CDO models: Opening the black box – Part two

The Finite Homogenous Pool model

September 2008

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Structured credit research: Global

Dresdner Kleinwort

Putting the theory to work…

The Finite Homogeneous Pool model

- After having released the Large Homogenous Pool Model in the first part of our series, we now move towards the finite homogenous pool model
- This publication builds up on the first publication of this series (*CDO models: Opening the black box*) and has been structured as a guide to be used in conjunction with the excel-based Finite Homogenous Pool model. Whilst we do briefly touch upon the main theoretical concepts, we do not go into detailed explanations and proofs, as this has been widely discussed and is readily available. Instead, we focus on how to implement the theory and apply the models
- We start by taking a closer look at how the loss distribution is constructed for a finite pool of homogenous assets
- Afterwards we address some important factors that have to be considered when using the Gauss-Hermite integration technique in combination with the binomial distribution

Finite Homogeneous Pool Model:

https://research.dresdnerkleinwort.com/document/FILE.pdf?REF=244439

Just like tossing a coin..

The Binomial distribution is used to build up the default distribution

- The assumption of homogenous assets allows us to use the Binomial distribution to construct the default distribution
- The Binomial distribution is a discrete distribution used to model binary random variables (eg "tossing a coin")
- For a given number of trials *n*, the probability of *k* successful trials (observing exactly *k*=20 tails for *n*=40 coin tosses) is given by:

$$P(k) = \binom{n}{k} p^k (1-p)^{n-k}$$

- Where *p* denotes the likelihood to succeed in a given attempt (50% for a fair coin)
- Within the context of the finite homogenous pool model, we can therefore apply this distribution by parametrising
  - *n* = number of assets
  - *k* = number of defaults,
  - *p* = PD(t|m), the probability of default by time ***t*** conditional on the common factor ***m***

From conditional to unconditional defaults

The Binomial distribution is used to build up the default distribution

- As we assume homogeneity, the PDs are identical for all assets and as before are given by

$$PD\left(t \mid m\right) = \Phi\left(\frac{\text{Default Barrier }(t) - \sqrt{\rho}\, m}{\sqrt{1-\rho}}\right)$$

- Applying the Binomial distribution, the probability of observing excatly ***k*** defaults conditional on the realisation of a common factor ***m*** is therefore given by

$$\text{Prob}('k \textit{ defaults until } t' \mid m) = \binom{n}{k} PD(t \mid m)^k \left(1 - PD(t \mid m)\right)^{n-k}$$

- The unconditional default distribution until time ***t*** is then given by

$$\text{Prob}\left('up \ to \ k \ defaults \ \ by \ time \ t'\right) = \sum_{n=0}^{k} \binom{n}{k} \int_{-\infty}^{+\infty} \left(\Phi\left(\frac{\text{Default Barrier }(t) - \sqrt{\rho}\, m}{\sqrt{1-\rho}}\right)\right)^k \left(1 - \Phi\left(\frac{\text{Default Barrier }(t) - \sqrt{\rho}\, m}{\sqrt{1-\rho}}\right)\right)^{n-k} \phi(m)\, dm$$

- We integrate over the common factor to receive unconditional probabilities, for ***k*** defaults
- Then we sum over all defaults up to ***k*** (0,1,..,k-1,k) to calculate the cumulative default distribution until time ***t***

Our spreadsheet – sheet “integration”

Screenshot (1/5) (spread 100 bps, 40% rec., 20% correlation)

As we assume flat CDS spreads, for a given spread S and recovery R, the cumulative default probability is simply:

$$PD_t = 1-\exp\left(-\frac{S}{1-R}t\right) = 1-\exp(-\lambda t)$$

The default barrier K for time period 3 is calculated using the PD of the asset:

$$Default \;\; Barrier \;\; (t=3) = \Phi^{-1}(0.908\,\%)$$

Notation used for standard normal:

ϕ (x)=f(x)
Φ(x)=F(x)=P(X≤x)

Time Period (t) ==...	...-Sep-0...	20-Dec-08	20-...	...-Jun-09	…	20-Mar-13	20-Jun-13	20-Sep-13
Individual asset pd ===>	0.074%	0.494%	0.908%	1.329%	…	7.389%	7.782%	8.174%
norminv(pd) ===>	-3.178	-2.580	-2.362	-2.218		-1.447	-1.420	-1.393

