Macrofinancial Risk Framework: Modeling Banking Sector and Sovereign Risk Interactions Using Contingent Claims Analysis

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Dr. Dale Gray

Monetary and Capital Markets Dept, IMF

Dgray@imf.org

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Using Contingent Claims Analysis (CCA) to Measure, Analyze and Mitigate Risk

- CCA balance sheets are risk-adjusted balance sheets
- Liabilities derive their value from assets; assets are uncertain. Over horizon period, CCA gives expected losses on debt and default probabilities
- Sovereign CCA models are calibrated for EM and Advanced Countries
Comparing Contingent Claims Analysis (CCA) Balance Sheet Models to Macroeconomic Models

- Macroeconomic models geared to try to forecast the mean of macro variables (i.e. first moment)
- CCA measures risk from stochastic assets relative to threshold (second and third moments critical to risk indicators).
- CCA is an excellent tool for analyzing macrofinancial linkages.
- Time pattern of CCA risk indicators can be linked to macroeconomic variables and to monetary policy models.
Macrofinancial Risk Analysis

- Framework integrates risk-adjusted balance sheets using Contingent Claims Analysis (CCA) of financial institutions, corporates, and sovereigns together and with macroeconomic and monetary policy models

- TOOLKIT FOR MACRO RISK ANALYSIS
Using risk-adjusted (CCA) balance sheets of banks to complement traditional balance sheet stress tests provides numerous advantages:

Impact of changes in bank assets (from profits and losses, including losses on sovereign bonds) on bank funding costs;

Impact of government implicit and explicit guarantees on bank funding costs;

Understanding banking-sovereign risk feedbacks and destabilization spirals;

Framework for joint bank and sovereign stress testing;

Relates equity capital levels to funding costs. Dynamic non-linear impact of changes in banks’ assets on equity capital and bank funding costs. (Provides insights on RWAs);

Promising framework for integrating the short-term liquidity risk with solvency risk.
Core Concept of the Risk-Adjusted Balance Sheet or Contingent Claims Analysis (CCA)

- Value of liabilities derived from value of assets.
- Liabilities have different seniority.
- Randomness in asset value.

\[
\text{Assets} = \text{Equity} + \text{Risky Debt} = \text{Equity} + \text{Default-Free Debt} - \text{Expected Loss}
\]

Note that when assets change, the equity value changes and the expected loss changes.

\[
\text{Assets} = \text{Implicit Call Option} + \text{Default-Free Debt} - \text{Implicit Put Option}
\]

\[\ldots\ldots\ldots \text{as shown by the seminal work of Robert Merton}\]
Risk-Adjusted (CCA) Balance Sheet

Changes in bank assets due to:

(i) profits, credit losses, dividends, and,

(ii) losses from holdings of sovereign bonds (trading and banking book) reduce assets.

Example: Assets decline

- Equity declines (how much it declines depends on how distressed bank is), and
- Expected losses to bank creditors go up, credit spreads on bank debt increase funding costs; Lower global risk appetite also increases funding costs.

(See Annex slides for more detail)
Equity Value

- \( \text{Equity} = \max(A - B, 0) \)

- **Equity Volatility Smile Skew**

Risky Debt = Default Barrier minus Expected Loss

- \( \text{Expected Loss} = \max(B - A, 0) \)

- **Credit spread (CDS)**
- **Default Probability**

Build up loss distribution from bottom up from exposures
Relationships between Risk Models for Individual Institutions Using Accounting and Market Information

- **Accounting Balance Sheet**
  - Traditional Balance Sheet Indicators
- **Market Equity-based**
  - Equity prices
  - Equity option implied volatility and skew
- **Market Debt-based**
  - CDS or Bond implied Probability of Default (PoD)
- **Contingent Claims Analysis (CCA)**
  - Advanced CCA & Govt contingent liabilities
- **Distress Insurance Premium**

- **CDS or Bond implied PoD**
One Way to Calibrate (Unobservable) Bank Asset Value and Asset Volatility

**INPUTS**

- Value and Volatility of Market Capitalization, E
- Debt Distress Barrier B (from Book Value)
- Time Horizon

**USING TWO EQUATIONS WITH TWO UNKNOWNS**

Gives:

- Implied Asset Value
- Asset Volatility $\sigma_A$

**OUTPUTS:**

- Total Expected Losses to Bank Creditors
- Credit spread (CCA implied spread)
- Default Probabilities

CCA can be calibrated without market information as well
Illustration of Change in a Bank’s Implied Asset Distribution going from Pre-crisis, to Moderate Distress, to Crisis

- Calm or Exuberant
- Moderate distress
- Crisis

Distress barrier
Risk Transfer: Estimating the Market Implied Government Contingent Liabilities to Banks

During the crisis, CCA Implied Bank CDS spreads were frequently much higher than observed CDS spreads.

