop in stock price increases leverage ratio
  - Share price drop $\Rightarrow$ higher leverage $\Rightarrow$ riskier stock $\Rightarrow$ more volatile stock
  - Alternatively, volatility is a measure of [investment] risk
  - Higher risk requires higher return, so stock price needs to drop first (volatility increase should be persistent)
  - CDS also reflects the riskiness of investment (spread over “risk-free” investment)
- Equity volatility embeds a measure of probability of jump-to-default
  - Excess return of equity over risk-free rate compensates for possible default
  - CDS reflect market view of the default probability

Structural approach – caution

- Spreads and index-constituent basis
  - What would be our conclusion for model designed in 2009?
- Is there a structural argument?
  - Yes, basis should react to liquidity stress: stress up ⇒ (assets down) ⇒ [abs value] basis up (without [] contains an expert assumption on the sign!), but…
- And in sovereign crisis in 2012? (remember : "assuming fundamental assumptions hold …")





Structural approach vs. role of an expert

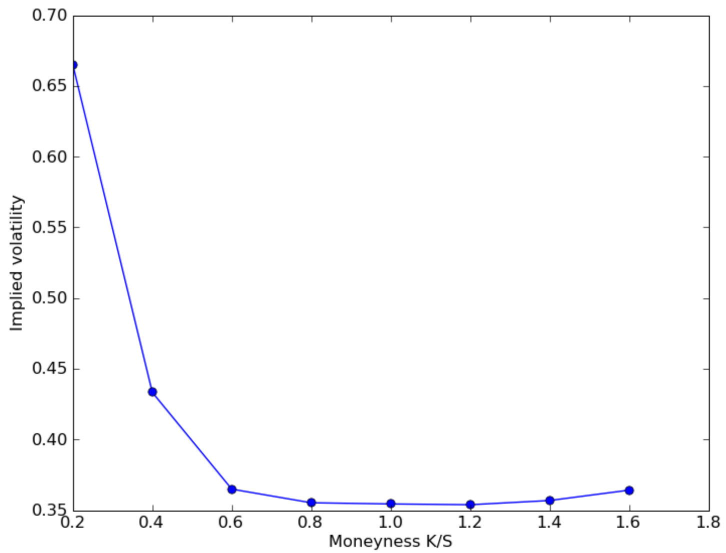
- The role of **fundamental assumptions and structural approach** in modelling are **strongly linked to the role of the expert**:

Is including structural insight based on expert view adds value, or if it merely pollutes the data and introduces potential human error to the already large uncertainty inherent in financial modelling?

- Structural approach camp (‘structural warriors’) vs. the pure data driven camp (‘data brigade’). Who is winning?
- Structural warriors win individual battles (e.g. CCR asset class models), but at least in the arena of market risk, the data brigade seems to have won the war (historic VAR dominance).
  - In CCR structural approach often wins as experts (quants) can
    - choose individual topic where their case is stronger
    - explain concept to non-technical colleagues and senior managers
  - Historical VAR (HVAR) statistical approach wins, as overall it is a model that is easier to explain and defend: aka “it happened before, it can happen again”
  - Common pro arguments for the 1 day HVAR:
    - HVAR contains no modelling assumptions [we will revisit this assertion]
    - Preserves complexities of risk factors’ non-Gaussian distributions and correlations
    - ‘Can be done’ - time series long enough. So HVAR is better than anything quants can contrive using (parametric) Monte Carlo approach.

Expert interpretation: example of skew

- Expert influence is hard to avoid in any approach. Example: skew
- Market quotes for vanilla options exhibit implied volatility skew

