

# Hedging and Pricing CDOs with Stochastic Recovery Rates

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An in-depth analysis of the recovery reduction and the discrete recovery model

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Global Derivatives Trading and Risk Management 2011, Paris, 14th April 2011

# AGENDA

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- **Model Overview**
    - Recovery reduction model (aka Amraoui/Hitier model)
    - Discrete recovery model (aka Krekel model)
  - **Recovery Distribution**
    - Historical Distribution
    - Model Distributions
  - **Sensitivity Analysis**
    - Correlation Skew
    - Credit Risk
    - JTD Risk
    - Recovery Risk
  - **Conclusion**
-

# Common Assumption: Gaussian Copula Approach

- In a generic one-factor copula model the default triggering factor of an obligor  $m$  at time  $T_i$  is modelled as:

$$X^m = \sqrt{\rho}M + \sqrt{1-\rho}Z^m$$

The default of obligor  $m$  is defined as:

$$X^m \leq c^m \equiv \tau^m \leq T \quad c^m \equiv N^{-1}(q^m)$$

- Conditional Default Probability:

$$\begin{aligned} p^m(q^m, z) &= P(\tau_m \leq T \mid M = z) \\ &= P(X^m \leq N^{-1}(q^m) \mid M = z) \\ &= P(\sqrt{\rho}z + \sqrt{1-\rho}Z^m \leq N^{-1}(q^m)) \\ &= N\left(\frac{N^{-1}(q^m) - \sqrt{\rho}z}{\sqrt{1-\rho}}\right) \end{aligned}$$

# Recovery reduction Model

Model overview – Hitier model

- Conditional recovery rate:

$$R^m(z) = 1 - (1 - \tilde{R}^m) \frac{p^m(\tilde{q}^m, z)}{p^m(q^m, z)}$$

- with

$$\tilde{q}^m = \frac{1 - REC^m}{1 - \tilde{R}^m} q^m$$

- $\tilde{R}^m$  recovery mark down is usually set to zero to generate a maximal effect.

# Discrete Recovery Model

- To induce stochastic recovery, a discrete recovery distribution conditioned on default must be chosen:

$$R^m = \begin{cases} r_1^m & \text{with probability } p_1^m \\ r_2^m & \text{with probability } p_2^m \\ \vdots & \vdots \\ r_J^m & \text{with probability } p_J^m \end{cases}$$

where

$$\sum_{j=1}^J p_j^m = 1$$

$$\sum_{j=1}^J p_j^m r_j^m = REC^m$$

and  $REC^m$  is the market recovery rate of obligor m.

## Discrete recovery Model

- The basic idea is to use the area below the default threshold to model stochastic recovery rates. The additional recovery thresholds are calculated as follows:

$$q_j^m := q^m \left( 1 - \sum_{k=1}^j p_k^m \right)$$

$$c_j^m := F_X^{-1}(q_j^m)$$

The recovery rate  $R_i^m$  for date  $T$  and asset  $m$  is defined as:

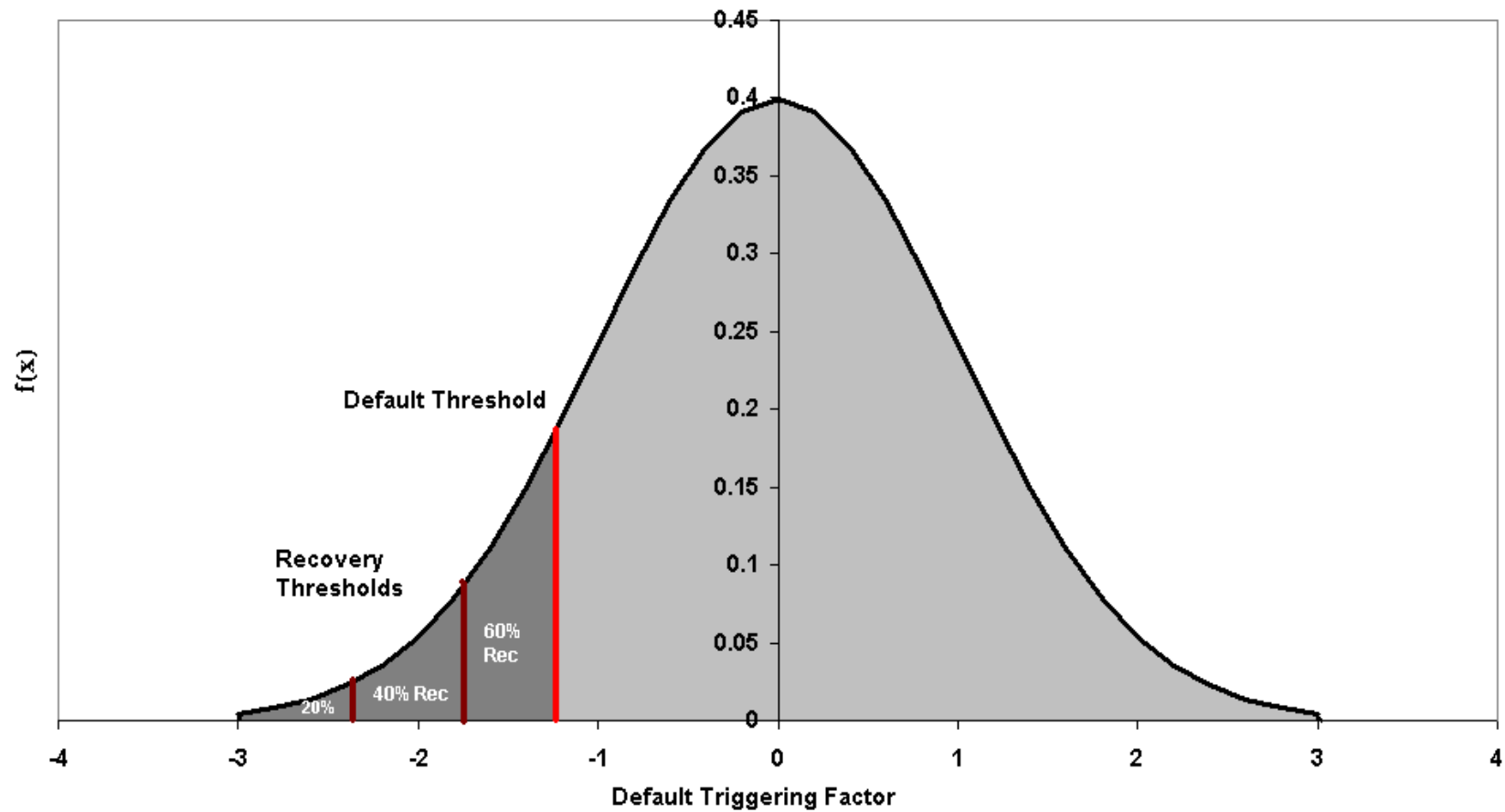
$$R^m := r^m(X^m)$$

$$r^m(x) := \begin{cases} r_j^m & \text{if } c_j^m < x \leq c_{j-1}^m \\ \text{else } 1 \end{cases} \quad \text{for } j \in \{1, \dots, J\}$$

# Discrete recovery Model

Model overview – MK model

Default and Recovery Rate Thresholds



## Discrete recovery Model

Model overview – MK model

- The probability, that the recovery rate equals  $r_j$  conditioned on  $M$  is for  $0 < \rho < 1$ :

$$p_j^m(z) = P(r^m = r_j | M = z, \tau_m \leq T)$$

$$= \left[ N\left(\frac{c_{j-1}^m - \sqrt{\rho}z}{\sqrt{1-\rho}}\right) - N\left(\frac{c_j^m - \sqrt{\rho}z}{\sqrt{1-\rho}}\right) \right] / N\left(\frac{c^m - \sqrt{\rho}z}{\sqrt{1-\rho}}\right)$$

- Recovery distribution conditional on default and  $z$ :
  - Introduction of an additional parameter  $\rho^m$  to control the individual recovery correlation.
  - $\rho^m=0 \rightarrow$  Independent
  - $\rho^m=1 \rightarrow$  fully dependent (standard case)

$$\widehat{R}^m(z) = \begin{cases} r_1^m & \text{with probability } \rho^m p_1^m(z) + (1-\rho^m) p_1^m \\ \vdots & \vdots \\ \vdots & \vdots \\ r_J^m & \text{with probability } \rho^m p_J^m(z) + (1-\rho^m) p_J^m \end{cases}$$



# AGENDA

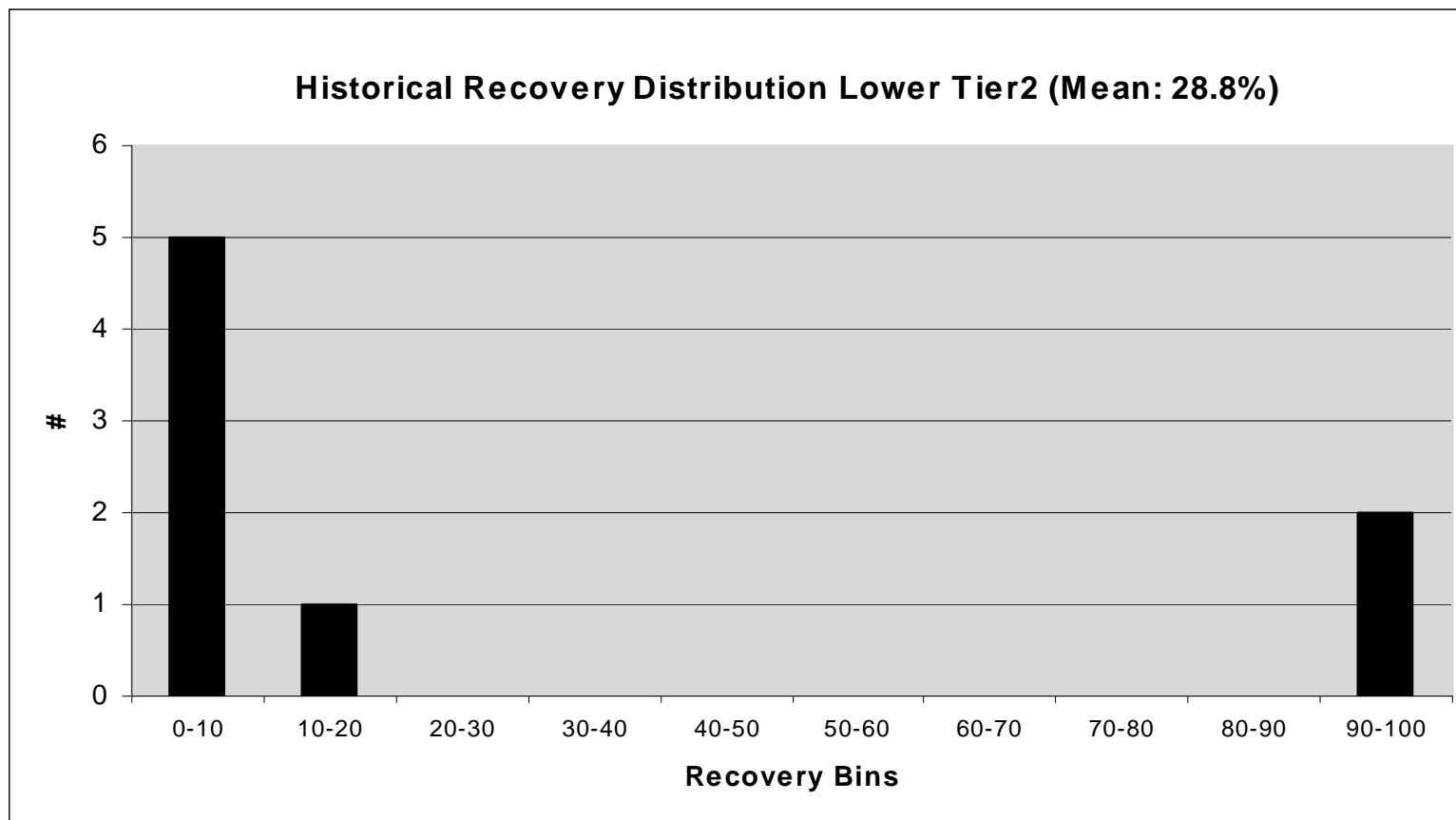
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- Model Overview
    - Recovery reduction model
    - Discrete recovery model
  - Recovery Distribution
    - Historical Distribution
    - Model Distributions
  - Sensitivity Analysis
    - Correlation Skew
    - Credit Risk
    - JTD Risk
    - Recovery Risk
  - Conclusion
-