1 2

Realisation of common factor and weights for each realisation. Integral calculated using P(M=m)=*f(m)**step size

$$P(m=-0.6039) = \phi(-0.6039)\cdot 0.4034 = 0.1341$$

Comm... ...or m	$w(x_k)e^{xk2}$ Weights	$f(x_k).w(x_k)e^{xk2}$ Integral
-6.8...	0.8342	0.0000
-6.138...	0.6491	0.0000
⋮		⋮
-0.6039	0.4034	0.1341
-0.2011	0.4023	0.1573
0.2011	0.4023	0.1573
0.6039	0.4034	0.1341

3

For	for(i = 0; i<Rows; i++)
No. of Assets in default	5
No. Rows	126
No. Columns	21

4

0.0000%	0.0000%	0.0000%	0.0000%	…	0.0000%	0.0000%	0.0000%
0.0000%	0.0000%	0.0000%	0.0000%		0.0000%	0.0000%	0.0000%
	⋮		⋮			⋮	
0.0000%	0.0050%	0.0826%	0.3672%		0.1650%	0.1076%	0.0690%
0.0000%	0.0004%	0.0098%	0.0640%	…	1.3773%	1.1138%	0.8832%
0.0000%	0.000...	...7%	0.0060%		2.7822%	2.6833%	2.5327%
0.0000%	...	...0%	0.0003%		1.7333%	1.9258%	2.0914%
Unconditional Prob of 5 Defaults 0...	...%	1.8731%	2.8867%		6.5129%	6.3985%	6.2715%

5 6

For each point of the default distribution, the matrix of conditional PDs is calculated. For 125 assets, this results in 126 iteration steps (0,1,2 ,…, 124, 125 defaults).

The screenshot shows the sixth iteration step, ie five defaults.

The probability of observing exactly 5 defaults up until 20/06/09 (t=3) in the portfolio, given market factor m=-0.6039:

$$PD(\#\,defaults_{\;t\le 3} = 5 \mid m=-0.6039) = B\left(n=125, k=5, p=\Phi\left(\frac{-2.362-\sqrt{\rho}\,(-0.6039)}{\sqrt{1-\rho}}\right)\right)\cdot P(m=-0.6039)$$

$$= B(n=125, k=5, p=0.0097)\cdot 0.1341 = 0.0826\,\%$$

The unconditional probability for exactly five defaults up until 20/09/13 (t=21) is then simply the sum over the corresponding conditional probabilities:

$$0.0000\,\% + 0.0000\,\% + \ldots + 2.5327\,\% + 2.0914\,\% = 6.2715\,\%$$

Building the loss distribution – sheet “integration”

Screenshot (2/5) (spread 100 bps, 40% rec., 20% correlation)

Expected portfolio default rate until 20 Mar 09:

$$E[PD(t)] = 0.0\% \cdot 0.5451 + 0.8\% \cdot 0.2132 + \ldots + 99.2\% \cdot 0.0000 + 100.0\% \cdot 0.0000 = 0.908\%$$

For each iteration step, the macro copies the unconditional probabilities of default to the matrix below.

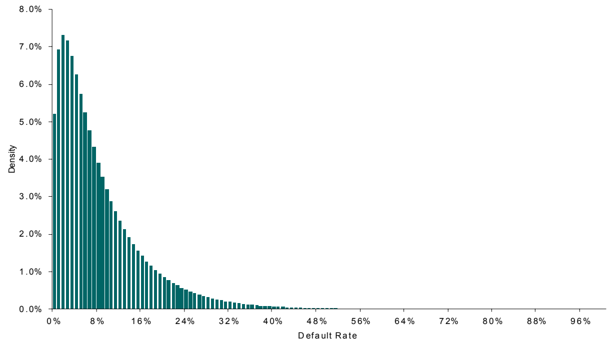
Once completed, the portfolio’s expected default rate as well as the default distribution can be obtained easily