**Government liability guarantees depressed bank CDS spreads**

**Government contingent liability = \( \alpha \) *Implicit put option derived from CCA model**

**Value of bank risky debt =  Default-free debt – (1 - \( \alpha \)) * Implicit put option from CCA model**

\[ \alpha = 1 - \frac{\text{Value of put option from CDS}}{\text{Value of put option from equity}} \]

During Crisis in US and Europe, \( \alpha = 0.5 \) to 0.85,

i.e. Market Implied Government Contingent Liabilities were 50% to 80% of the Banks’ Expected Losses!
Example: CCA Implied Bank Credit Spreads Higher than Observed Bank CDS Spreads
Non-linear Relationships: Citi Example 9/08 to 3/09; Mkt Cap fell from $125bn to $6bn, EDF 25%, Bank EL $500 bn but Cont Liab $220 bn
Example - Banco Comercial Example – Portugal Fair Value (equity mkt based) CDS vs Observed CDS

Clear impact of government guarantees 2008/09 but Spillover from sovereign to bank in 2011
An adverse feedback loop ties sovereigns stresses to banking sector challenges

**DOMESTIC**
- **SOVEREIGN**
  - E. Similar sovereigns come under pressure
  - B. Increase in bank funding costs
  - C. Erosion in potential for official support
  - A. Mark-to-market fall in value of govt bonds held by local banks
  - I. Increase in contingent liabilities of govt.

**FOREIGN**
- **SOVEREIGN**
  - D. Mark-to-market fall in value of govt bonds held by foreign banks
  - F. Contagion channels (A, B, & C as above)
  - G. Rise in counter-party credit risk
  - H. Withdrawal of funding for risky banks

**BANKS**
Example Transfer of Risk: Ireland CDS spreads of banks declined following guarantees in 4Q 2008 and sovereign spreads increased.

Source: Bloomberg L.P.
Example Transfer of Risk: Higher Contingent Liabilities Can Increase Sovereign Risk

_Austria Example:_ contingent liabilities are strongly correlated with sovereign default probability (inferred from sovereign CDS spreads)
Expected losses for banking systems in selected countries, % of GDP, IRELAND was Highest
Sovereign-Banking Sector Spillovers

Sovereign CDS < Bank CCA implied spread

Sovereign spreads spill over to increase bank spreads by $\delta$

$$s_{Bank} = -\frac{1}{T} \ln(1 - \frac{(1 - \alpha)P_{Equity, bank}}{B_{Bank} e^{-rT}}) + \delta$$

Sovereign CDS > Bank CCA implied spread
Applying CCA to the Sovereign

Use *term structure of sovereign CDS spreads* and an estimate of *sovereign debt default default barrier* to estimate implied sovereign assets and implied asset volatility that is consistent with the whole term structure of CDS (see IMF GFSR Oct 2010 Box 1.2 Annex 1.2 & RISK book chapter)

**Graph:**

- **Ordinate:** CDS (bps)
- **Abscissa:** Years forward (in term structure)

**Legend:**
- Blue line: 12/1/2009
- Red line: 5/8/2011
- Green line: 12/31/2010
- Purple line: 8/21/2011

**Equation:**

\[
\text{Sovereign assets} = \text{Present Value of Primary Fiscal Surplus} + \text{Other Assets} - \text{Cont Liabilities to Banks}
\]
Using sovereign CDS spreads and estimated debt default barrier the calibration results are: Implied sovereign asset equal to 1006 billion SEK, broken down into: (i) FX reserves equal to 256 bn SEK ($37.9 bn, end 2010), (ii) PV of the primary fiscal surplus of 457 bn SEK, 2011 to 2016, (iii) implicit contingent liabilities to the financial sector of -75 billion SEK, and, (iv) other assets of 351 billion SEK.

**Sovereign CCA balance sheet and bank example joint stress test:**

<table>
<thead>
<tr>
<th>Historical</th>
<th>Banking System Expected Losses (Sum)</th>
<th>Sovereign Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Billion SEK</td>
<td>Five year, in basis points</td>
</tr>
<tr>
<td>Pre-Crisis</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>2008</td>
<td>60</td>
<td>145</td>
</tr>
<tr>
<td>2009</td>
<td>190</td>
<td>130</td>
</tr>
<tr>
<td>Pre-Crisis</td>
<td>89</td>
<td>30</td>
</tr>
<tr>
<td>end 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projections</td>
<td>Baseline Scenario</td>
<td>Adverse Scenario</td>
</tr>
<tr>
<td>end 2011</td>
<td>85</td>
<td>180</td>
</tr>
<tr>
<td>end 2012</td>
<td>83</td>
<td>150</td>
</tr>
<tr>
<td>end 2013</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>end 2014</td>
<td>77</td>
<td>98</td>
</tr>
</tbody>
</table>