# Historical Recovery Distribution

Recovery Distribution – Historical Distribution

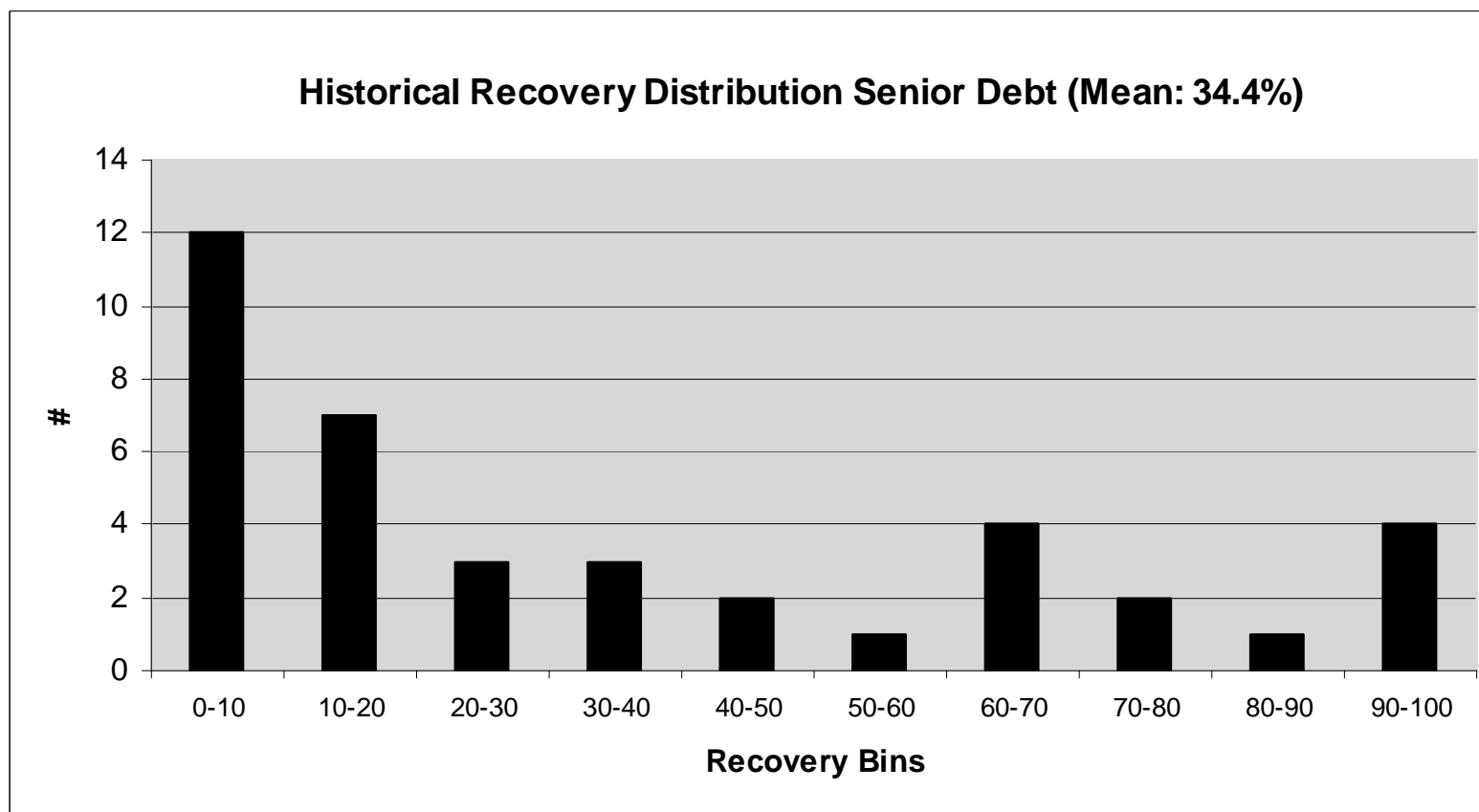
■ Settled Recovery Rates or Lower Tier2



# Historical Recovery Distribution

Recovery Distribution – Historical Distribution

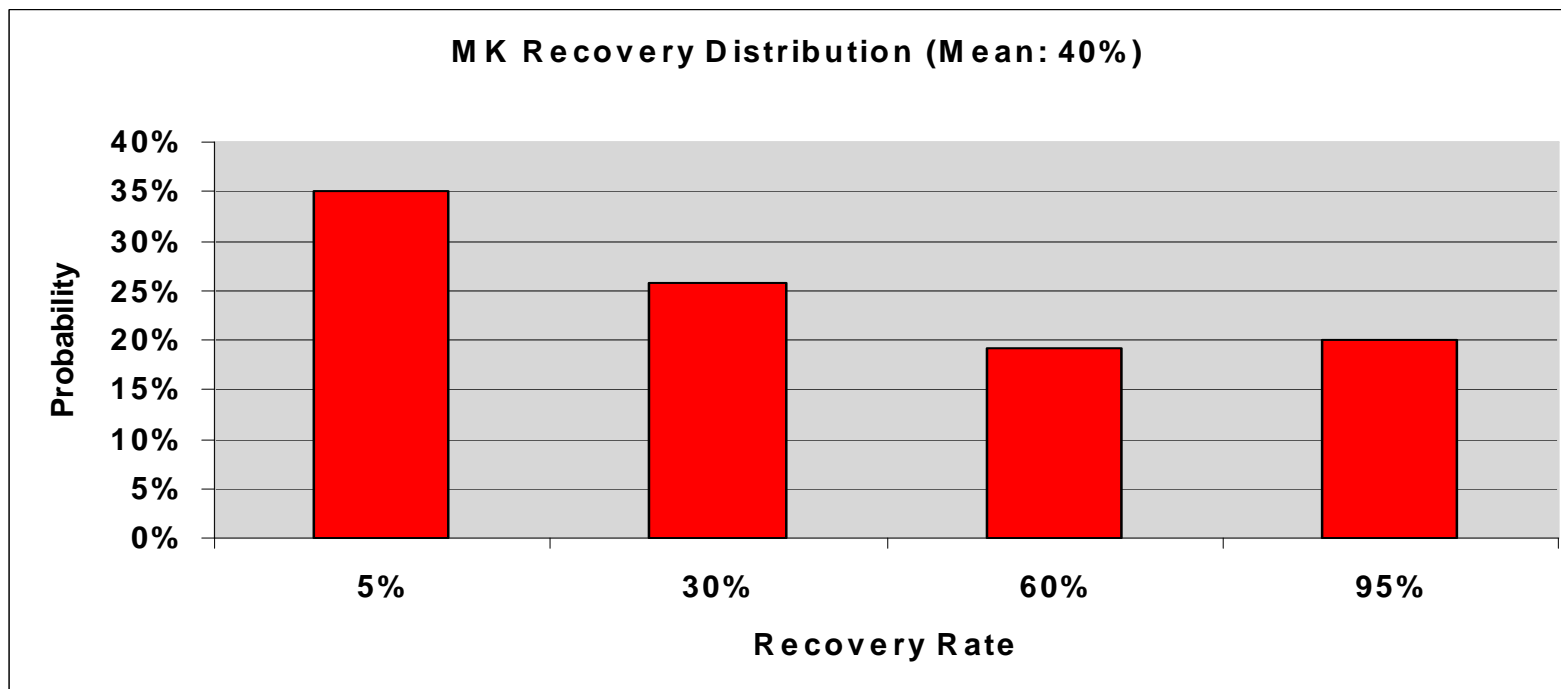
■ Settled Recovery Rates of Senior Debts