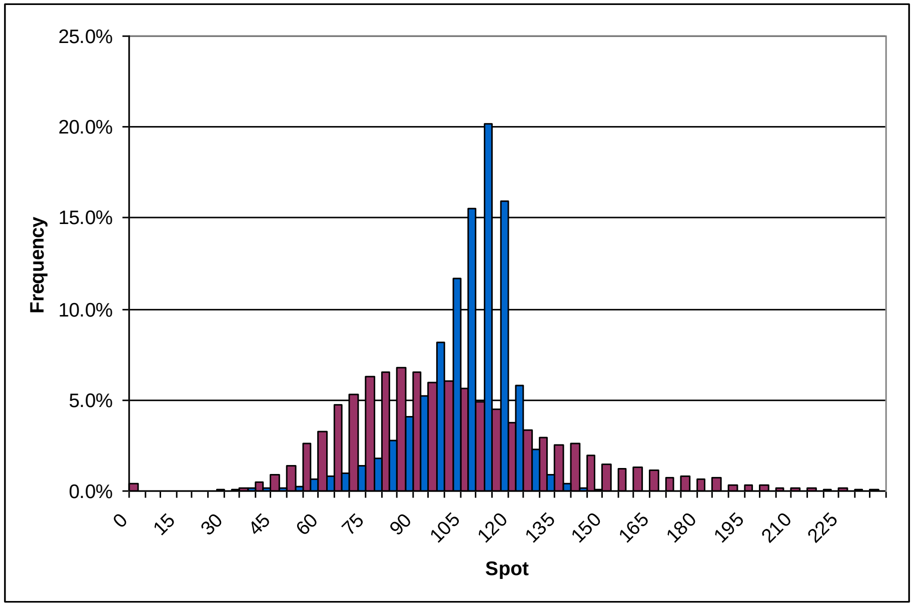


We can replicate this observed skew with different models:

- Constant volatility geometric Brownian motion (35%) plus jumps to default with 0.4% probability
  - Could easily be alternatively calibrated on historical data
- Local volatility model (or stochastic volatility model)
  - Predicts that volatility increases when spot goes down, which fits with intuition

Expert interpretation: example of skew

- We can match market prices with either model but what distribution of the spot is implied by each model?



- GBM + jumps in purple:

Quantiles 1%/99% = 40/210

- Local volatility in blue:

Quantiles 1%/99% = 49/127

- Use these models for risk calculations: get radically different PFE results with the same calibration
- Front office alignment might prefer local volatility model, Risk might favour jumps

Expert view and conditional events

- Expert influence is hard to avoid, but can we carve it out – superimpose it on the system as clearly separate layer? Makes origin of model error clearer
- Modelling of rare/conditional events may offer an opportunity. First let's look at example from classical angle
- Electricity markets jump (or spike) together (also true for gas). Table below illustrates the behaviour of price jumps in 'neighbouring' markets given a jump in one market.
- Joint behaviour has real world underpinning – existence of interconnect(s). Surge demand and corresponding surge in price can propagate across market. The reverse effect, pull to mean, is also true

Driving Market: Germany		Neighbour Markets: France, Netherlands	
Number of standard deviations	Number of Spike Occurrences	Number of standard deviations	Numer of Simulataneous Events
>3	32	>2 >1	17 29
>2	123	>1	99

- A spike may be a rare event, but given a spike in one market, *conditional probability* of spike in the connected market is high
  - Expert can also opine on potential impact of future infrastructure on conditional probability

Bayesian nets

- There is approach which just that – Bayesian Nets. Could or should we introduce it into world of IMM?

Primer on BNs:

- Bayesian nets is a compact graphical representation of joint distributions of several variables by means of a directed acyclic graph (DAG – sometimes also called ADG, for acyclic directed graph)
- Nodes of correspond to variables, arcs signify dependence between them
  - Absence of arcs signals conditional independence assumption
  - Arrows often represent a causal relationship between variables, although this is not necessarily the case; but directed cycles are not allowed in DAGs, as otherwise they can break causal relationships
  - Node that is directly to either 'parent' or 'child', depending on which way the causal arrow points
  - Key property of BN: any node is independent of its non-descendants given its parents (given the 'influence' of parent(s) on children, the children have no dependence on which/how grandparent(s) influence the parents)
  - Each node has conditional probability table/distribution (CPT/CPD), which gives probabilities of this node taking each of its possible values given each combination of values of its parents. Tables can be updated independently and as long as the conditional distribution is internally consistent the joint distribution implied by all CPTs together is also consistent by construction

Bayesian nets

- BNs data representation makes them amenable to 'learning', which is understood as updating probabilistic information using new data or expert judgement
  - 'Updating priors' – when new data or something else alters our estimates of probabilities for a particular event/factor/random variable, given other factor it depends on
- BN avoids many problems common to other methods, where changing one component of a complicated multi-dimensional model can have unanticipated and undesirable effects on other components of the [updated] joint distribution
- **For a risk manager BNs is a tool to explore expert views on links between rare events and the corresponding conditional probabilities**
- Conditional probability (in expert world). Example:
  - probability to be taken to hospital on a particular day – low and hard to guess
  - probability of being hit by a car – low and hard to guess
  - probability of ending up in the hospital ***conditional*** on being hit by a car is high (unfortunately) and most people will venture a reasonable guess. (A less dramatic example: rain and use of sprinklers in the garden)
- What is current use in Risk?

