Modeling Credit Correlations Using Macroeconomic Variables
Agenda

1. Introduction
2. Challenges of working with macroeconomic variables
3. Relationships between risk factors and macroeconomic variables
4. Putting it all together
5. Conclusion
1 Introduction
The objective: linking a credit portfolio model to the state of the economy

- Moody’s Analytics maintains and updates its global multi-factor correlation model GCorr, used for modeling losses on credit portfolios.
- GCorr Corporate describes correlations among asset returns of borrowers.
  - Asset return – a proxy for a change in credit quality of a borrower.

Borrower’s asset return (change in credit quality)

Systematic credit risk factors

Country Risk

Industry Risk

Latent factors – defined as indexes of the asset returns.

Question: How to link the systematic factors to macroeconomic variables in order to make the interpretation of the model more intuitive?
How can a link between credit risk factors and macroeconomic variables be used in practice?

» Providing more intuitive interpretation for the systematic factor returns:
  – To what state of the economy does a two standard deviation drop in the U.S. Mining factor correspond?

» Understanding the dependence of credit portfolio losses on macroeconomic variables.
  – Does increasing oil price increase or decrease expected loss on a portfolio? How strong is the impact?

» Stress testing
  – What is the expected credit portfolio loss, given a scenario defined using macroeconomic variables?
Why focus on this topic now?

» Following the financial crisis, stress testing has become a focus of regulatory agencies and financial institutions.

» Stress testing exercises conducted by the Federal Reserve define a "stress scenario" and evaluate how well banks might perform if the scenario materializes:
  – Supervisory Capital Assessment Program (SCAP) – 2009.

» European Banking Authority (EBA) and Committee of European Banking Supervisors (CEBS) have been conducting EU-wide stress tests of the banking sector since 2009.

» Increased demand from our clients – a tool that would link our credit portfolio model to macroeconomic variables.
Basic idea…

» Credit portfolio losses are related to the state of the economy.

» During periods of economic downturns, losses tend to be higher, and vice versa.
How to link credit portfolio losses to macroeconomic variables?

- A model for estimation of credit portfolio loss distribution.

Draws of borrower specific credit risk factors

Draws of systematic credit risk factors: $\phi_1, \phi_2, \ldots$

Joint distribution with correlation matrix $\Sigma$

1-RSQ

Draws of asset returns (credit quality changes)

PD, LGD, EAD, Credit Migration

Credit portfolio loss distribution on a horizon
By linking input parameters to macroeconomic variables...

Linking PD, RSQ, and other parameters to macroeconomic variables. → A model which can predict stressed PD, RSQ, and other parameters given an adverse macroeconomic scenario.
By linking input parameters to macroeconomic variables...

Draws of systematic credit risk factors
\( \phi_1, \phi_2, \ldots \)

Joint distribution with correlation matrix \( \Sigma \)

Draws of asset returns (credit quality changes)
1-RSQ

PD, LGD, EAD, Credit Migration

Future credit portfolio loss distribution

Draws of borrower specific credit risk factors

1-RSQ

RSQ

Stressed PD, RSQ, and other parameters imply stressed portfolio loss distribution, which can be used to determine stressed expected loss and economic capital.
... or by linking systematic factors to macroeconomic variables.

→ Focus of this presentation.

Draws of systematic credit risk factors $\phi_1, \phi_2, \ldots$
Joint distribution with correlation matrix $\Sigma$

Draws of asset returns (credit quality changes)$\rightarrow 1$-RSQ$\rightarrow$ PD, LGD, EAD, Credit Migration
… or by linking systematic factors to macroeconomic variables.

→ Focus of this presentation.

Draws of borrower specific credit risk factors

Draws of asset returns (credit quality changes)

1-RSQ

Draws of systematic credit risk factors $\phi_1, \phi_2, \ldots$

Joint distribution with correlation matrix $\Sigma$

Correlations of systematic factors and macroeconomic variables (MVs):

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Future credit portfolio loss distribution

EL given a macroeconomic shock

Range of losses given a macroeconomic shock

Specific levels of macroeconomic variables imply a conditional distribution of systematic factors. → Credit portfolio loss.
Example: effect of an oil price drop on the systematic factor of the U.S. oil industry

- $\phi_{US,Oil} =$ systematic credit risk factor of U.S. “Oil, Gas, and Coal Expl/Prod” industry.
- $\phi_{\Delta OilPrice} =$ standard normal shock representing oil price changes.
- Effect of the negative two standard deviation shock to the oil price: $\phi_{\Delta OilPrice} = -2$?