# Input Recovery Distributions

Recovery Distribution – Model Distribution

■ Assumed Recovery Distribution for MK model

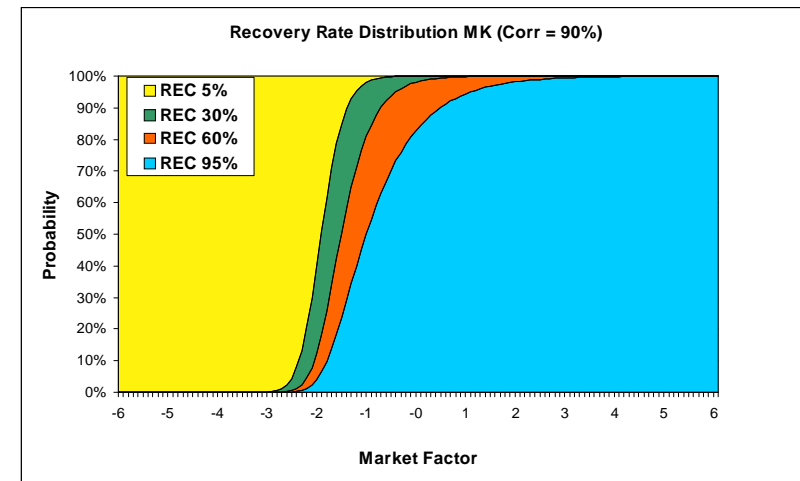
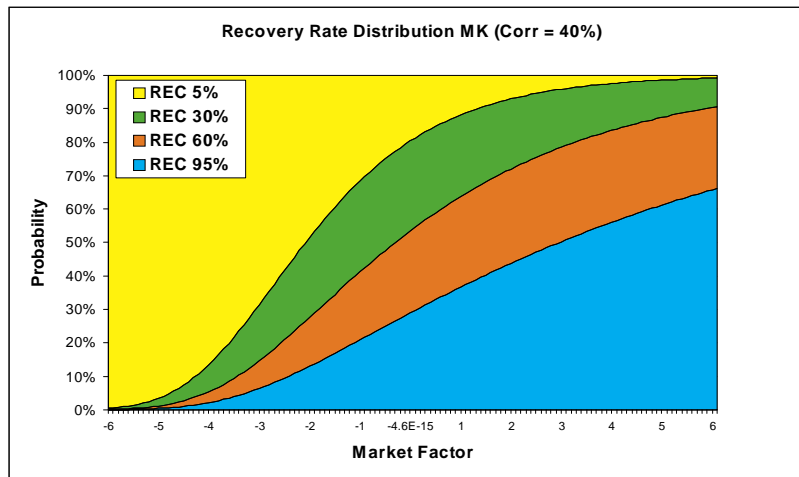
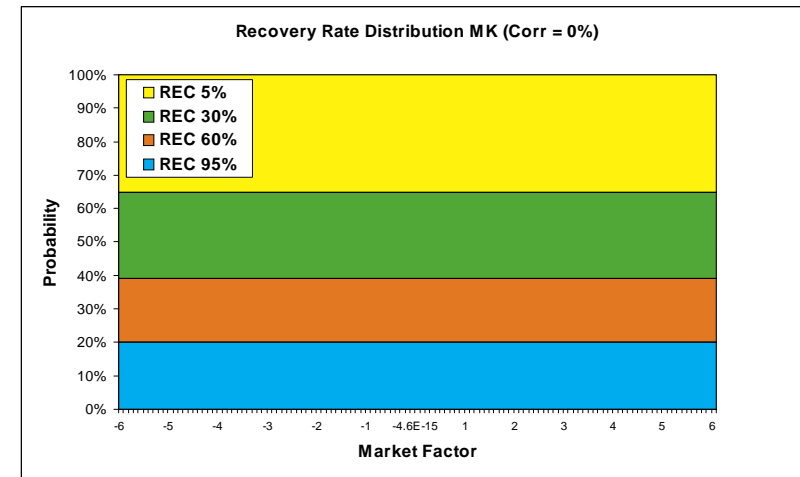


■ Recovery reduction model:  
Mean: 40%  
Markdown recovery: 0%

# MK recovery distribution in dependency of the market factor

Recovery Distribution – Model Distribution

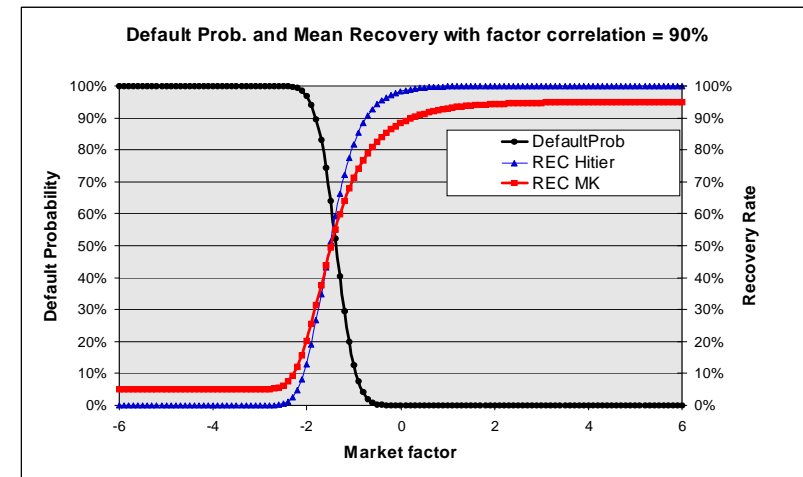
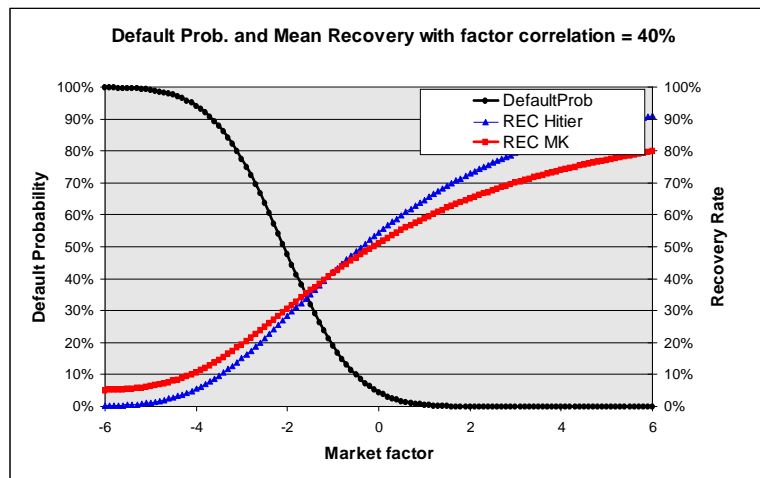
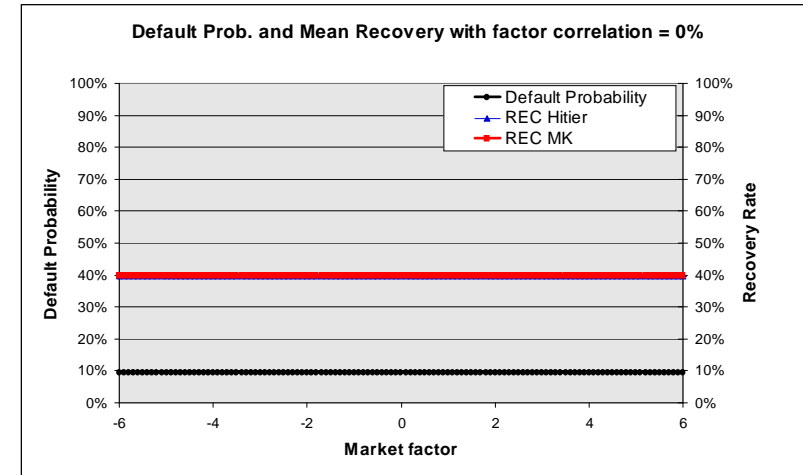
- Recovery Rates do not change
- Only the corresponding probabilities
- Recovery low in bad states
- Recovery high in good states



# Recovery reduction distribution in dependency of the market factor

## Recovery Distribution – Model Distribution

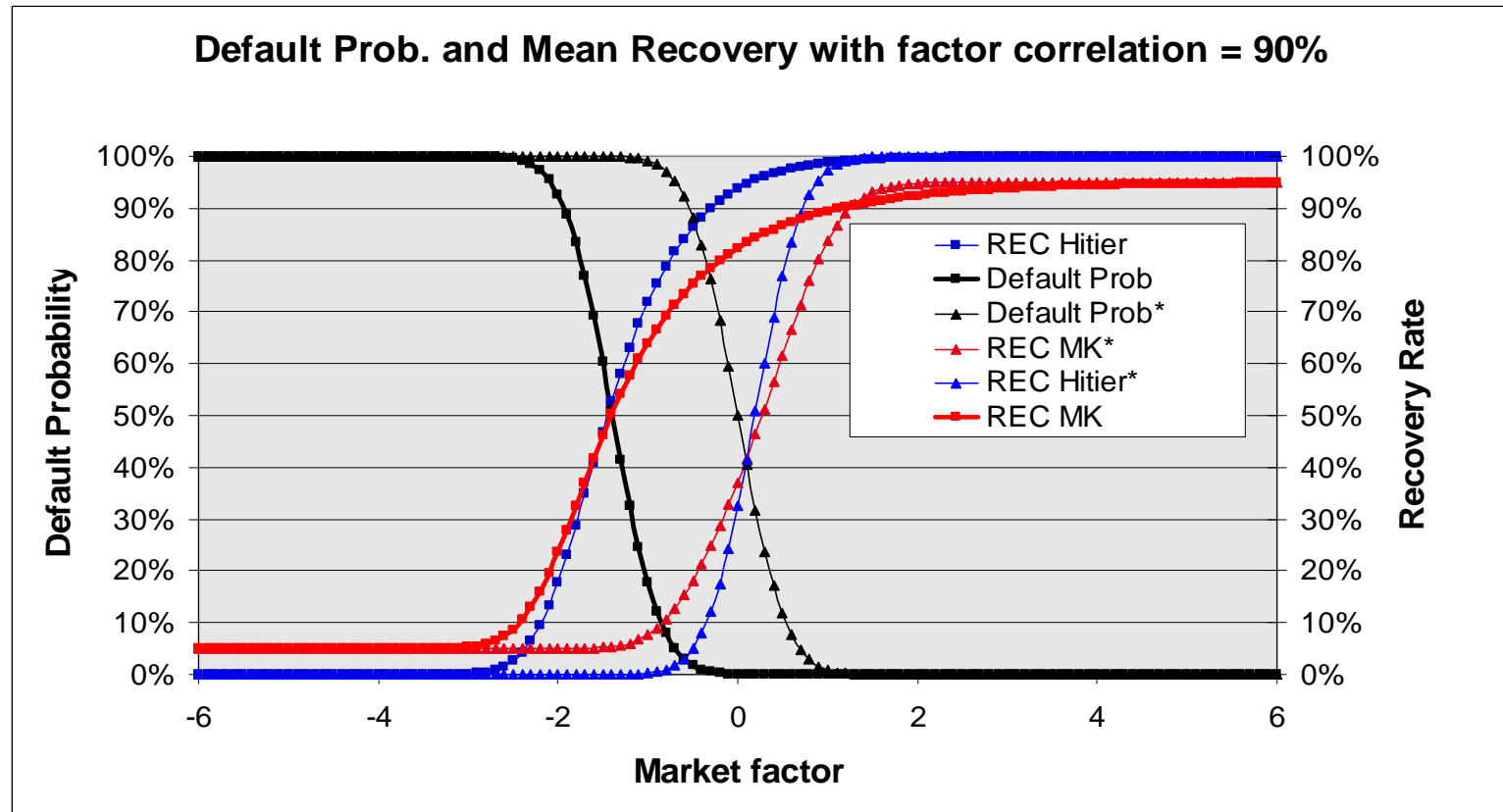
- For factor correlation 0% curves constant
- Default probability 10%
- The higher the factor correlation the steeper the curves get.