Bayesian nets

- Use for stress test design: Rebonato (2010) *Coherent Stress Testing. A Bayesian Approach to the Analysis of Financial Stress*, discusses creating discrete scenario stress tests for portfolios to assist risk managers
- For asset allocation: in further development Rebonato & Denev (2013) *Portfolio management Under Stress. A Bayesian-Net Approach to Coherent Asset Allocation* discuss first creating and then joining a subjective view tail events (the 'exceptional' distribution described by Bayesian net) with a business-as-usual, 'normal' distribution
- This looks like adding jumps to diffusion process in IMM world (e.g., modelling power). Equivalence?!
- Yes and No. For detailed discussion see Chorniy & Greenberg (2015) *Bayesian Networks and Stochastic Factor Models*, (https://ssrn.com/abstract=2688324)
- Yes, there is close equivalence. BNs are useful to explain conditional structures in IMM models, and are good for stand alone stress tests, but does not offer advantage to classic IMM language of factor model for production systems. Conditioning of a section of a main system on expert – may be. Major caveat: use AI/Machine Learning use in Risk may reverse our conclusion

Choice of a modelling object: modelling Complex Entities

- Key choice: not only ‘how’ to model as **what (or with what) to model and what to backtest**
- Choice of what to model
  - Economic/risk objects
  - ‘Traded’ observable
  - ‘Latent’ variable
  - Example: IR curve (or perhaps volatility) surface may be a single object for risk manager. Movements of level, slope have macroeconomic meaning, but modelling using short rate model (CCR) or individual tenors (market risk) may be preferred. Another example: CDS spreads vs. hazard rates
- Next choice: what to backtest. Example: yield curve in IMM CCR. Use short rate model, but backtest what?
  - Use exposure as weight – good, but does not give us insight into the model
  - Test all points – comprehensive, but what does it mean? Pass/fail exist per point – “pass” on 1, 3, 7, 20 years, “fail” 2 and 15 years? Very difficult to analyse the results
  - Select “representative” term – short, medium and long segments. Good start, but what about curve dynamics?
  - Parameters to measure main drivers of curve shape. Select curve shape parameters: level, slope, curvature?
- Solution should be aligned with modelling choice and practitioners’ choice
  - Risk managers think in objects – may prioritise ‘meaning’, else: ‘mechanics’

Neglected aspects of real world modelling

- Key choice: “**what to model” Mk.II - implied and realised universes**
- Dynamics of asset values in the Risk-Neutral and Real World Measures
- One realised universe for each market forward universe? Strictly speaking: yes
- In practice for some there is no difference, for some dynamics is similar enough, and if dynamics is different it may not always matter for Risk
  - It matters if difference builds up: compounding trades with pay-out at the end , e.g., some rates/inflation trades
  - Realised inflation and BEI had notably different dynamics (in the past market persistently overshoot its expectation)
  - Realised and implied volatility is another example
- So quantitative risk scope is not twice the pricing universe, but it is still much larger
- Strategy arbitrage operates in this space
- Different information (whether ‘forward’ information exist) creates different modelling preferences: model which fits ‘forwards’ for implied aligned with front office approach vs. model with explicit dynamics, e.g. mean reversion, for realised universe