Time Period (t) ===>		20-Se	08	20-Mar-09	20-Jun-09	…	20-Mar-13	20-Jun-13	20-Sep-13
Unconditional Prob of 5 Defaults		0.0323%	0.829	1.87	2.8867%		6.5129%	6.3985%	6.2715%
E[PD(t)]===>		0.074%	0.494%	0.908%	1.329%	…	7.389%	7.782%	8.174%
Check		0.000%	0.000%	0.000%	0.000%		0.000%	0.000%	0.000%
Port Default Rate %	No. of Assets in default	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000
0.0%	0	0.9274	0.6858	0.5451	0.4451		0.0636	0.0575	0.0521
0.8%	1	0.0592	0.1809	0.2132	0.2198		0.0804	0.0746	0.0693
1.6%	2	0.0095	0.0664	0.0996	0.1189	…	0.0819	0.0774	0.0732
2.4%	3	0.0024	0.0297	0.0528	0.0701		0.0778	0.0747	0.0716
3.2%	4	0.0008	0.0151	0.0305	0.0440		0.0717	0.0697	0.0676
4.0%	5	0.0003	0.0083	0.0187	0.0289		0.0651	0.0640	0.0627
⋮	⋮			⋮				⋮	
98.4%	123	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
99.2%	124	0.0000	0.0000	0.0000	0.0000	…	0.0000	0.0000	0.0000
100.0%	125	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000

1 2 3 4

The ***k***th point of the portfolio’s unconditional default rate distribution until 20 Mar 2013 is calculated by summing over all defaults up to *k* (0,1,..,k-1,k)

The portfolio’s default rate distribution at maturity is displayed in the sheet “pricing”



Loss and recovery waterfalls – sheet "pricing"

Screenshot (3/5) (spread 100 bps, 40% rec., 20% correlation)

Portfolio loss for one default (40% Recovery):

$$= \text{Fraction of Portfolio in Default} \cdot (1 - \text{Recovery Rate}) = 0.8\% \cdot (1-40\%) = 0.48\%$$

Portfolio recovery for one default (40% Recovery):

$$= \text{Fraction of Portfolio in Default} \cdot \text{Recovery Rate} = 0.8\% \cdot 40\% \cdot = 0.32\%$$

Port: Defaults =>Loss | **…: Loss waterfall**

Number of Defaults	Portfolio Default Rate	Portfolio Los… Rate	0% 3%	3% 6%	6% 9%	9% 12%	12% 22%	22% 100%
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.8% (1)	0.5% (2)	16.0%	0.0%	0.0%	0.0%	0.0%	0.0%
⋮	⋮					⋮	(4)	
124	99.2%	59.5%	100.0%	100.0%	100.0%	100.0%	100.0%	48.1%
125	100.0%	60.0%	100.0%	100.0%	100.0%	100.0%	100.0%	48.7%

…

Port: Re… …che: Recovery waterfall

Portfoli… Recovery …te	0% 3%	3% 6%	6% 9%	9% 12%	12% 22%	22% 100%
0.0%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.3% (3)	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%
⋮				⋮	(5)	
39.7%	0.00%	0.00%	0.00%	0.00%	0.00%	50.87%
40.0%	0.00%	0.00%	0.00%	0.00%	0.00%	51.28%

For 125 assets with same notional, 1 default equals 0.8% of the portfolio

For 40% RR, 124 defaults (equal to a portfolio default rate of 99.2%) result in a Portfolio loss rate of 59.52%. The 22% -100% tranche therefore experiences a loss of 48.1% of its notional:

$$\frac{\{\text{Min}\,[\text{Max}\,(0;\ \text{Portfolio Loss Rate - Attachment Point});\ \text{Tranche Width}]\}}{\text{Tranche Width}}$$

$$= \frac{\{Min\,[Max\,(0;\ 59.52\%\text{- }22\%);78\%]\}}{78\%}$$

$$= \frac{37.52\%}{78\%} = 48.10\%$$

For 40% RR, 124 defaults (equal to a portfolio default rate of 99.2%) result in a Portfolio loss rate of 59.52%. The 22% -100% tranche therefore recovers 50.87% of its notional:

$$\frac{\{\text{Min}\,[\text{Max}\,(0;\ \text{Portfolio Recovery Rate - }(1\text{ - Detachment Point}));\ \text{Tranche Width}]\}}{\text{Tranche Width}}$$

$$= \frac{\{Min\,[Max\,(0;\ 39.68\%\text{- }(1-100\%));78\%]\}}{78\%}$$

$$= \frac{39.68\%}{78\%} = 50.87\%$$

Tranche pricing

From conditional to unconditional tranche loss and recovery

- The way the calculation of the tranche losses and recoveries is implemented differs slightly from the previously published LHP models
- We now directly multiply the tranche's principal loss for a given number of defaults (ie a specific point of the loss distribution) with the corresponding unconditional probability of observing precisely this event
- The cumulative loss is therefore calculated by multiplying the default probability matrix (shown on slide 5 in pink) with the tranche's principal loss (shown on slide 6)
- The cumulative recoveries are obtained analogously. The default probability matrix is now multiplied with the tranche's recovered amount (shown on slide 6)