# Recovery Distribution dependent on market factor

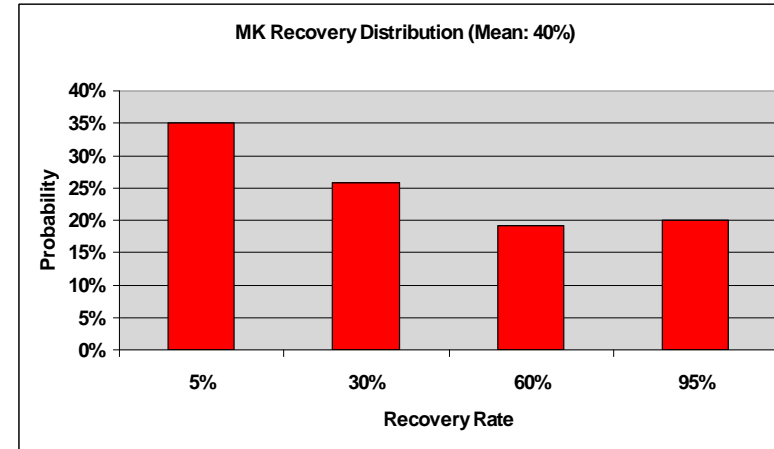
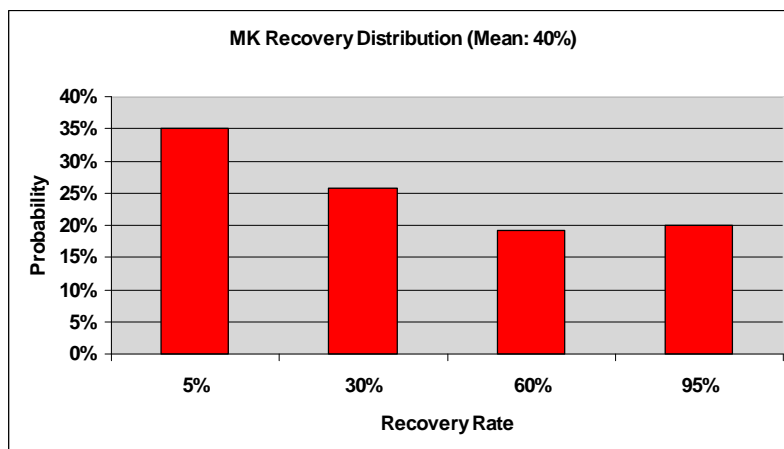
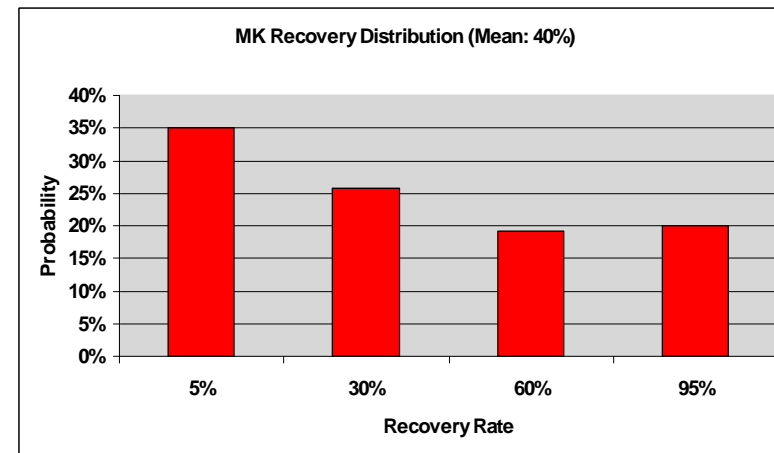
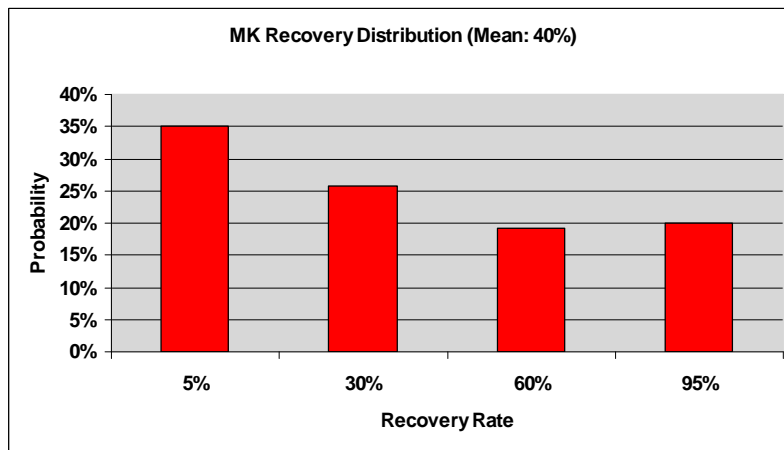
Recovery Distribution – Model Distribution

- Conditional defaults probability and recovery rate for a default probability of 10% and 95%
- Parallel shift for 95% curve\*



# Marginal recovery distribution of Krekel model does not depend on the correlation

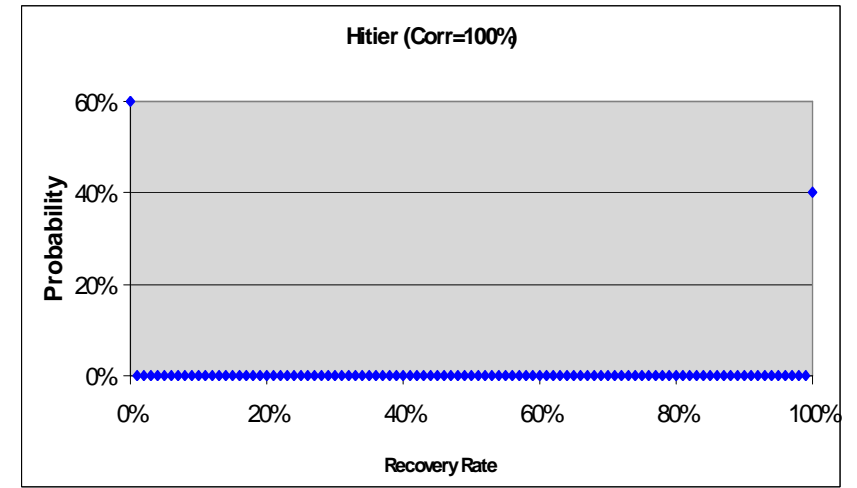
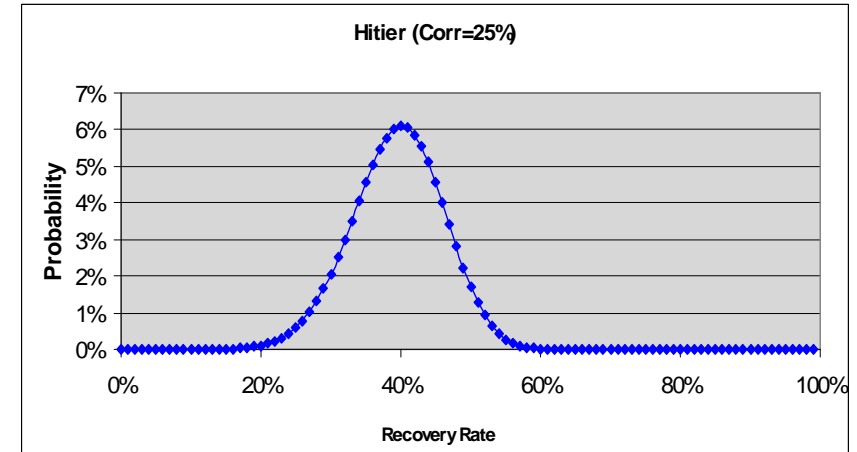
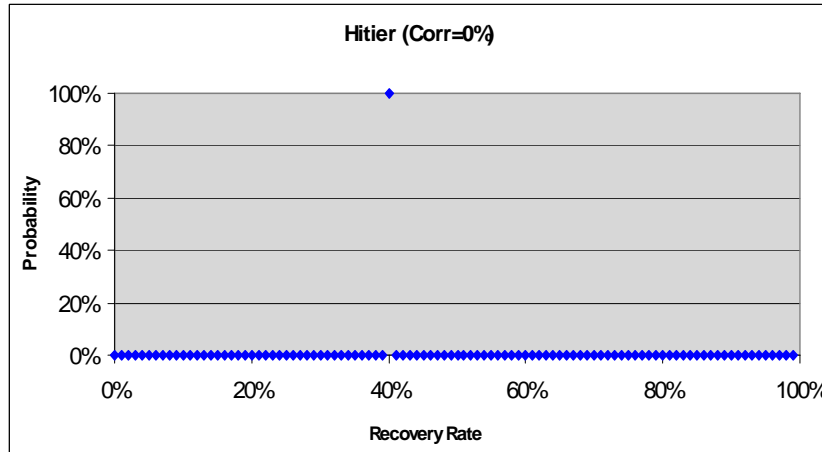
Recovery Distribution – Model Distribution





# Marginal recovery distribution of the recovery reduction model for different correlations

Recovery Distribution – Model Distribution



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# Sensitivity Analyses

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Sensitivity Analysis – Test Setup