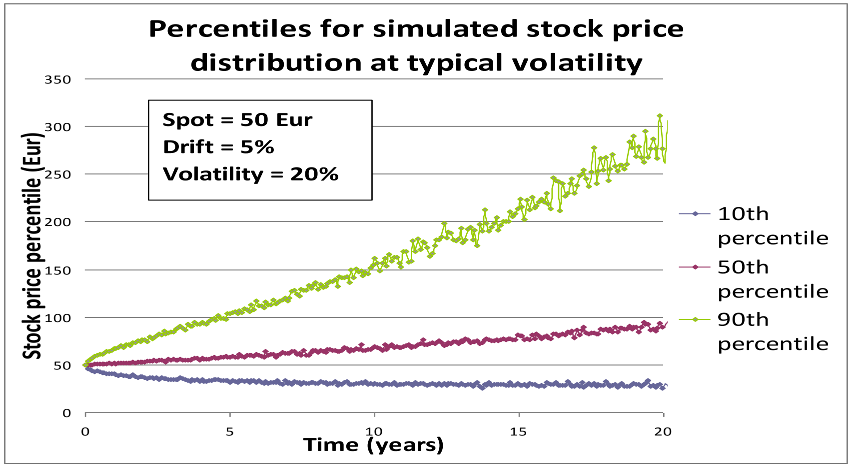
Neglected aspects of real world modelling

- Front office (pricing) tools are often not best suited for risk modelling and vice versa. However re-using tools cut cost and helps FO/Risk understanding. Key choice: **choice of FO or Risk specific models**

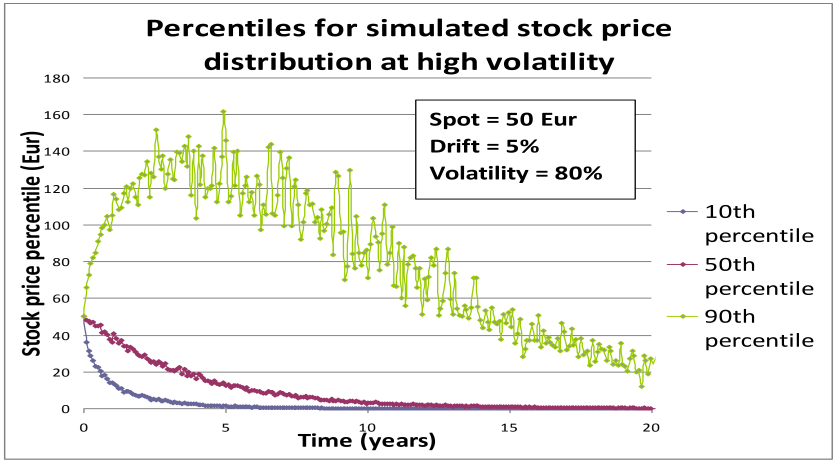
- Example: use of GBM

Stock prices often modelled as lognormal

$$S_t = S_0 \exp\left[\left(\mu(t) - \frac{\sigma^2}{2}\right)t + \sigma\sqrt{t}\varepsilon\right]$$



- High volatilities can make the drift term negative
  - Common in a risk-neutral context
  - Problematic in a real-world (risk) context
- Consider the risk of a long maturity call option on the stock
  - We show no risk at a given percentile beyond a certain future time



AMC or Full pricer MC approach: practical constraints

- <u>Key choice</u>: **treatment of exotics and operational resiliency. Inside or outside IMM**
- Full pricers may be too slow for exotics; AMC is viewed as alternative. AMC is an “all-or-nothing” technique: either it is possible to price the deal, or it isn’t (at least within MC approximation)
- For risk measures such as PFE (or even XVA), and for small number of trades, or small “one-off” exotic trades, the bank may not require the quality of the official P&L pricer for future deal PV computations.
  - Approximate, or even partial pricers for future valuations may suffice

- In addition, two other cases need to be considered:
  - Case 1: exotics or new underlyings
  - Case 2: poor availability of trade data in feeds, or poor integration with Front Office trade data

Practical constraints: unknown underlyings

- Case 1: ‘exotic’ or newly traded underlyings:
  - Bank can have a small number trades on rare (for this bank) underlyings (e.g. on local inflation, housing index, an illiquid currency pair, etc.)
  - The requirement under AMC is to be able to model the underlying jointly with all other risk factors “everywhere” – and certainly in the PFE and XVA engine
  - In practice, for “one-off” transactions, this is excessive: the primary requirement is to price the deal today (with a valuation reserve if necessary)
    - For market risk VAR: either replicate, reprice “today”, or use “today’s” sensitivities
    - Or, the trade may be “back-to-back” so an official P&L pricer may not be developed, and VAR is zero; only the counterparty risk remains
- For PFE and XVA, an approximation may be a more cost efficient alternative