Screenshot (4/5) (spread 100 bps, 40% rec., 20% correlation)

Unconditional cumulative loss by time *t*=
*'Uncond Prob of exactly n defaults by time t ' * 'Tranche principal loss by time t given n defaults'*

Unconditional cumulative recovery by time *t*=
*'Uncond. Prob. of exactly n defaults by time t' * 'Tranche principal loss by time t given n defaults'*

Model outputs for specific tranches

Time period	Equity: Notional (End Period)	Equity: Marg. Loss	Equity: Marg. Recoveries	Equity: Cum. Recoveries	Equity: Cum. Loss (1)
1	98.52%	1.48%	0.00%	0.00%	1.48%
2	90.56%	7.96%	0.00%	0.00%	9.44%
…	…	…	…	…	…
20	25.19%	1.66%	0.00%	0.00%	74.81%
21	23.65%	1.54% (3)	0.00%	0.00%	76.35%

Time period	Super Senior: Notional (End Period)	Super Senior: Marg. Loss	Super Senior: Marg. Recoveries	Super Senior: Cum. Recoveries (2)	Super Senior: Cum. Loss
1	99.96%	0.00%	0.04%	0.04%	0.00%
2	99.75%	0.00%	0.22%	0.25%	0.00%
…	…	…	…	…	…
20	95.97%	0.01%	0.20%	3.99%	0.04%
21	95.76% (4)	0.01%	0.20%	4.19%	0.04%

Marginal loss for time period *t*

$$MarLoss_{Eq}(t) = TL_{Eq}(t) = TL_{Eq}(t-1) = 76.35\% - 74.81\%$$

Similar calculation for marginal recovery

End period tranche notional is simply the difference between the notional at the start of the period and the marginal loss and marginal recovery for that period

Tranche pricing: equivalent to pricing single name CDS

Screenshot (5/5) (spread 100 bps, 40% rec., 20% correlation)

- Once the loss distribution has been built and the losses and recoveries for each tranche have been determined, tranche pricing is straightforward and implemented identical to the previous models

Coupon leg + Accrual on default

Tranche Pricing

Tranche	Discounted Contingent Leg	Discounted Coupon Leg	Discounted Accrual on Default	Discounted Fee leg≈DV01	Discounted Fair Spread
Equity	71.993%	2.18	0.09	2.27	31.725%
Mezz Jun	35.656%	3.68	0.05	3.72	9.573%
Mezz Sen	17.868%	4.14	0.02	4.17	4.288%
Senior Junior	9.052%	4.33	0.01	4.34	2.084%
Senior	2.478%	4.45	0.00	4.45	0.556%
Super Senior	0.030%	4.39	0.00	4.39	0.007%
Index	4.3081%	4.30	0.009	4.31	1.0000%

End

$$S = \frac{Contigent\ Leg}{Fee\ Leg}$$

To ensure no arbitrage, the final index spread calculated using the tranche spread should be the same as the initial spread input

The Gauss-Hermite integration technique (1/2)