### Conditional distribution of $\phi_{US,Oil}$, given $\phi_{\Delta OilPrice}$

$$
\phi_{U.S.,Oil} \mid \phi_{\Delta OilPrice} \sim N(\rho \phi_{\Delta OilPrice}, 1 - \rho^2)
$$

**Unconditional distribution of $\phi_{US,Oil}$**

$\text{Mean} = 0$

$\text{Std} = 1$

$\text{Corr}(\phi_{US,Oil}, \phi_{\Delta OilPrice})$

$\rho = 41\%$

Oil Price drops by 2 standard deviations
Effect of an **oil price increase** on the systematic factor of the U.S. oil industry

» \( \phi_{US,Oil} \) = systematic credit risk factor of U.S. “Oil, Gas, and Coal Expl/Prod” industry.

» \( \phi_{\Delta OilPrice} \) = standard normal shock representing oil price changes.

» Effect of the positive two standard deviation shock to the oil price: \( \phi_{\Delta OilPrice} = 2? \)

**Unconditional distribution of \( \phi_{US,Oil} \)**

\[
\text{Corr}(\phi_{US,Oil}, \phi_{\Delta OilPrice}) = \rho = 41\%
\]

**Conditional distribution of \( \phi_{US,Oil} \) given \( \phi_{\Delta OilPrice} \)**

\[
\phi_{U.S.,Oil} \mid \phi_{\Delta OilPrice} \sim N(\rho \phi_{\Delta OilPrice}, 1 - \rho^2)
\]
What is the impact of an oil price drop on a credit portfolio loss distribution?

A large credit portfolio of homogenous exposures to the U.S. “Oil, Gas, and Coal Expl/Prod” industry

» Input parameters: PD=1%, RSQ=20%, LGD=100%, EAD=1.

Conditional distribution of $\phi_{US,Oil}$ given $\phi_{\Delta OilPrice}$

Conditional loss distribution, given $\phi_{\Delta OilPrice}$
What is the impact of an **oil price drop** on a credit portfolio loss distribution?

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Conditional distribution of $\Phi_{US,Oil}$ given $\Phi_{\Delta OilPrice}$

Conditional loss distribution, given $\Phi_{\Delta OilPrice}$

Conditional expected loss:

$$E[L | \Phi_{\Delta OilPrice}] = N\left(\frac{N^{-1}(PD) - \rho \sqrt{RSQ} \Phi_{\Delta OilPrice}}{\sqrt{1 - \rho^2 \cdot RSQ}}\right)$$
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Conditional expected loss:

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E[L | \phi_{\Delta OilPrice} = N \left( \frac{N^{-1}(PD) - \rho \sqrt{RSQ} \phi_{\Delta OilPrice}}{\sqrt{1 - \rho^2 RSQ}} \right)
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Challenges of working with macroeconomic variables
Estimating the framework...

The parameters to be estimated are the entries of the correlations matrix linking macroeconomic variables and systematic credit risk factors, as well as correlations among macroeconomic variables:

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Parameters to be estimated.

Challenges:

- Data – Variables selection and data preparation.
- Estimation of the link between macroeconomic variables and systematic factors.
- Accounting for certain statistical properties of macroeconomic variables – Non-normality, significant autocorrelations and cross-correlations.
- Correlation levels and patterns can vary over time.
Preparing and transforming macroeconomic data

» Types of macroeconomic variables to consider:
  – Variables measuring real economic activity, labor market, personal income – GDP growth, Unemployment rate, Industrial production, Real disposable income, other variables. Economy-wide variables and specific sector-related variables.
  – Financial markets variables: stock market index and volatility, interest rates, exchange rates.
  – Consumer prices, Producer prices.
  – Real estate price.
  – Commodity prices.
  – Variables from various countries.

