Pricing of Collateralized Derivatives *

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Introduction : Outstanding Issues

- **Wide and Volatile Basis Spreads:**
  - Libor-OIS, Cross Currency basis, 3m/6m basis etc...
- **Pricing consistent with CSA (Credit Support Annex):**
  - Take into cash flow arising from the collateral account.
  - Collateral Asset, particularly, the choice of collateral currency.
- **New Regulations**
  - CVA/DVA, LCR, mandatory clearing at CCP, stricter collateral control in OTC.
- **Forthcoming ISDA CSA (SCSA)**
  - Daily electric margin call with MTA=Threshold=0.
  - USD collateralization for non-G5
- **New Financial Services**
  - Collateral transformation to allow clients to access CCPs.

All these developments require clear understanding of counter party risk and cost of collateralization.
Market Data: LIBOR-OIS Spread (3m)
Market Data: Cross Currency Basis Spread (1yr)
Market Data: CCS Term Structure
Market Development

What is going on?

- **Loss of Price-Transparency:**
  - Counter-party Credit Risk
  - Collateralization

- **New market benchmark price is appearing:**
  - Collateralized Deals
    - Moving to CSA-consistent pricing
  - Un-collateralized Deals
    - Credit Value Adjustment (CVA/DVA)
Survey by KPMG

New valuation and pricing approaches for derivatives in the wake of the financial crisis

Moving towards a new market standard?
October 2011

kpmg.com
Survey by KPMG (collateralized deals)

Survey result – When do you plan to go live with your CSA discounting methodology?

**Major international banks**

<table>
<thead>
<tr>
<th>Year</th>
<th>Pricing</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>All eight banks have implemented the pricing</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
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</table>

**Medium sized banks**

<table>
<thead>
<tr>
<th>Year</th>
<th>Pricing</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Seven banks have already implemented the pricing (two of them implemented it only for IR business), the remaining are further behind in the implementation (2012-2014)</td>
<td></td>
</tr>
<tr>
<td>2011</td>
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<tr>
<td>2012</td>
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</tr>
</tbody>
</table>
Survey by KPMG (collateralized deals)

Survey results – For which asset classes are you using/planning to use CSA discounting?

Valuation: Major international banks

- Vanilla products:
  - Implemented: 5
  - Planned: 1
- Credit derivatives:
  - Implemented: 1
  - Planned: 4
- Equity derivatives:
  - Implemented: 4
  - Planned: 1
- Interest rate derivatives:
  - Implemented: 5
  - Planned: 2
- FX derivatives:
  - Implemented: 3
  - Planned: 4
- Energy / Commodities / Developing Products:
  - Implemented: 2
  - Planned: 6
Survey by KPMG (collateralized deals)

Valuation: Medium sized banks

Vanilla products
- Credit derivatives: 9
- Equity derivatives: 8
- Interest rate derivatives: 8
- FX derivatives: 6
- Energy / Commodities / Developing Products: 6

Exotic products
- Credit derivatives: 9
- Equity derivatives: 8
- Interest rate derivatives: 10
- FX derivatives: 7
- Energy / Commodities / Developing Products: 6
Survey by KPMG (collateralized deals)

Figure 4
Survey Result – Do you (plan to) consider the currency of the respective collateral posted when building the discount curve?

Major international banks
Survey by KPMG (collateralized deals)
Survey by KMPG (un-collateralized deals)

Figure 5
Survey Result – Do you use/plan to use a CVA/DVA approach in pricing uncollateralized derivatives?