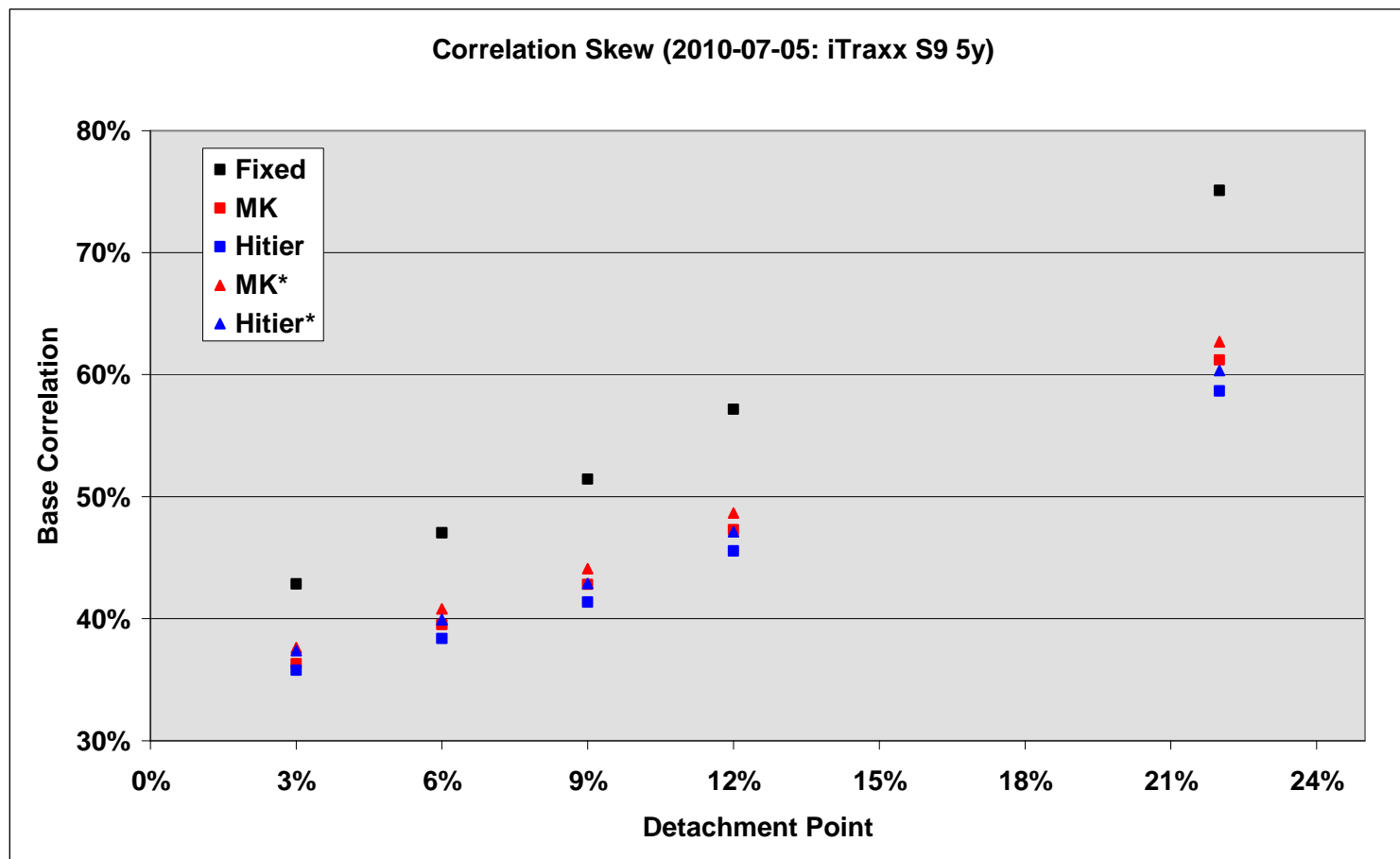
- Setup
  - Index: iTraxx S9 5y, Maturity: 2013-06-20
  - Each credit reference has nominal of 8 million, total notional 1000 million
  - Risks are calculated for Equity 0-3, Mezz 6-9, Senior 12-22 and 22-100 Tranche
  - PV change calculated for a tranche notional of 30m each
  - Protection Buyer Position
- Sensitivity definition
  - Spread Risk: parallel upwards bump of CDS spread by 10 bps
  - Recovery Risk: absolute upwards shift by 5%
    - MK: recovery pillars shifted by 5%
    - Recovery Reduction: mean recovery shifted by 5%
  - JTD Risk: default probability set to 1, recovery rate is still stochastic

# Sensitivity Analyses

- To overcome SR model-specific flaws following additional scenarios are defined
  - MK\*
    - JTD risk is calculated with fixed recoveries for the respective defaulted names
    - Recovery correlation set to 0% for the 5 names with the widest spreads
  - Recovery reduction\*
    - JTD risk is calculated with fixed recoveries for the respective defaulted names
    - Recovery markdown 40% for the 5 widest names → recovery fixed
    - For recovery risk also the markdown recovery is bumped by 5%

# Base Correlation Skews

Sensitivity Analysis – Correlation Skew



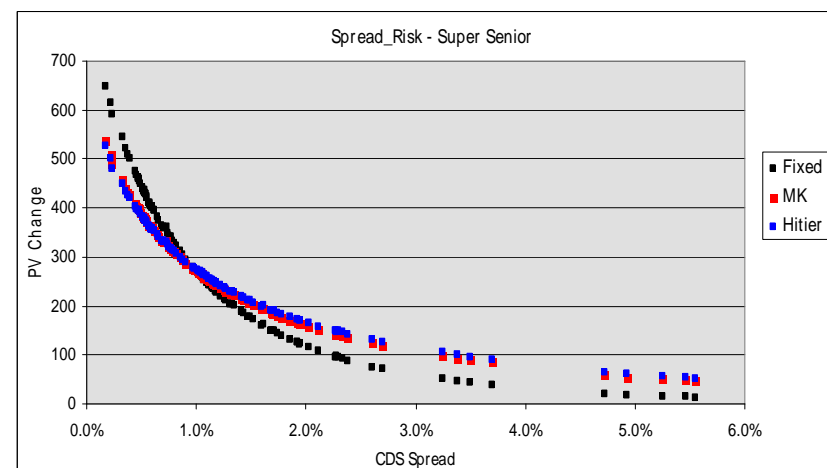
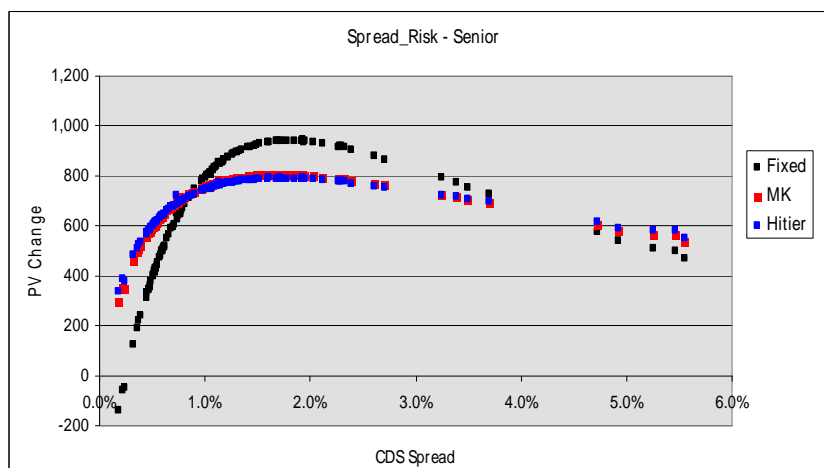
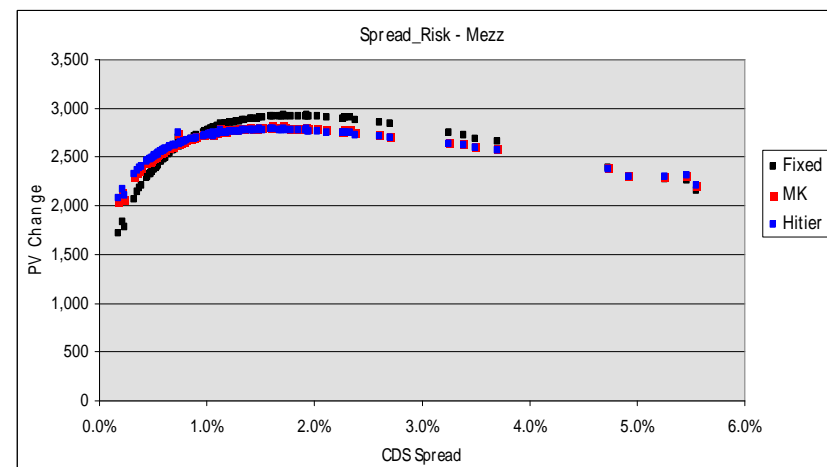
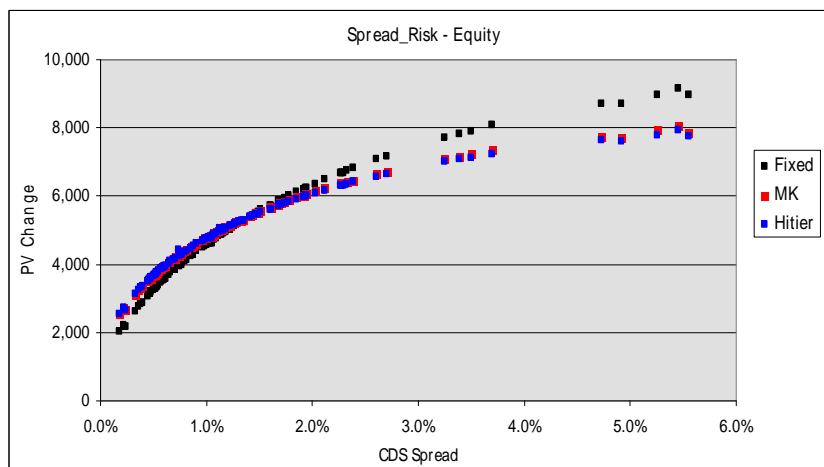
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# Credit Risk