» Transformations of the macroeconomic variables:
  – Objective – stationary time series that can be used for estimating correlations. → Differences of the variables (e.g. interest rates) or returns (e.g. stock market index).
  – Frequency – monthly, quarterly, annual.
  – Choice of period for the macroeconomic data – important question because correlation patterns of macroeconomic variables change over time and depend on the state of the economy.
Modeling challenges

» Univariate statistical properties of transformed macroeconomic variables:
    Example: Typical quarterly U.S. GDP growth over the past twenty years has been 0% - 8% (annualized rate). Drop during the financial crisis: - 8%.
  – Autocorrelations. An economic shock may impact a macroeconomic variable over several periods.

» Modeling correlations
  – Lead-lag structure among macroeconomic variables as well as between macroeconomic variables and systematic credit risk factors.
    Example: Unemployment rate is a lagging economic indicator. → Unemployment rate may decline only after several periods of GDP growth and stock market recovery.
  – Correlations strongly depend on the chosen period over which they are estimated.
    Correlations not only differ between “good times” and “recessions”, but they also depend on the type of recession the economy is going through. Example: recent financial crisis versus high inflation recessions of the 1970’s. → “Every recession is unique.”

» How to overcome the challenges?
Relationships between risk factors and macroeconomic variables
Empirical analysis – GCorr Corporate factors and select macroeconomic variables

» 15 U.S. related macroeconomic variables were selected for an empirical analysis.
   – Transformations to ensure stationarity, quarterly time series.

» 61 systematic credit risk factors from the GCorr Corporate model representing U.S. industries.
   – Returns at quarterly frequency.

» Questions:
   – Correlations among the 15 macroeconomic variables?
   – Correlations between the macroeconomic variables and the systematic factors?
   – Do we see a lead-lag structure in the time series of the variables?
   – How do correlations depend on the chosen time period?
Correlations of changes in macroeconomic variables

» 1999 Q3 – 2012 Q1 (51 observations)

» Prior to calculating correlations, all variables are subject to transformations to ensure stationarity.

- For example Real GDP → Real GDP growth rate or Oil Price → Percentage change in Oil Price.

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<tr>
<td>Real Disposable Personal Income</td>
<td>0.328</td>
<td>-0.282</td>
<td>0.078</td>
<td>0.210</td>
<td>0.167</td>
<td>0.158</td>
<td>0.126</td>
<td>0.191</td>
<td>0.339</td>
<td>1</td>
<td>-0.172</td>
<td>0.288</td>
<td>0.011</td>
<td>-0.025</td>
<td>0.200</td>
</tr>
<tr>
<td>Average Exchange Rate</td>
<td>-0.325</td>
<td>0.180</td>
<td>-0.224</td>
<td>-0.091</td>
<td>0.450</td>
<td>-0.134</td>
<td>-0.423</td>
<td>-0.077</td>
<td>-0.147</td>
<td>-0.172</td>
<td>1</td>
<td>-0.320</td>
<td>-0.533</td>
<td>0.267</td>
<td>-0.529</td>
</tr>
<tr>
<td>Industrial Production</td>
<td>0.770</td>
<td>-0.848</td>
<td>0.021</td>
<td>0.411</td>
<td>-0.174</td>
<td>0.157</td>
<td>0.278</td>
<td>0.456</td>
<td>0.747</td>
<td>0.288</td>
<td>-0.320</td>
<td>1</td>
<td>0.329</td>
<td>0.015</td>
<td>0.334</td>
</tr>
<tr>
<td>S&amp;P 500</td>
<td>0.459</td>
<td>-0.279</td>
<td>0.549</td>
<td>0.328</td>
<td>-0.269</td>
<td>0.375</td>
<td>0.224</td>
<td>0.164</td>
<td>0.145</td>
<td>0.011</td>
<td>-0.533</td>
<td>0.329</td>
<td>1</td>
<td>-0.733</td>
<td>0.329</td>
</tr>
<tr>
<td>VIX</td>
<td>-0.154</td>
<td>-0.005</td>
<td>-0.447</td>
<td>-0.116</td>
<td>0.070</td>
<td>-0.220</td>
<td>0.067</td>
<td>-0.098</td>
<td>0.116</td>
<td>-0.025</td>
<td>0.267</td>
<td>0.015</td>
<td>-0.733</td>
<td>1</td>
<td>-0.197</td>
</tr>
<tr>
<td>Oil Price</td>
<td>0.448</td>
<td>-0.360</td>
<td>0.420</td>
<td>0.384</td>
<td>-0.315</td>
<td>0.303</td>
<td>0.745</td>
<td>0.166</td>
<td>0.195</td>
<td>0.200</td>
<td>-0.529</td>
<td>0.334</td>
<td>0.329</td>
<td>-0.197</td>
<td>1</td>
</tr>
</tbody>
</table>