Major international banks

<table>
<thead>
<tr>
<th></th>
<th>Implemented</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVA/DVA</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>CVA only</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
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Medium sized banks

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Motivation of This Talk

Our Goal

- Explain the Current Market Issues and Developments *(done)*.
- Explain CSA-consistent pricing and CVA
  - Pricing under Perfect Collateralization
  - Effect of Collateral Currency Choice
  - Embedded Cheapest-to-Deliver Option in CSA
  - Imperfect Collateralization and Bilateral CVA
  
under the unified framework.
Setup

- Probability space \((\Omega, \mathcal{F}, \mathbb{F}, Q)\), where \(\mathbb{F}\) contains all the market information including defaults.
- Consider two firms, \(i \in \{1, 2\}\), whose default time is \(\tau^i \in [0, \infty]\), and \(\tau = \tau^1 \wedge \tau^2\).
- \(\tau^i\) (and hence \(\tau\)) is assumed to be totally-inaccessible \(\mathbb{F}\)-stopping time.
- Indicator functions: \(H^i_t = 1_{\{\tau^i \leq t\}}\), \(H_t = 1_{\{\tau \leq t\}}\)
- Assume the existence of absolutely continuous compensator for \(H^i\):
  \[
  A^i_t = \int_0^t h^i_s 1_{\{\tau^i > s\}} ds, \quad t \geq 0
  \]
- Assume no simultaneous default, and hence the hazard rate of \(H\) is
  \[
  h_t = h^1_t + h^2_t.
  \]
- Money market account: \(\beta_t = \exp \left( \int_0^t r_u du \right)\)
Collateralization

When party $i \in \{1, 2\}$ has negative mark-to-market, it has to post collateral (cash) to party $j (\neq i)$, and it is assumed to be done continuously.

- collateral coverage ratio is $\delta_t^i \in \mathbb{R}_+$, and the value of collateral at time $t$ is given by $\delta_t^i (-V_t^i)$.
  - $\delta_t^i$ effectively takes into account under- as well as over-collateralization. Thus $\delta_t^i < 1$, and also $\delta_t^i > 1$ are possible.

- party $j$ has to pay the collateral rate $c_t^i$ on the posted cash continuously.

- $c_t^i$ is determined by the currency posted by party $i$.
  - In general, $c_t^i \neq r_t^i$, which is the risk-free interest rate of the same currency. This is necessary to explain CCS swap market consistently.
Counterparty Exposure and Recovery Scheme

- **Counterparty exposure to party** $j$ **at time** $t$
  (from the view point of party $i$)

  \[
  \max(1 - \delta_t^j, 0) \max(V_t^i, 0) + \max(\delta_t^i - 1, 0) \max(-V_t^i, 0)
  \]

- **Assume party-** $j$’s recovery rate at time $t$ as $R_t^j \in [0, 1]$

- **Recovery value at the time of** $j$’s default:

  \[
  R_t^j \left( [1 - \delta_t^j]^+[V_t^i]^+ + [\delta_t^i - 1]^+[-V_t^i]^+ \right)
  \]
Pricing Formula

• Pricing from the viewpoint of party 1.

\[
S_t = \beta_tE^Q \left[ \int_{t,T} \beta_u^{-1}1_{\{\tau > u\}} \left\{ dD_u + (y_u^1\delta_u^11_{S_u<0} + y_u^2\delta_u^21_{S_u\geq0}) S_u du \right\} \right. \\
\left. + \int_{t,T} \beta_u^{-1}1_{\{\tau \geq u\}} \left( Z^1(u, S_u-)dH^1_u + Z^2(u, S_u-)dH^2_u \right) \mid \mathcal{F}_t \right]
\]

• \( D \): cumulative dividend to party 1.

• \( y_t^i = r_t^i - c_t^i, \ (i \in \{1, 2\}) \) denotes the instantaneous return at time \( t \) from the cash collateral posted by party \( i \), or stochastic dividend yield.

• Default payoff:

\[
Z^1(t, v) = \left( 1 - (1 - R_t^1)(1 - \delta_t^1)^+ \right)1_{v<0} + \left( 1 + (1 - R_t^1)(\delta_t^2 - 1)^+ \right)1_{v\geq0}
\]

\[
Z^2(t, v) = \left( 1 - (1 - R_t^2)(1 - \delta_t^2)^+ \right)1_{v\geq0} + \left( 1 + (1 - R_t^2)(\delta_t^1 - 1)^+ \right)1_{v<0}
\]
Pricing Formula