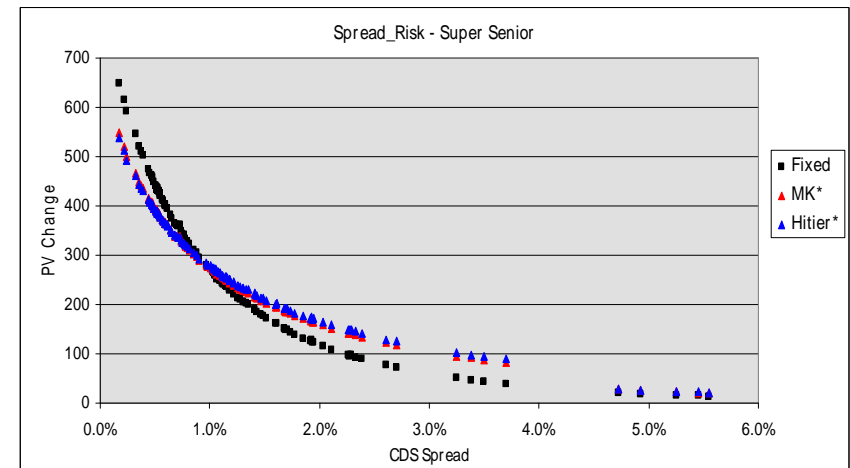
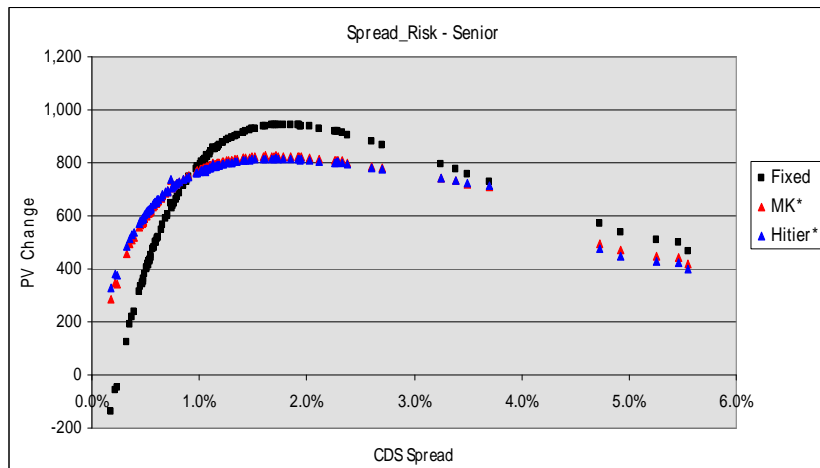
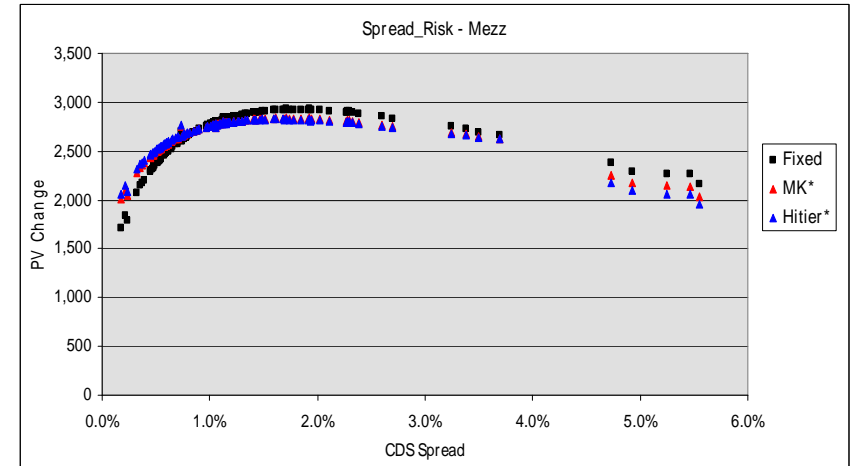
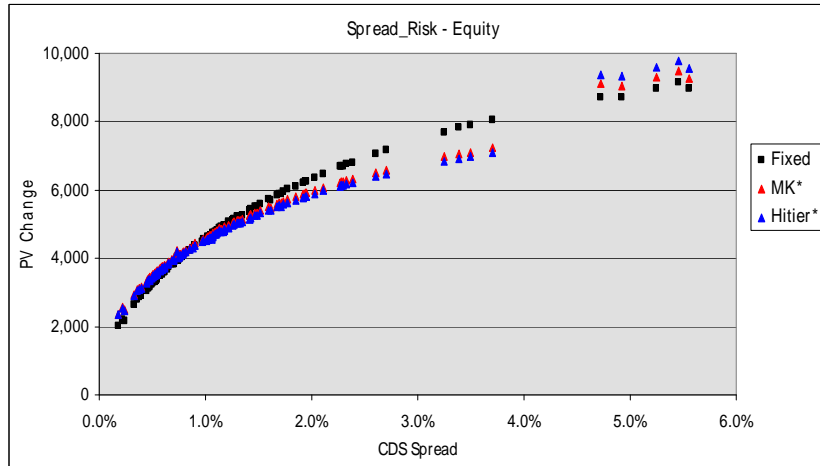
## Sensitivity Analysis – Spread Risk



# Credit Risk\*

(Recovery fixed resp. Uncorrelated for 5 widest names)

## Sensitivity Analysis – Spread Risk





# Interpretation

- Credit references with wide spreads
  - The equity tranche is hit by defaults of wide names under good market states. For these states the recovery rate is greater than 40%, therefore the spread risk is smaller as with fixed recovery rates.
  - Only in bad states wide names hit the super senior tranche, therefore the recovery rate is smaller than 40% and the risk larger.
- Credit reference with tight spreads
  - Tight names hit the equity tranche only in extremely bad states, therefore the recovery rate is smaller, and the risk larger than with fixed recovery.
  - Tight names hit the super senior tranche in relatively good states (in worse states they hit the tranches before), therefore the recovery rate is larger than 40% and risk smaller than with fixed recovery.
- Without recovery correlation (\*scenario for wide names) we get similar spread risks.

# Hedge Ratios

Sensitivity Analysis – Spread Risk

Hedge Ratios					
	Fixed	MK	Hitier	MK*	Hitier*
Equity	6.93	7.08	7.04	6.92	6.85
Junior Mezz	6.01	6.04	6.02	6.01	6.00
Mezz	3.93	3.94	3.93	3.95	3.95
Senior Mezz	2.26	2.28	2.27	2.29	2.29
Senior	1.01	1.06	1.05	1.07	1.07
Super Senior	0.27	0.26	0.27	0.27	0.27
Index	1.00	1.00	1.00	1.00	1.00

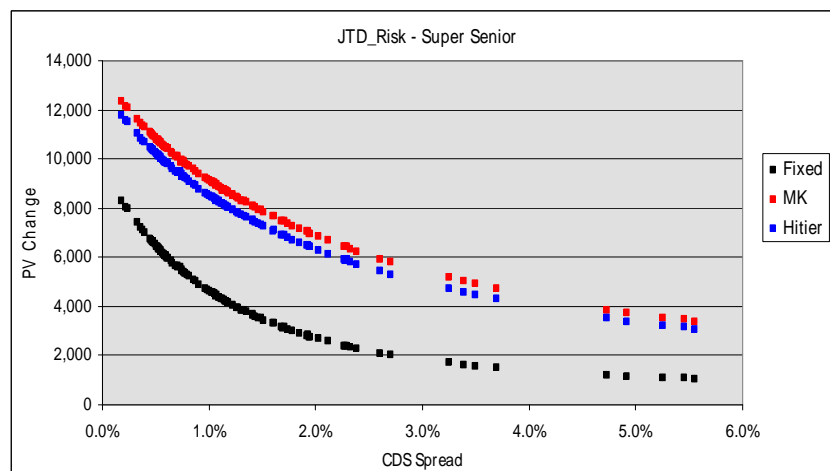
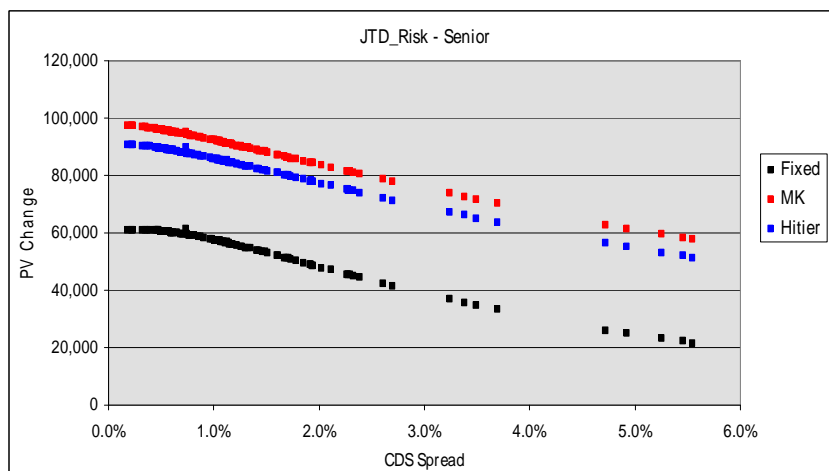
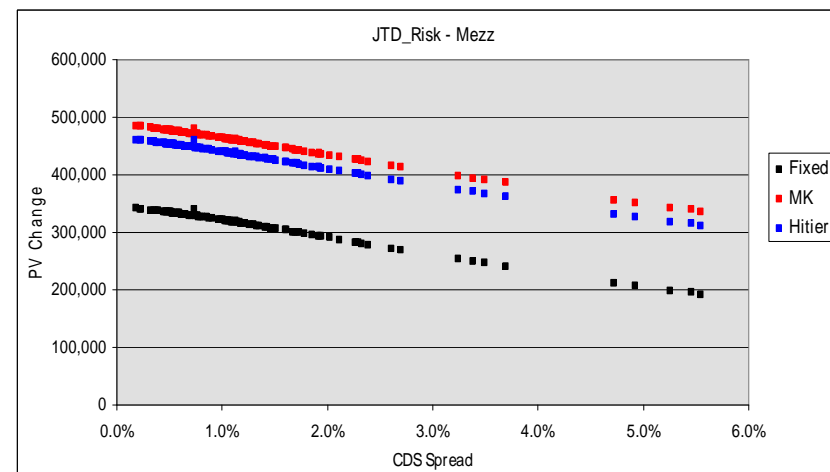
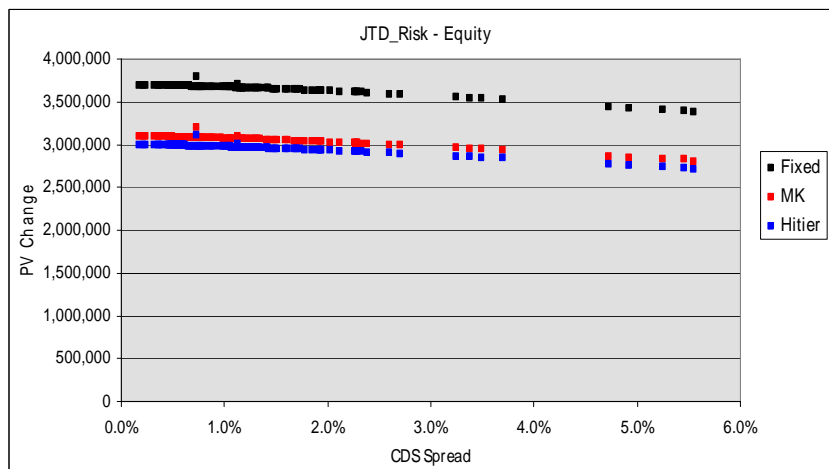
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# Jump-To-Default Risk