Systemic Risk Models for Multiple Entities

**Accounting Balance Sheet**
- Aggregate FSIs

**Market Debt-based** (CDS & bond spreads)
- CDS/Spread implied JPoD
- CDS CoRisk

**Systemic CCA**
- CDS - Joint Probability of Distress (JPoD)
- CDS/Spread implied JPoD

**Equity-based**
- Equity Joint Tail Risk (from returns or from option derived higher moments: SES, MES)
- Equity option implied joint risk

**Market**
- CoVaR

**Network**
- Interbank Exposures
- Lo–Getmansky model

**CCA Joint Risk**
- Merton-type CCA Joint Risk

**Systemic Distress Insurance Premium**

**Network Interbank Exposures**
- Merton-based Network
Systemic CCA Results for European Country Banking Systems: Expected Losses in Billion Euros (1/07 to 6/10)

**Median, i.e. 50\textsuperscript{th} percentile, peak 300bn Euros**

**Tail Risk, i.e. 95\textsuperscript{th} percentile, peak 720bn Euros**

One year horizon, forward-looking estimates
First, historical sensitivity of the bank median expected losses to macro variables was estimated (real GDP growth and unemployment rate). Second, for each country banking sector the baseline/stress scenario of median expected losses are projected based on their historical sensitivity derived from a dynamic factor model. Stress scenario projections based on annual decrease of 1.5 percentage points GDP growth and increase in unemployment 1.5 and 1.0 percentage points respectively. (A Jobst; see Gray, Jobst 2010)
Results of the US FSAP Systemic CCA Stress Test—Baseline and Adverse Scenarios

Systemic CCA of Financial Sector -
Average Systemic Risk from Expected Losses and Contingent Liabilities
(In billion US dollars unless indicated otherwise)

<table>
<thead>
<tr>
<th>Forecasting Period, 2010 Q1 - 2014 Q4</th>
<th>50th percentile</th>
<th>VaR (95%)</th>
<th>ES (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline Scenario</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market-Implied Contingent Liabilities</td>
<td>31</td>
<td>92</td>
<td>180</td>
</tr>
<tr>
<td>Market-Implied Expected Losses</td>
<td>75</td>
<td>219</td>
<td>429</td>
</tr>
<tr>
<td><strong>Adverse Scenario</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market-Implied Contingent Liabilities</td>
<td>41</td>
<td>130</td>
<td>382</td>
</tr>
<tr>
<td>Market-Implied Expected Losses</td>
<td>97</td>
<td>308</td>
<td>910</td>
</tr>
</tbody>
</table>

First, the historical sensitivity of the bank expected losses to macro variables was estimated (nominal and real GDP growth, real consumption, output gap, unemployment rate, housing prices, 3 month LIBOR-treasury rate spread). Second, for each bank the baseline/adverse scenarios of implicit expected losses are extrapolated based on their joint historical sensitivity derived from a dynamic factor model. See Annex slides and US FSAP Stress Testing Tech Note 2010.
Liquidity ratios are usually accounting ratios, which by their nature are not measures of liquidity risk exposures over a horizon period;

However, it is possible to construct a short-term liquidity CCA balance sheet which is embedded in the longer term CCA solvency balance sheet ---- this is a joint liquidity risk and solvency risk-adjusted bank balance sheet;

A promising line of investigation is to construct new liquidity risk measures integrated with solvency. One approach (published in IMF GFSR spring 2011) is to estimate the market-implied expected loss associated with the liquidity position defined by a revised NSFR measure modeled as an implicit (liquidity) put option.

See Annex slide for more details
Summary

CCA risk-adjusted balance are very useful in modeling financial system, corporate, and sovereign risk and risk spillovers between sectors and economies.

CCA bank models can be used to complement traditional stress testing and incorporate sovereign and global risks giving new indicators of funding cost and capital.

Systemic Risk Models (Systemic CCA) can be used to calculate median and tail-risk losses for banking system, implied contingent liabilities, joint sovereign & banking tail-risk.
Stress testing banking system and sovereigns together using CCA models captures risk transmission from banks to sovereigns via bank holdings of sovereign debt, via explicit and implicit guarantees, and risk transmission from sovereign to banks and spillovers from sovereign spreads into bank borrowing costs. New research using CCA bank and sovereign models with GVAR models.

Stress-testing sovereigns and banks can help identify potential destabilization spirals.