Practical constraints: poor integration with FO systems

- Case 2: poor integration with Front Office systems:
  - Again, if an approximation is deemed to be sufficient, then not all trade information (for the exotics trades in particular) need to be passed from front office to risk systems
    - Exotics trades carry relatively more information on legs and scheduling information
  - If an approximation is employed, then it is sufficient to pass only the information that is required for the approximate risking of the trade
  - The approximate risking is however likely to be conservative: the lesser the information, the more conservative the risking

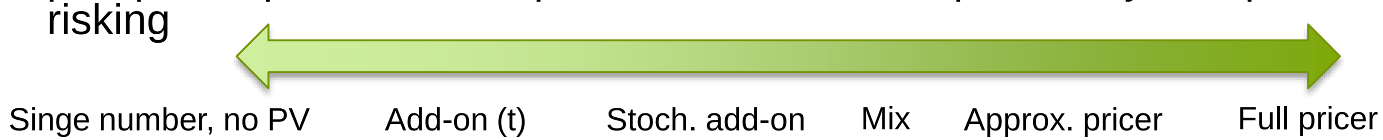
- An added advantage is that a system which is designed to handle partial data form the outset (even for trades which are priced usually) – can use such approximations as fall-back
  - In cases of data failure, the system does not fail, but uses instead a conservative approximation for risking
  - In such cases, the CCR PV will be away from the official PV used for P&L
    - Automated checks (at trade level) can be introduced to monitor the extent the PVs diverge

Approximate risking framework: extra benefits

- Operational resiliency: the risk system switches to a more conservative risking mode instead of failing; which provides correct incentive to business, but “business-friendly”
- Know a trade’s risk “before risking” – allows fast automated pass/fail filter on PV FO vs. PV Risk engine diverge
- “Apples with apples”: The conservative risking could be viewed as reserves, but in exposure space (inside IMM), which helps risk management.
- It aligns with the current regulatory thinking of more advanced standardised methods (SA-CCR)
- A framework for overriding exposure (the risking approach) can be introduced:
  - Introduce the capability to risk a given trade off an externally designed add-on instead, or force-mapped to another pricer if deemed more suitable. Possible to group trades together (portfolio override). Very strong governance and oversight should be deployed for overrides

Simplified add-on methodology

- Approximate risking framework can build using broadly defined add-on based methodology:
  - The add-on term can be (maturity and) time-dependent: the level of add-on through the life of the trade is varying
  - Add-on “profile” can mirror, conservatively, the profile obtained with a pricer
  - Design could top-down or bottom-up depending on the product group
- Important point: there is no divide between fixed add-ons and (analytical) pricers:
  - But rather a ***continuum***: the add-on term could be stochastic, representing a part-pricer, part-fixed component, or also mixed potentially with partial AMC risking

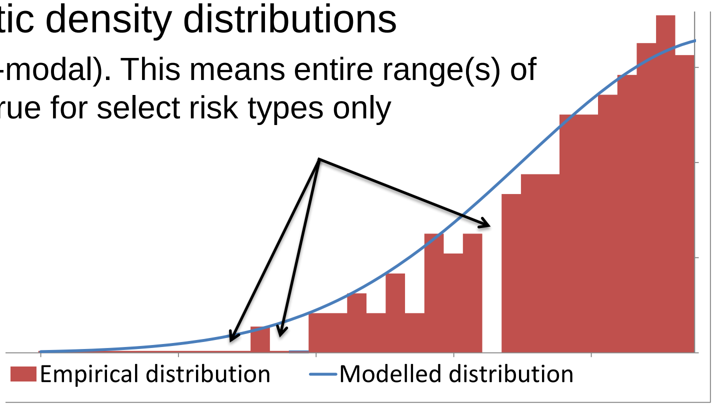


  - For example, for variance swap on equities:
    - Generally, volatility of stock returns and stock returns themselves are negatively correlated → increases in volatility related to sudden decreases in stock price
    - This implies a correlation between stock returns and variance swap price, a stochastic (margined) add-on for variance swaps can be devised which incorporates this correlation
- The complexity of add-ons can be tailored to the requirements:
  - Simplified add-ons can be used for more conservative risking (for example, when less information is available)