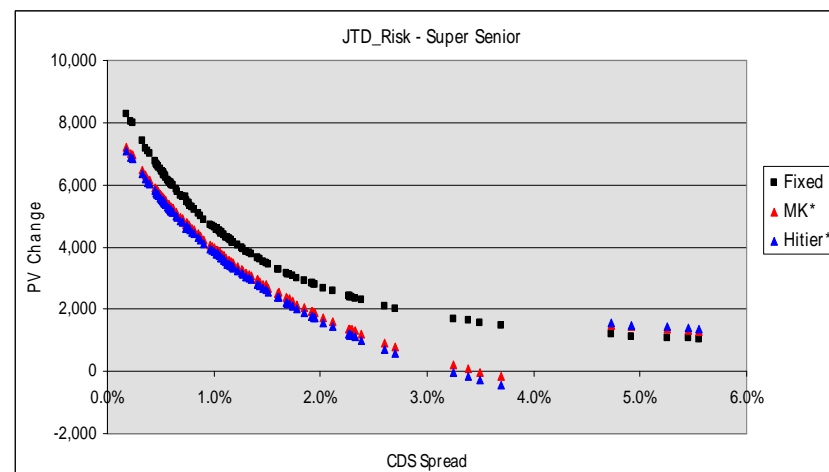
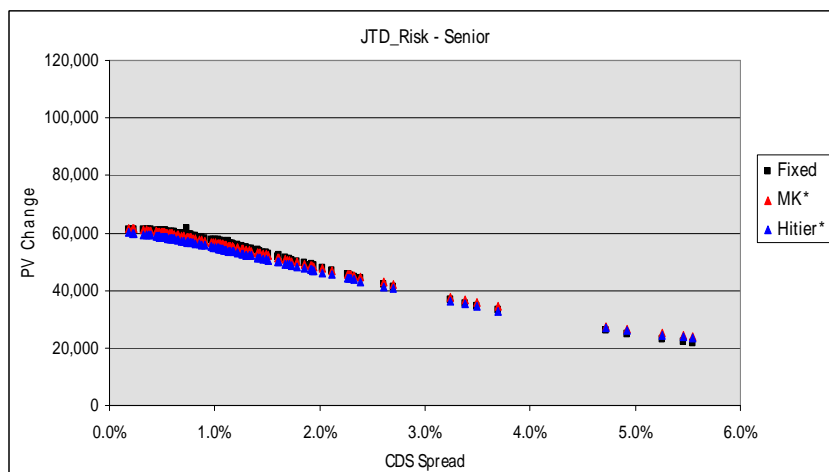
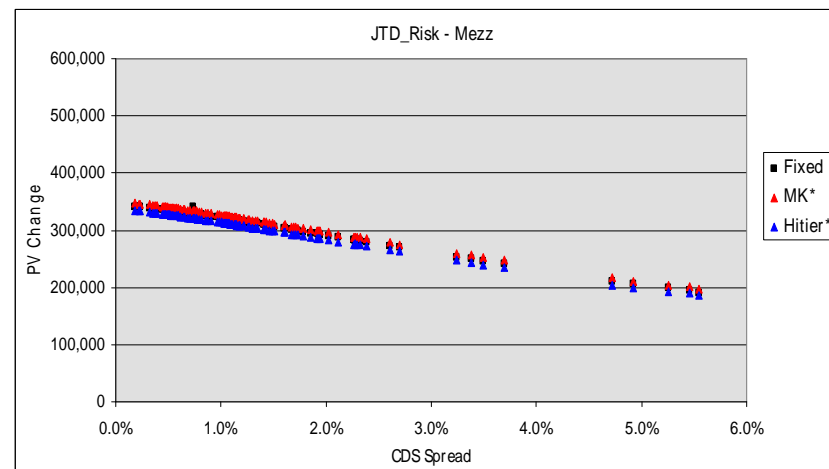
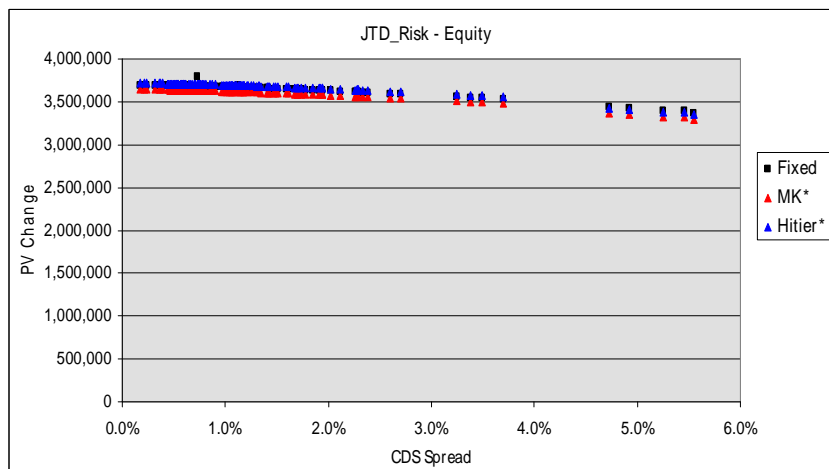
## Sensitivity Analysis – JTD Risk



# Jump-To-Default Risk\*

(Recovery Rates fixed for JTD calculation)

## Sensitivity Analysis – JTD Risk



# Interpretation

- Jump-to-Default Risk
  - Defaults are simulated by setting the default probability to 1.  
Recovery rates conditional on default are assumed to be stochastic.
  - The equity tranche is hit in relative good states, in these states the recovery rate is larger than 40%, hence then JTD-risk is smaller than with a fixed recovery of 40%. The same argumentation applies vice versa to senior tranches.
- Jump-to-Default Risk\*
  - Defaults are simulated by setting default probability equal to 1.  
Recovery rates conditional on default are assumed to be fixed.
  - Results are very similar to the fixed recovery model
  - But can go negative for wide names in super senior tranches, this can be prevented by setting the recovery correlation to zero or the markdown to the mean, respectively.
- How should JTD Risk be simulated ?
  - ➔ Simulation of hedge ratios under different realized recovery assumptions

## Hedge notionals with stochastic JTD recoveries

Sensitivity Analysis – JTD Risk

- CDS Hedge notionals are not constant
- Recovery is effectively fixed for 0%

JTD Hedge with stochastic recovery defaults (Hitier)						
REC	Equity	Junior Mezz	Mezz	Senior Mezz	Mezz	Super Senior
	<b>JTD Risk</b>					
0%	6,030,417	1,400,091	552,625	267,269	95,671	7,448
20%	4,374,834	1,267,003	527,416	260,300	94,834	7,881
40%	<b>2,929,142</b>	<b>1,008,982</b>	<b>454,552</b>	<b>233,401</b>	<b>89,701</b>	<b>8,279</b>
60%	1,669,726	679,986	334,162	179,667	75,135	8,456
80%	625,468	307,966	166,776	93,538	43,456	7,534
90%	215,742	117,157	66,848	37,742	18,353	5,453
	<b>CDS Hedge Notional</b>					
0%	6,030,417	1,400,091	552,625	267,269	95,671	7,448
20%	5,468,542	1,583,753	659,269	325,375	118,542	9,851
40%	<b>4,881,904</b>	<b>1,681,636</b>	<b>757,587</b>	<b>389,001</b>	<b>149,502</b>	<b>13,798</b>
60%	4,174,315	1,699,965	835,406	449,168	187,838	21,139
80%	3,127,340	1,539,831	833,878	467,688	217,282	37,670
90%	2,157,416	1,171,572	668,478	377,418	183,533	54,526

## Hedge notionals with fixed recoveries

Sensitivity Analysis – JTD Risk

- CDS Hedge Notionals rather constant for junior tranches

JTD Hedge with fixed recovery defaults (Hitier)							
REC		Equity	Junior Mezz	Mezz	Senior Mezz	Mezz	Super Senior
	<b>JTD Risk</b>						
	0%	6,030,417	1,400,091	552,625	267,269	95,671	7,448
	20%	4,865,025	1,078,996	426,940	206,690	74,071	5,330
	40%	<b>3,672,864</b>	<b>775,185</b>	<b>305,957</b>	<b>148,007</b>	<b>53,000</b>	<b>3,240</b>
	60%	2,455,686	487,285	189,446	91,148	32,443	1,177
	80%	1,215,062	214,078	77,191	36,047	12,387	858
	90%	586,408	82,641	22,595	9,135	2,543	1,866
	<b>CDS Hedge Notional</b>						
	0%	6,030,417	1,400,091	552,625	267,269	95,671	7,448
	20%	6,081,281	1,348,745	533,675	258,363	92,588	6,663
	40%	<b>6,121,440</b>	<b>1,291,975</b>	<b>509,928</b>	<b>246,678</b>	<b>88,333</b>	<b>5,400</b>
	60%	6,139,214	1,218,213	473,615	227,870	81,108	2,943
	80%	6,075,310	1,070,392	385,953	180,236	61,937	4,291
	90%	5,864,078	826,415	225,951	91,354	25,430	18,657