Values in bold are different from 0 with a significance level alpha=0.05.
Contemporaneous correlations between changes in macroeconomic variables and GCorr Corporate factors

Prior to calculating correlations, all variables are subject to transformations to ensure stationarity.

<table>
<thead>
<tr>
<th>Macroeconomic variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Number of correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP</td>
<td>37.1%</td>
<td>7.4%</td>
<td>61</td>
</tr>
<tr>
<td>Unemployment Rate</td>
<td>-20.6%</td>
<td>3.6%</td>
<td>61</td>
</tr>
<tr>
<td>10 Year Treasury Rate</td>
<td>24.6%</td>
<td>18.4%</td>
<td>61</td>
</tr>
<tr>
<td>3 Month Treasury Rate</td>
<td>16.0%</td>
<td>7.6%</td>
<td>61</td>
</tr>
<tr>
<td>Baa Corporate Bond Rate</td>
<td>-38.4%</td>
<td>7.3%</td>
<td>61</td>
</tr>
<tr>
<td>Mortgage Rate</td>
<td>9.2%</td>
<td>15.8%</td>
<td>61</td>
</tr>
<tr>
<td>CPI</td>
<td>4.1%</td>
<td>11.2%</td>
<td>61</td>
</tr>
<tr>
<td>House Price Index</td>
<td>15.1%</td>
<td>6.1%</td>
<td>61</td>
</tr>
<tr>
<td>Commercial Property Price Index</td>
<td>9.8%</td>
<td>4.6%</td>
<td>61</td>
</tr>
<tr>
<td>Real Disposable Personal Income</td>
<td>-3.4%</td>
<td>4.6%</td>
<td>61</td>
</tr>
<tr>
<td>Average Exchange Rate</td>
<td>-39.2%</td>
<td>8.7%</td>
<td>61</td>
</tr>
<tr>
<td>Industrial Production</td>
<td>29.8%</td>
<td>4.2%</td>
<td>61</td>
</tr>
<tr>
<td>S&amp;P 500</td>
<td>82.9%</td>
<td>10.7%</td>
<td>61</td>
</tr>
<tr>
<td>VIX</td>
<td>-62.4%</td>
<td>8.9%</td>
<td>61</td>
</tr>
<tr>
<td>Oil Price</td>
<td>10.4%</td>
<td>13.5%</td>
<td>61</td>
</tr>
</tbody>
</table>
Do the correlations follow economic intuition?

» Change in House Price Index:
  - The US real estate industry has the highest correlation with house price returns (28%) among the 61 US custom indexes.

<table>
<thead>
<tr>
<th>U.S. Industry Systematic Factor</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephone</td>
<td>2%</td>
</tr>
<tr>
<td>Utilities, Gas</td>
<td>8%</td>
</tr>
<tr>
<td>Real Estate Investment Trusts</td>
<td>20%</td>
</tr>
<tr>
<td>Real Estate</td>
<td><strong>28%</strong></td>
</tr>
</tbody>
</table>

» Industrial Production Growth:

<table>
<thead>
<tr>
<th>U.S. Industry Systematic Factor</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobacco</td>
<td>21%</td>
</tr>
<tr>
<td>Medical Services</td>
<td>22%</td>
</tr>
<tr>
<td>Steel &amp; Metal Products</td>
<td><strong>34%</strong></td>
</tr>
<tr>
<td>Transportation</td>
<td><strong>37%</strong></td>
</tr>
</tbody>
</table>

» Oil Price Change:

<table>
<thead>
<tr>
<th>U.S. Industry Systematic Factor</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Transportation</td>
<td>-17%</td>
</tr>
<tr>
<td>Paper</td>
<td>1.6%</td>
</tr>
<tr>
<td>Oil Refining</td>
<td><strong>32%</strong></td>
</tr>
<tr>
<td>Mining</td>
<td><strong>35%</strong></td>
</tr>
<tr>
<td>Oil, Gas &amp; Coal Expl/Prod</td>
<td><strong>41%</strong></td>
</tr>
</tbody>
</table>
Some lead or lag correlations can be significant

» Unemployment rate change and select systematic credit risk factors

<table>
<thead>
<tr>
<th>U.S. Industry Systematic Factor</th>
<th>Unempl. Rate, t-2</th>
<th>Unempl. Rate, t-1</th>
<th>Unempl. Rate, t</th>
<th>Unempl. Rate, t+1</th>
<th>Unempl. Rate, t+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Services, t</td>
<td>14.1%</td>
<td>-10.2%</td>
<td>-19.8%</td>
<td>-40.4%</td>
<td>-32.3%</td>
</tr>
<tr>
<td>Food &amp; Beverage Retl/Whsl, t</td>
<td>19.7%</td>
<td>-12.2%</td>
<td>-21.0%</td>
<td>-34.6%</td>
<td>-27.3%</td>
</tr>
<tr>
<td>Construction, t</td>
<td>16.9%</td>
<td>-14.0%</td>
<td>-23.8%</td>
<td>-40.2%</td>
<td>-35.8%</td>
</tr>
<tr>
<td>Steel &amp; Metal Products, t</td>
<td>19.9%</td>
<td>-11.2%</td>
<td>-24.4%</td>
<td>-45.4%</td>
<td>-31.9%</td>
</tr>
</tbody>
</table>

Negative systematic credit risk shocks are associated with future rises in the unemployment rate. → Unemployment rate is “lagging”.

» S&P 500 returns and select systematic credit risk factors

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Banks and S&amp;Ls, t</td>
<td>11.7%</td>
<td>-4.4%</td>
<td>42.7%</td>
<td>-10.2%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Tobacco, t</td>
<td>6.1%</td>
<td>-1.4%</td>
<td>57.5%</td>
<td>-21.0%</td>
<td>-10.9%</td>
</tr>
<tr>
<td>Consumer Products, t</td>
<td>3.1%</td>
<td>8.4%</td>
<td>85.3%</td>
<td>0.2%</td>
<td>-9.8%</td>
</tr>
<tr>
<td>Business Services, t</td>
<td>-0.5%</td>
<td>3.1%</td>
<td>93.6%</td>
<td>12.7%</td>
<td>-0.3%</td>
</tr>
</tbody>
</table>

Strong contemporaneous correlations, no significant lead lag relationships.
Correlation levels and patterns can change over time…

» Contemporaneous correlations between GCorr Corporate systematic factors and GDP growth over two periods.
  – The correlation level is generally higher for the period 1999 Q3 – 2012 Q1, which includes the financial crisis.

\[
\text{corr}(\phi_{US,Ind}, \Delta GDP)
\]

- 1999Q3-2012Q1
- 1992Q1-2007Q4
Putting it all together
How to map macroeconomic variables to standard normal shocks?

A possible approach – quantile mapping

Empirical distribution of quarterly oil price percentage changes (1999Q3 – 2012Q1)

ΔOilPrice

Oil price drops by 52%

Observation from 2009 Q2
Observation from 2008 Q4

Standard normal distribution $\Phi_{\Delta\text{OilPrice}}$

Two standard deviation shock
Analyzing how credit portfolio losses depend on various macroeconomic variables

» IACPM portfolio – 3000 reference entities distributed across 7 developed countries and 60 industries.