Market risk estimators: absent or sparse data

- Key choice: **What do missing return(s) mean for the model?** Do nothing? (recall claim that "HVAR has no methodological assumptions")
- Using empirical returns with no adjustments assumes that only what happened in the past can happen in the future. Two implications:
  - A particular return cannot happen: this risk scenario is never realised
  - Large number of missing returns imply unrealistic density distributions
    - Can a risk factor have ***multi-modal density***? (e.g. tri-modal). This means entire range(s) of outcomes cannot (or are unlikely) to happen. This is true for select risk types only

Example of missing events which will never occur in the VAR using the empirical distribution.



- For sparse (rare) events there are additional problems:
  - Poor risk aggregation at higher levels
    - Empirical returns (HVAR) or empirical density (MC VAR) with rare events might lead to higher VAR at the risk factor level, but when adding other risk factors the effect on higher nodes is unknown, e.g. VAR may be underestimated: risk wash-out.
  - Instability in the VAR over time does not reflect the real risk level: poor risk management.
    - Rare events moving in/out of calibration window. HVAR can be worst affected

Market risk estimators: sparse data

- The incomplete data (time series) is truly sparse (rare) if no obvious or reliable distribution property can be extracted

- In this case other methods with additional modelling assumptions are usually needed (note: under FRTB for risk internal model and potentially for desk level modelling only)

- First step is to examine the origins of illiquid and sparse data

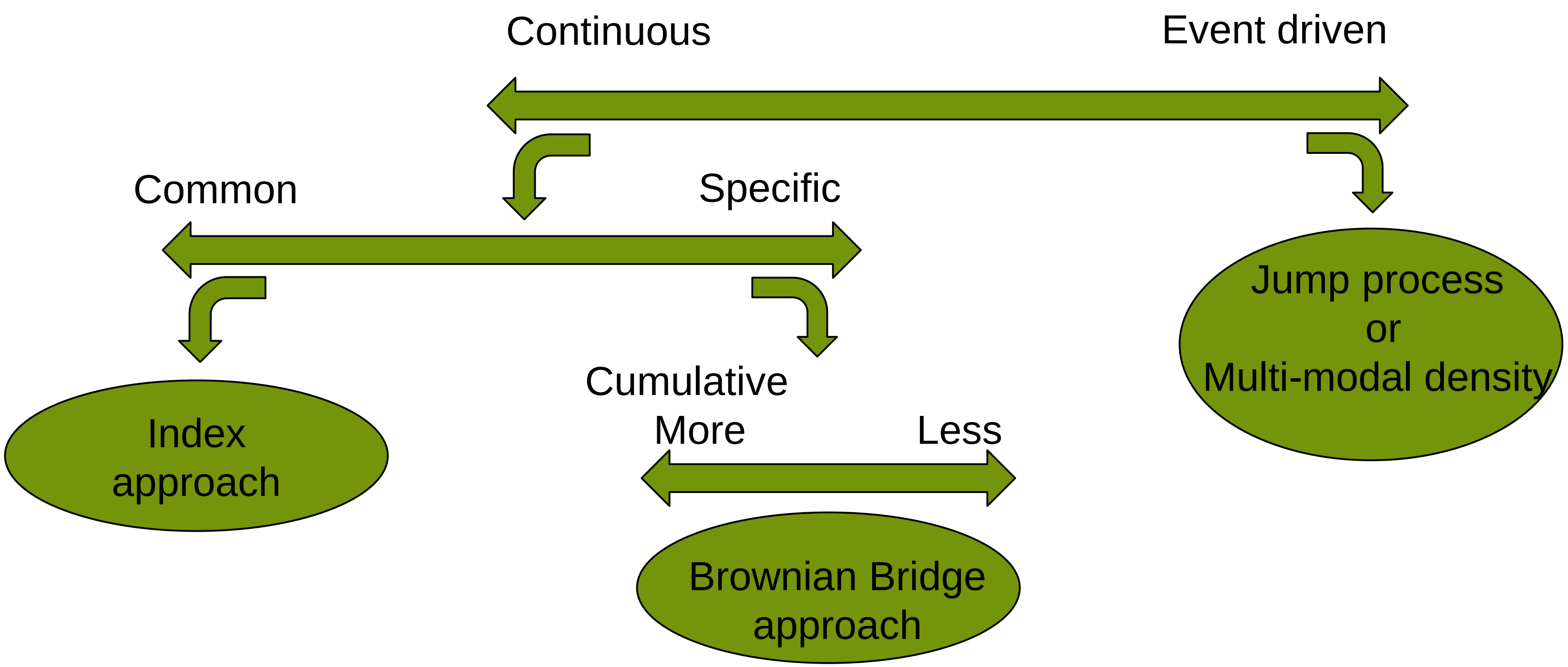
- For the process (driver) behind the data, three aspects are important to consider (will be relevant for the modelling choices):
  - Continuous or event driven
  - Common or unique
  - Cumulative or non-cumulative