Pre-default value of the contract $V_t 1_{\{\tau > t\}} = S_t$ is given by

$$V_t = E^Q \left[ \int_{[t,T]} \exp \left( - \int_t^s (r_u - \mu(u, V_u)) \right) dD_s \mid F_t \right], \quad t \leq T$$

where

$$\mu(t, v) = \tilde{y}_t^1 1_{\{v < 0\}} + \tilde{y}_t^2 1_{\{v \geq 0\}}$$

$$\tilde{y}_t^i = \delta_t^i y_t^i - (1 - R_t^i) (1 - \delta_t^i)^+ h_t^i + (1 - R_t^j) (\delta_t^i - 1)^+ h_t^j$$

- Duffie & Huang (1996) derives under some technical conditions.
- More precisely, the measure is different from the usual money-market measure, but rather "survival measure" introduced by Schönbucher (2000) and Collin-Dufresne et.al. (2004).
- It has an important meaning when dealing with the credit derivatives, such as CDS (Fujii & Takahashi, 2011).
- In this talk, we focus on the usual fixed income derivatives, and do not go into details about this.
Symmetric Case

Effective discount factor is non-linear

\[ r_t - \mu(t, v) = r_t - (\tilde{y}^1_t 1_{v<0} + \tilde{y}^2_t 1_{v \geq 0}) \]

which makes the portfolio value non-additive.

If \( \tilde{y}^1_t = \tilde{y}^2_t = \tilde{y}_t \), then we have

\[ \mu(t, v) = \tilde{y}_t . \]

If \( \tilde{y} \) is not explicitly dependent on \( V \), we can recover the linearity.

\[ V_t = E^Q \left[ \int_{[t,T]} \exp \left( - \int_t^s (r_u - \tilde{y}_u) du \right) dD_s \bigg| F_t \right] \]

Portfolio valuation can be decomposed into that of each payment.

\[ A \]

A good characteristic for market benchmark price.
Generic Situations

- If $\bar{y}^1 \neq \bar{y}^2$,

\[
V_t = E^Q \left[ \int_t^T \exp \left( -\int_t^s (r_u - \mu(u, V_u)) \right) dD_s \mid \mathcal{F}_t \right]
\]

\[
\mu(t, v) = \bar{y}^1_t 1_{v<0} + \bar{y}^2_t 1_{v\geq0}
\]

\[
\bar{y}^i_t = \delta^i_t y^i_t - (1 - R^i_t)(1 - \delta^i_t)^+ h^i_t + (1 - R^j_t)(\delta^i_t - 1)^+ h^j_t
\]

$V$ and the other processes form a system of non-linear FBSDE.

Marginal Impact of asymmetry:

- Make use of Gateaux derivative as the first-order Approximation:

\[
\limsup_{\epsilon \downarrow 0} \sup_t \left| \nabla V_t(\tilde{\eta}; \eta) - \frac{V_t(\tilde{\eta} + \epsilon \eta) - V_t(\tilde{\eta})}{\epsilon} \right| = 0
\]

$\eta$ and $\tilde{\eta}$ are bounded and predictable.
Marginal Impact of Asymmetry

- We want to expand the price around symmetric benchmark price.

\[
\mu(t, v) = \tilde{y}_t^1 1_{\{v < 0\}} + \tilde{y}_t^2 1_{\{v \geq 0\}} \\
= y_t + \Delta \tilde{y}_t^1 1_{\{v < 0\}} + \Delta \tilde{y}_t^2 1_{\{v \geq 0\}}
\]

\[
\Delta \tilde{y}_t^i = \tilde{y}_t^i - y_t
\]

- Calculate GD at symmetric \( \mu = y \) point.