More work is needed on the relationship of loss distributions and ‘capital adequacy’ between traditional balance sheet ST, CCA implied loss distributions (affected by risk appetite and government guarantees) and joint bank and sovereign loss distributions within and between countries.
Thank you. For more information see:

- **Book:** *Macrofinancial Risk Analysis*, Gray and Malone *(Wiley Finance book Foreword by Robert Merton)*


- *IMF, USFSAP Stress Testing Note, July 2010; GFSR 2010 Oct and 2011 April; Sweden Stress Testing Note Using CCA, 2011, UK FSAP and Germany FSAP ST Notes*

- **Papers** by D. Gray, Robert C. Merton, Zvi Bodie:
  - *HBS WP 09/015 August 2008*


Annex - Essence of Interrelationships Between Assets, Equity, Bank Spreads, Expected Losses, Global Risk Appetite, and Guarantees

Bank assets equal market value of equity plus default-free value of debt (i.e. default barrier present value) minus expected losses to bank creditors.

\[ A = E + D = E + \bar{B} - EL \]

A change in A leads to change in E, and change in EL.

The expected losses are a function of assets, volatility of assets, default barrier, and time:

\[ EL = f(A, \text{volatility of } A, \bar{B}, t) \]

Using the CCA formulas EL can be rewritten as the risk-neutral default probability, RNDP, times the loss given default (LGD associated with the RNDP) and the default barrier present value:

\[ EL = RNDP \times LGD_{RNDP} \times \bar{B} \]
The credit spread is a function of time, EL, B or equivalently time, RNDP, LGD:

\[
\text{credit spread} = -\frac{1}{T} \ln(1 - \frac{EL}{B}) = -\frac{1}{T} \ln(1 - RNDP \times LGD_{RNDP})
\]

Note how the RNDP incorporates a global or regional risk appetite factor (called the market price of risk), if the risk appetite factor increases, spreads increase.

\[RNDP = f(PD, \text{Risk appetite factor})\]

This risk appetite as been measured and can be used to quantitatively estimate impacts on credit spreads and thus funding costs.

\[
\text{credit spread after govt guarantee} = -\frac{1}{T} \ln(1 - \frac{(1-\alpha)EL}{B}) = -\frac{1}{T} \ln(1 - RNDP \times (1-\alpha)LGD_{RNDP})
\]
Annex – Illustrative Values for Calm, Crisis and Crisis with Implicit or Explicit Guarantees

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Calm Period</th>
<th>Crisis Period (no guarantees)</th>
<th>Crisis Period (including guarantees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Value</td>
<td>Bn Euros</td>
<td>1000</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Market Capitalization</td>
<td>Bn Euros</td>
<td>145</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Default Barrier (PV)</td>
<td>Bn Euros</td>
<td>860</td>
<td>860</td>
<td>860</td>
</tr>
<tr>
<td>Expected Losses</td>
<td>Bn Euros</td>
<td>5</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Credit Spread (w/o guarantee)</td>
<td>Basis points (5 yr horizon)</td>
<td>20</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>RNDP</td>
<td>Percent, 1 yr</td>
<td>1.8</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>PD</td>
<td>Percent, 1 yr</td>
<td>0.04</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Risk Appetite Factor</td>
<td>Excess return per unit volatility</td>
<td>0.36</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Alpha (share of EL born by govt)</td>
<td>Fraction</td>
<td>0</td>
<td>0</td>
<td>0.75</td>
</tr>
<tr>
<td>Bank Credit Spread after Govt Guarantee</td>
<td>Basis points (5 yr horizon)</td>
<td>20</td>
<td>500</td>
<td>220</td>
</tr>
<tr>
<td>Government Contingent Liability</td>
<td>Bn Euros</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>
Severe shock to GDP in periods 1 to 3 reduces bank assets and sovereign assets, bank assets decline from reduced value of sovereign debt, government contingent liabilities increase, sovereign spreads increase and spill over into bank spreads, destructive feedback process. Value of sovereign guarantee falls in period 5.
Annex - Applying CCA to the Sovereign

Sovereign spreads are related to the sovereign implicit put option ($P_{Sov}$) and sovereign default barrier ($B_{Sov}$) via the following relationship.

$$S_{Sov} = -\frac{1}{T} \ln\left(1 - \frac{P_{Sov}}{B_{Sov} e^{-rT}}\right)$$

Implicit Put Option Calculations for Hypothetical Examples: Non-Distressed and Distressed Sovereigns

<table>
<thead>
<tr>
<th>Horizon Year</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sovereign Not in Distress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sovereign spread (bps)</td>
<td>37</td>
<td>70</td>
<td>71</td>
<td>67</td>
<td>61</td>
</tr>
<tr>
<td>Implicit Put Option Value (bn Euros)</td>
<td>0.4</td>
<td>2.0</td>
<td>3.2</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>Sovereign in Distress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sovereign spread (bps)</td>
<td>829</td>
<td>612</td>
<td>511</td>
<td>450</td>
<td>391</td>
</tr>
<tr>
<td>Implicit Put Option Value (bn Euros)</td>
<td>7.8</td>
<td>15.8</td>
<td>20.4</td>
<td>23.5</td>
<td>26.5</td>
</tr>
</tbody>
</table>

Default barrier assumed to be 100 bn $ in this example.