Market risk estimators: sparse data

- Continuous or event driven
  - Is the process continuous (always evolving), or a single event driven e.g. specific decisions driven by political, economical or industrial events/decisions?
    - If it is event driven, only certain ranges of outcomes are possible (e.g. fixed “tick” size? Firing up a power plant?)
    - Is the density multi (tri)-modal? If yes, does it persist across different timescales (intraday, 1 day, 10 day, 20 day, ..)?
- Common or unique
  - Is the process relatively common or unique?
    - For example, the modelling of AA bonds can have a common approximation, but USD currency is considered unique
- Cumulative or non-cumulative
  - How does the process evolve between markings (structural assumptions may be required). Is the process cumulative, i.e. do observed changes build up gradually, or instantaneously, or in between?
    - Non-financial example: a bomb with random fuse exploding with paint and a group of enthusiastic children with a bucket of paint and brushes “redecorating” a room. If checked at the end of the day the resulting disaster is the same, but first is instantaneous and happens at some specific time in the day; the second is cumulative. We can deduce this from structural arguments (risk quants/experts adding value)

Market risk estimators: sparse data

- Framework should allow modelling risk for horizons shorter than spacing between re-marking, e.g. 1d VAR vs. weekly updated data, whilst maintaining consistency with modelling for horizons longer than re-marking (e.g. 3 months)



Conclusion

Often there is no “right” answer

- Structural or data driven modelling: not a single choice, but a **strategy**
- Role of expert in risk modelling is wider than often assumed (both direct and hidden)
- Bayesian nets: useful tool, but not a magic solution

Key choices cover wide range of areas:

- Modelling objects and backtesting objects. Model transparency
- Neglected aspects of real world modelling
  - Choice of FO or Risk specific models
  - Choice of modelled risk factor universe (implied and realised)
- Model resilience and system resilience
  - Simplified model framework
  - Sparse and illiquid data framework
- “No choice” is still an implied expert choice

References

In additional to already quoted SSRN articles* this talk is based on joint work with multiple contributors:

ICBI: Global Derivatives Trading & Risk Management (Budapest, Hungary), May 2016
“Stochastic Volatility vs. Jumps Role in Equity-Credit Modelling for Risk Management” with Andrei Greenberg

ICBI: Risk Minds (Amsterdam, Netherlands), December 2015
“Back To Basics: cost-effective methodology and infrastructure for non-standard trades in counterparty Risk IMM” with Vinay Kotecha

ICBI: Risk Minds (Amsterdam, Netherlands), December 2014
“Modellable Risk and Fundamental Review of Trading Book” with Vinay Kotecha

WBS: Fixed Income (Barcelona, Spain), September 2014
“Credit-Equity Model Building Blocks” with Andrei Greenberg, Lee Moran

WBS: Fixed Income (Berlin, Germany), October 2011
“Risk Quant and Pricing Quant - Two Sides of the Same Coin or Just Two Sides?” with Lee Moran

*Chorniy & Greenberg (2015) *Review of Equity-Credit Dependence Studies: Towards Building a Practical Equity-Credit Model for Counterparty Risk*, http://ssrn.com/abstract=2708143 and Chorniy & Greenberg (2015) *Bayesian Networks and Stochastic Factor Models*, https://ssrn.com/abstract=2688324

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