» Running simulation engine, which generates draws of systematic factors as well as macroeconomic standard normal shocks ($\phi_{MV}$).
  – Each trial → credit portfolio loss and a macroeconomic shock.

» Example: impact of a macroeconomic variable on two portfolios

Losses more strongly associated with macroeconomic shocks $\phi_{\Delta S&P500}$ than $\phi_{\Delta OilPrice}$. 
Stress testing – credit portfolio loss given a macroeconomic scenario

» A structure of stress testing:

1. Scenario defined using macroeconomic variables
2. Conditions on draws of standard normal shocks representing macroeconomic variables
3. Run simulation engine and select only the trials in which relevant shocks met the conditions
4. Analyzing credit portfolio losses given the scenario

A mapping. For example, quantile mapping

Alternatively, building an econometric model which links losses and macroeconomic normal shocks across trials:

\[
\text{Loss}_{\text{trial}} \leftrightarrow N \left( \alpha + \sum_{k=1}^{K} \beta_k \Phi_{\text{MV},\text{trial}} \right)
\]
An example of how the framework can work...

IACPM portfolio:

Scenario – changes over a year (2008 scenario)
- Real GDP drops by 3.3%
- 10YTR drops by 1.68 perc. pts.
- S&P500 drops by 37%
- Oil price drops by 55%

Simulation engine with the GCorr – macroeconomic variables module

Loss L versus macroeconomic shocks – strength and direction of the relationships?

\[
\text{Corr}(N^{-1}(L), \phi_{\Delta GDP}) = -37\%
\]
\[
\text{Corr}(N^{-1}(L), \phi_{\Delta 10YTR}) = -21\%
\]
\[
\text{Corr}(N^{-1}(L), \phi_{\Delta S&P500}) = -79\%
\]
\[
\text{Corr}(N^{-1}(L), \phi_{\Delta OilPrice}) = -16\%
\]

A fitted econometric model – expected loss versus macroeconomic shocks

\[
\mathbb{E}[L \mid \phi_{\Delta GDP}, \phi_{\Delta 10YTR}, \phi_{\Delta S&P500}, \phi_{\Delta OilPrice}] = N(-2.0683 -0.0033 \phi_{\Delta GDP} +0.0731\phi_{\Delta 10YTR} -0.2091 \phi_{\Delta S&P500} +0.0096 \phi_{\Delta OilPrice})
\]

Expected loss wrt TS, given the scenario (Translating MV to \( \phi_{MV} \) using quantile mapping to annual data over 1972 – 2007)

\[
\mathbb{E}[L \mid \text{Scenario}] = 1.95\%
\]

Compare to the unconditional expected loss: \( \mathbb{E}[L] = -1.04\% \)

Loss distribution given the scenario

Unconditional distribution

Distribution given the scenario
Conclusion
Takeaways

» Creating a framework which links macroeconomic variables and a credit portfolio model:
  – What type of analysis will this framework be used for?
  – Which components of the model will be linked to macroeconomic variables?
  – How to interpret output of the analysis?

» Estimating a link between macroeconomic variables and systematic credit risk factors:
  – Processing macroeconomic data – stationarity, frequency, time period.
  – Intuitive relationships between macroeconomic variables and GCorr Corporate systematic factors.

» Implementation challenges
  – Macroeconomic variables are not normally distributed → mapping to standard normal shocks.
  – Lead-lag relationships and autocorrelations → need to be accounted for if an analysis is conducted over multiple periods.
  – Correlation patterns change over time and with economic conditions → estimating several sets of parameters, representing various macroeconomic scenarios/episodes.
Impact of this research

» Develops a framework which links macroeconomic variables and credit risk factors.
   – One can understand how credit portfolio losses vary with shocks to macroeconomic variables.

» By considering correlations one can calculate a distribution of portfolio losses given a macroeconomic scenario.
   – For example, this goes one step farther than just computing expected losses as defined by CCAR.
   – Stressed expected losses can be calculated considering a dependency structure between sub-portfolios.

» More comprehensive stress testing
   – Impact of different types of recessions can be tested against.
   – Analysis can lead to risk mitigation strategies.