\[
V_t(\mu) \simeq V_t(y) + \nabla V_t(y, \mu - y)
\]
Generic Situations

- Applying Gateaux Derivative at μ = y point:

\[ V_t = E^Q \left[ \int_{t,T} \exp \left( - \int_t^s (r_u - \mu(u, V_u)) \, du \right) dD_s \bigg| \mathcal{F}_t \right], \quad t \leq T \]

is decomposed as \( V_t \simeq \overline{V}_t + \nabla V_t \), where

\[
\overline{V}_t = E^Q \left[ \int_{t,T} \exp \left( - \int_t^s (r_u - y_u) \, du \right) dD_s \bigg| \mathcal{F}_t \right]
\]

\[
\nabla V_t = E^Q \left[ \int_t^T e^{-\int_t^s (r_u - y_u) \, du} \overline{V}_s \left( \Delta \tilde{y}_s^1 1_{\{\overline{V}_s < 0\}} + \Delta \tilde{y}_s^2 1_{\{\overline{V}_s \geq 0\}} \right) \, ds \bigg| \mathcal{F}_t \right]
\]

If \( y \) is chosen in such a way that it reflects the funding cost of the standard collateral agreements, \( \overline{V} \) turns out to be the market benchmark price, and \( \nabla V \) represents the corrections (CVA, non-standard CSA, etc). For analytical approximation including higher order corrections for generic non-linear FBSDEs, see Fujii & Takahashi (2011).
Perfect Collateralization with a Domestic Currency

Special Cases

Case 1: Benchmark for single currency product

- bilateral perfect collateralization ($\delta^1 = \delta^2 = 1$)
- both parties use the same currency ($i$) as collateral, which is also the payment (evaluation) currency.

$$\mu(t, v) = y^{(i)} = r^{(i)} - c^{(i)}$$

$$V_t^{(i)} = E^{Q^{(i)}} \left[ \int_t^T \exp \left( - \int_t^s c_u^{(i)} du \right) dD_s \bigg| \mathcal{F}_t \right]$$

The valuation method for single currency swap adopted by LCH Swapclear (2010) is the same with this formula.
Perfect Collateralization with a Foreign Currency

Special Cases

Case 2: Collateral posted by a Foreign Currency
Particularly relevant for **non-G5 currencies allocated in USD-silo** in SCSA.

- bilateral perfect collateralization \((\delta^1 = \delta^2 = 1)\)
- both parties use the same currency \((k)\) as collateral, which is **different** from the payment (evaluation) currency \((i)\)
  \[
  r^{(i)} - \mu(t, \nu) = r^{(i)} - y^{(k)}
  \]

\[
V_t^{(i)} = E^{Q(i)} \left[ \int_{[t,T]} \exp \left( - \int_t^s \left( c_{u}^{(i)} + y_u^{(i,k)} \right) du \right) dD_s \bigg| \mathcal{F}_t \right]
\]

Funding Spread between the two currencies

\[
y^{(i,k)} = y^{(i)} - y^{(k)} = \left( r^{(i)} - c^{(i)} \right) - \left( r^{(k)} - c^{(k)} \right)
\]
Special Cases

Case 3: Multiple Eligible Collaterals

- bilateral perfect collateralization \( (\delta^1 = \delta^2 = 1) \)
- both parties choose the optimal currency from the eligible collateral set \( \mathcal{C} \). Currency \((i)\) is used as the evaluation currency.

\[
V_t^{(i)} = EQ^{(i)} \left[ \int_{[t,T]} \exp \left( - \int_t^s \left( c_u^{(i)} + \max_{k \in \mathcal{C}} [y_u^{(i,k)}] \right) du \right) dD_s \bigg| \mathcal{F}_t \right]
\]

- The party who posts collateral has the optionality of collateral choice.
- The cheapest collateral currency should be chosen based on CCS information.
Term Structure Modeling under Collateralization

Modeling of Collateral Rate: $c(t, s)$

- OIS collateralized with Domestic Currency:
  - Both of the reference and discounting rate is equal to collateral rate (O/N-rate).
  - Market OIS rates determine collateral rate term structure.

\[
dc(t, s) = \sigma_c(t, s) \cdot \left( \int_t^s \sigma_c(t, u) du \right) dt + \sigma_c(t, s) \cdot dW_t^Q
\]
Term Structure Modeling under Collateralization