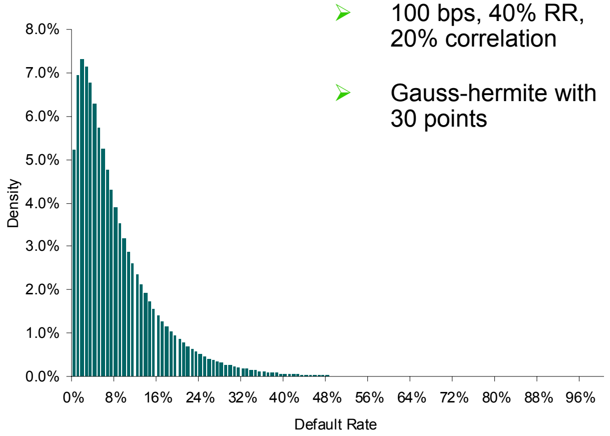
A numerical procedure to increase speed

- A variant of the Gaussian quadrature, the Gauss Hermite integration can be used to approximate integrals ranging from (-∞,+∞)
- As demonstrated in the our first two spreadsheets for the Large homogenous pool model (LHPM), the basic idea is to reduce the number of points that are used to approximate the distribution of the common factor
- While in the basic version of the LHPM we integrated over the interval (-5, 5) using decimal steps, resulting in 101 points, in the LHPM with the Gaussian-Hermite we reduced this to 30 points
- While significantly reducing the number of calculations that have to be carried out and therefore increasing speed, we still achieve a high level of accuracy because of the way the points are chosen within the Gaussian Hermite integration approach
- The 30 points we use in model two as well as in this model achieve almost the same level of accuracy as the 101 equally spaced points in model one, and a considerably higher level of precision than would be achieved with 30 equally spaced points

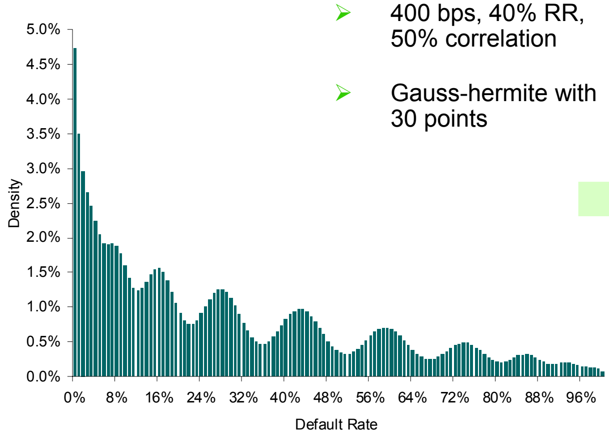
The Gauss-Hermite integration technique – some caveats (2/2)

A numerical procedure to increase speed

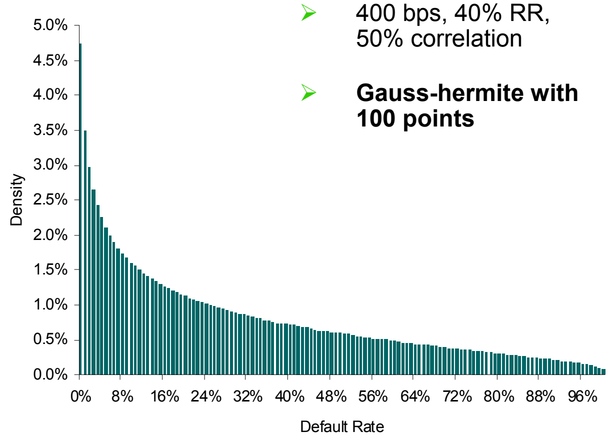
- However, as with any approximation, the gain in speed comes at a cost
- For a low number of points for the Gauss-Hermite, especially in combination with high spreads and correlations, the loss distribution will exhibit waves. The higher the number of assets, the more pronounced this behaviour
- These waves do however not result from the use of the Gaussian-Hermite technique per se but are rather induced by the fact that we now look at a finite rather than infinite pool of homogenous assets
- For given model inputs with respect to number of assets, spreads, recoveries and correlations, increasing the number of points results in a smoother default distribution.
- As this comes at the cost of slower computation, when choosing the adequate number of points for the Gauss-Hermite, the trade-off between calculation speed and the required degree of accuracy has to be kept in mind



- 125 assets
- 100 bps, 40% RR, 20% correlation
- Gauss-hermite with 30 points



- 125 assets
- 400 bps, 40% RR, 50% correlation
- Gauss-hermite with 30 points



- 125 assets
- 400 bps, 40% RR, 50% correlation
- **Gauss-hermite with 100 points**

Disclosure appendix

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Issuer	Definition
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	All covered companies		Companies where a Dresdner Kleinwort company ha provided investment banking service	
Overweight	15	29%	9	60%
Marketweight	22	43%	7	32%
Underweight	14	27%	8	57%
Total	51		24	

Source: Dresdner Kleinwort Research

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