Modeling of LIBOR-OIS Spread: $B(t; T, \tau)$

- IRS and TS (tenor swap, such as 3m/6m basis swap) collateralized with Domestic Currency:
  - Discounting is given by the collateral rate $c$.
  - Market IRS and TS rates determine the term structures of LIBOR-OIS spreads.

$$
\frac{dB(t, T; \tau)}{B(t, T; \tau)} = \sigma_B(t; T, \tau) \cdot \left( \int_t^T \sigma_c(t, s) ds \right) dt + \sigma_B(t; T, \tau) \cdot dW_t^Q
$$
Currency Funding Spread $y^{(i,j)}$

- Cross Currency Swap (USD vs JPY, EUR, GBP, etc)
  - Collateralized by USD (to be standardized by SCSA).
  - USD leg: all the ingredients are already fixed by USD domestic IR market.
  - X leg: $c(X)$, LIBOR-OIS($X$) are already fixed by X domestic IR market. Only freedom to fix is $y^{\{X,USD\}}$.
  - Term structure of $y^{\{X,USD\}}$ is fixed by market quotes of CCS basis.

$$dy^{(i,j)}(t, s) = \sigma_{y^{(i,j)}}(t, s) \cdot \left( \int_t^s \sigma_{y^{(i,j)}}(t, u) du \right) dt + \sigma_{y^{(i,j)}}(t, s) \cdot dW_t^{Q^{(i)}}$$
Term Structure Modeling under Collateralization

Generic IR-FX Framework under the Perfect Collateralization

\[ dc^{(i)}(t, s) = \sigma_{c}^{(i)}(t, s) \cdot \left( \int_{t}^{s} \sigma_{c}^{(i)}(t, u) du \right) dt + \sigma_{c}^{(i)}(t, s) \cdot dW^{Q}_{t}^{(i)} \]

\[ dB^{(i)}(t, T; \tau) = \sigma_{B}^{(i)}(t; T, \tau) \cdot \left( \int_{t}^{T} \sigma_{c}^{(i)}(t, s) ds \right) dt + \sigma_{B}^{(i)}(t; T, \tau) \cdot dW^{Q}_{t}^{(i)} \]

\[ dy^{(i,j)}(t, s) = \sigma_{y}^{(i,j)}(t, s) \cdot \left( \int_{t}^{s} \sigma_{y}^{(i,j)}(t, u) du \right) dt + \sigma_{y}^{(i,j)}(t, s) \cdot dW^{Q}_{t}^{(i)} \]

\[ df_{x}^{(i,j)}(t) \bigg| f_{x}^{(i,j)}(t) = (c^{(i)}(t) - c^{(j)}(t) + y^{(i,j)}(t)) dt + \sigma_{x}^{(i,j)}(t) \cdot dW^{Q}_{t}^{(i)} \]

- SDEs for the other currencies are just given by the measure change.
- The above framework allows to take into account LIBOR-OIS basis, Tenor basis, and Cross Currency basis spreads.
CVA as the Deviation from the Perfect Collateralization

Assume the both parties use the same currency for simplicity, and hence $y^1 = y^2 = y$.

$$\mu(t, v) = y_t - \left\{ \left( (1 - \delta_t^1)y_t + (1 - R_t^1)(1 - \delta_t^1)^+h_t^1 - (1 - R_t^2)(\delta_t^1 - 1)^+h_t^2 \right) 1_{\{v < 0\}} + \left( (1 - \delta_t^2)y_t + (1 - R_t^2)(1 - \delta_t^2)^+h_t^2 - (1 - R_t^1)(\delta_t^2 - 1)^+h_t^1 \right) 1_{\{v \geq 0\}} \right\}$$

GD around $\mu = y$ decomposes the price into three parts:
- Symmetric perfectly collateralized benchmark price
- $(1 - \delta^i)y 1_{\{v \leq 0\}} \Rightarrow$ Collateral Cost Adjustment (CCA)
- Remaining $h$ dependent terms $\Rightarrow$ Credit Value Adjustment (CVA)

$$V_t \simeq \overline{V}_t + \nabla V_t$$
$$= \overline{V}_t + \text{CCA} + \text{CVA}$$
Imperfect Collateralization

Price adjustment of imperfectly collateralized contract

\[
V_t = E^Q \left[ \int_{[t,T]} \exp \left(-\int_t^s (r_u - y_u) du \right) dD_s \mid \mathcal{F}_t \right]
\]

CCA = \[E^Q \left[ \int_t^T e^{-\int_t^s (r_u - y_u) du} y_s \left( (1 - \delta_1^s) [-\bar{V}_s]^+ - (1 - \delta_2^s) [\bar{V}_s]^+ \right) ds \mid \mathcal{F}_t \right] \]

CVA = \[E^Q \left[ \int_t^T e^{-\int_t^s (r_u - y_u) du} (1 - R_1^s) h_1^s \left( (1 - \delta_1^s)^+ [-\bar{V}_s]^+ + (\delta_2^s - 1)^+ [\bar{V}_s]^+ \right) ds \mid \mathcal{F}_t \right] \]

- \[E^Q \left[ \int_t^T e^{-\int_t^s (r_u - y_u) du} (1 - R_2^s) h_2^s \left( (1 - \delta_2^s)^+ [\bar{V}_s]^+ + (\delta_1^s - 1)^+ [-\bar{V}_s]^+ \right) ds \mid \mathcal{F}_t \right] \]

\[V_t \simeq \bar{V}_t + CCA + CVA\]
Imperfect Collateralization

A simple case of Imperfect Collateralization.

- Both parties use currency \((j)\) as collateral.
- Evaluation (payment) currency is \((i)\).
- Assume common collateral coverage ratio \(\delta < 1\).
- Assume constant recovery ratio \(R^1\) and \(R^2\), respectively.

\[
\overline{V}_t = E^Q(i) \left[ \int_{[t,T]} \exp \left( -\int_t^s \left( c_u(i) + y_{u,j}(i,j) \right) du \right) \, dD_s \middle| \mathcal{F}_t \right]
\]

\[
\text{CCA} = -E^Q(i) \left[ \int_t^T e^{-\int_t^s \left( c_u(i) + y_{u,j}(i,j) \right) du} y_{s,j}(i) (1 - \delta_s) \overline{V}_s \, ds \middle| \mathcal{F}_t \right]
\]

\[
\text{CVA} = (1 - R^1) E^Q(i) \left[ \int_t^T e^{-\int_t^s \left( c_u(i) + y_{u,j}(i,j) \right) du} (1 - \delta_s) h^1_s[-\overline{V}_s]^+ \, ds \middle| \mathcal{F}_t \right]
\]

\[
- (1 - R^2) E^Q(i) \left[ \int_t^T e^{-\int_t^s \left( c_u(i) + y_{u,j}(i,j) \right) du} (1 - \delta_s) h^2_s[\overline{V}_s]^+ \, ds \middle| \mathcal{F}_t \right]
\]

Dependence among \(y, \delta\) and other factors, such as \(\overline{V}, h^i\) is particularly important. ⇒ New type of Wrong (Right)-way Risk.
Devaluation of Collateral

How to handle the situation where there exists significant risk of the **devaluation of collateral** at the time of counter party default?

- EUR posted by European banks as collateral
- JGB posted by Japanese mega-banks as collateral
- Domestic currency or government bond posted by the sovereign as collateral

Assume perfect collateralization for simplicity.

- CCA $\Rightarrow 0$.
- CVA $\Rightarrow$ interpret $\delta (< 1)$ as the fraction of devaluation.
- More general situations, one needs to introduce multiple $\delta$ processes.
We have explained:

- Current Market Issues
- CSA-consistent Benchmark Pricing
- Adjustments for remaining costs: CCA, CVA/DVA

Challenge for Japanese Financial Firms and Authorities

- Adopt the new standards as quickly as possible in order not to be arbitraged away by foreign firms and protect the interests of depositors.
- Improve the status of JPY as collateral.
- Deepen the discussion on CCPs and related topics, such as the accessibility from funds, local banks, and corporates and associated risk-management issues.


References II