## Hedge notionals under different recovery scenarios (MK)

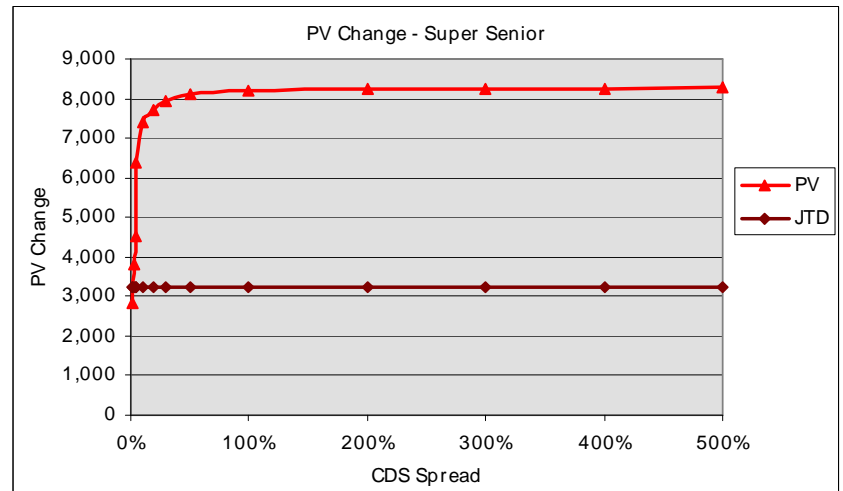
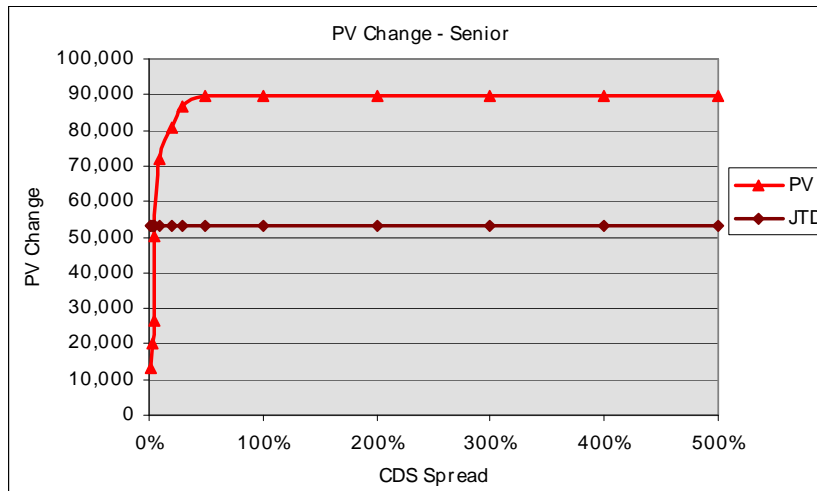
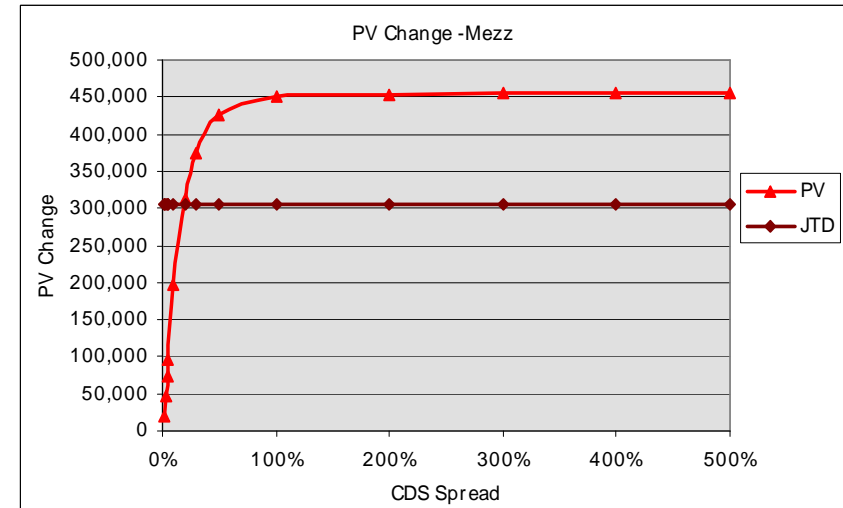
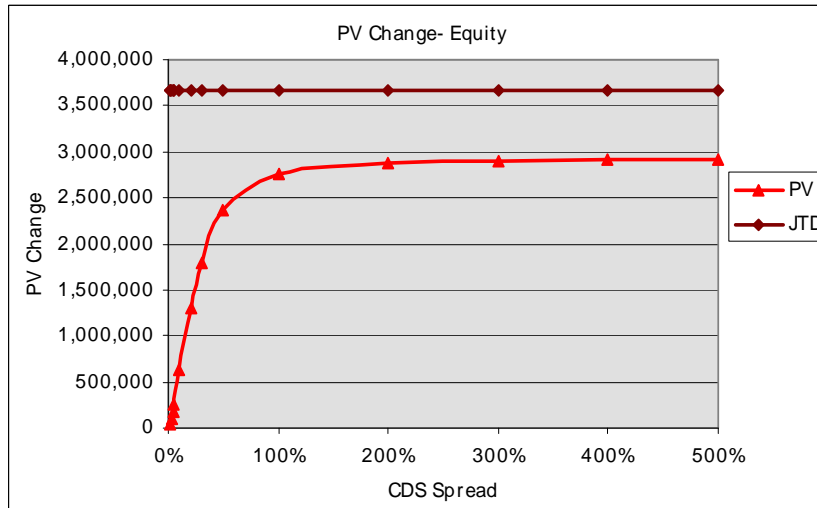
Sensitivity Analysis – JTD Risk

- Conclusion:  
CDO JTD – Risk with stochastic recoveries not consistent to CDS JTD Risk

JTD Hedge with fixed recovery defaults (MK)						
REC	Equity	Junior Mezz	Mezz	Senior Mezz	Mezz	Super Senior
	JTD Risk					
0%	5,972,757	1,436,713	562,571	271,122	96,695	7,433
20%	4,806,948	1,116,090	437,011	210,642	75,150	5,298
40%	<b>3,602,901</b>	<b>819,820</b>	<b>318,287</b>	<b>152,944</b>	<b>54,387</b>	<b>3,205</b>
60%	2,415,660	512,763	196,587	94,042	33,287	1,093
80%	1,199,995	223,830	79,961	37,203	12,766	987
90%	579,973	86,989	23,868	9,700	2,766	2,013
	CDS Hedge Notional					
0%	5,972,757	1,436,713	562,571	271,122	96,695	7,433
20%	6,008,685	1,395,113	546,264	263,303	93,938	6,623
40%	<b>6,004,836</b>	<b>1,366,367</b>	<b>530,479</b>	<b>254,906</b>	<b>90,645</b>	<b>5,341</b>
60%	6,039,151	1,281,907	491,467	235,104	83,217	2,733
80%	5,999,975	1,119,150	399,804	186,013	63,829	4,935
90%	5,799,727	869,891	238,679	96,996	27,662	20,129

## But obviously, no convergence of SR-Model to Fixed Recovery-JTD-PV for increasing spreads !

### Sensitivity Analysis – JTD Risk



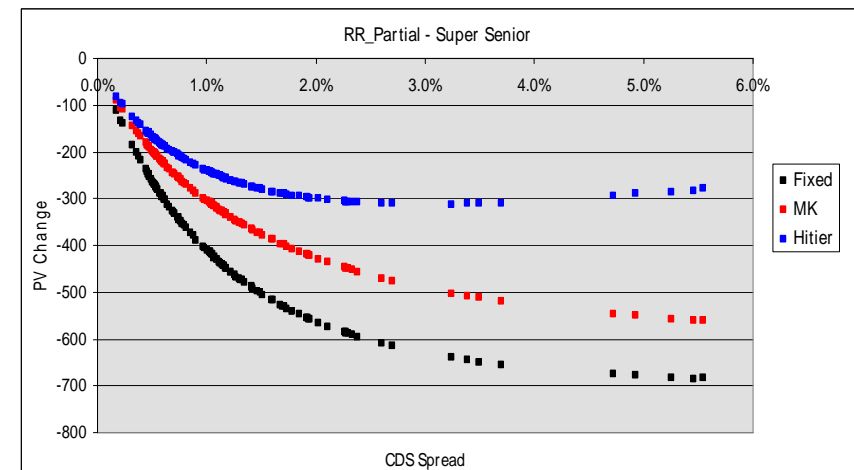
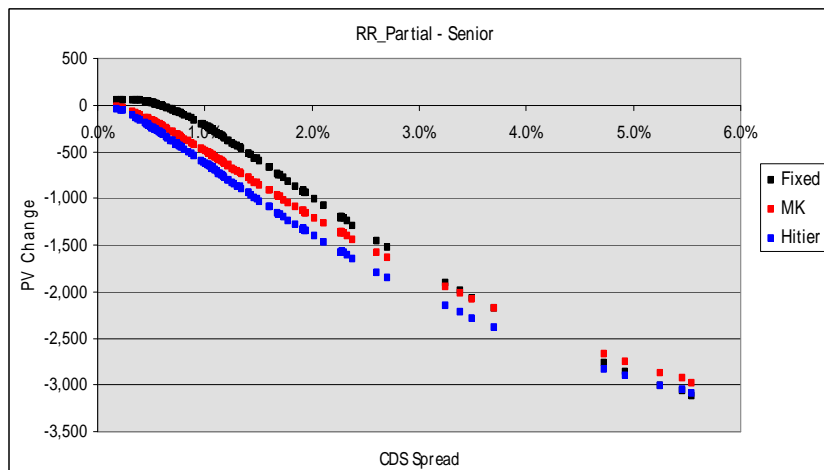
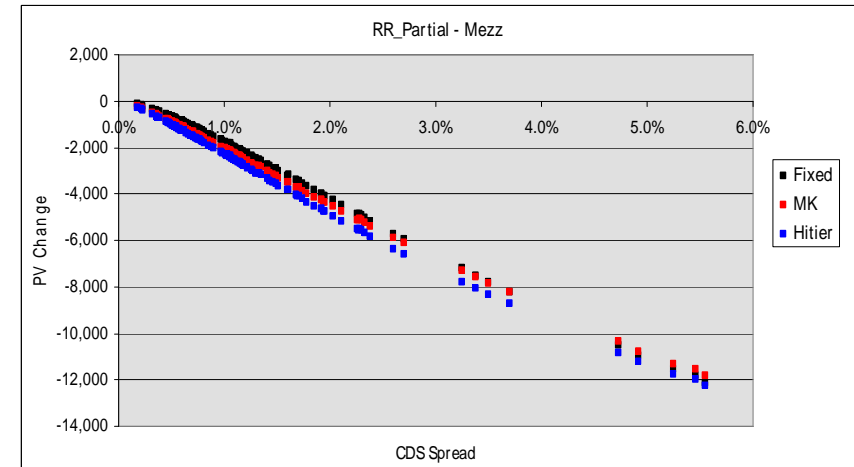
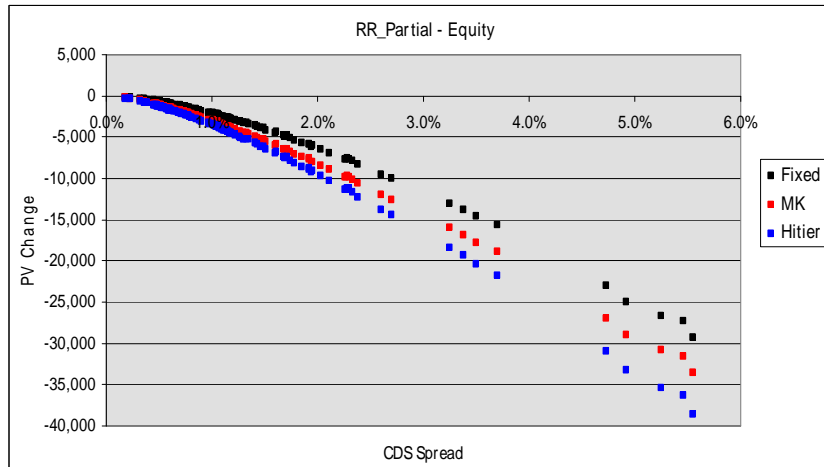
# AGENDA

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- Model Overview
    - Recovery Reduction model
    - Krekel model
  - Recovery Distribution
    - Historical Distribution
    - Model Distributions
  - Sensitivity Analysis
    - Correlation Skew
    - Credit Risk
    - JTD Risk
    - Recovery Risk
  - Conclusion
-

# Partial Recovery Risk (without CDS-Recalibration)

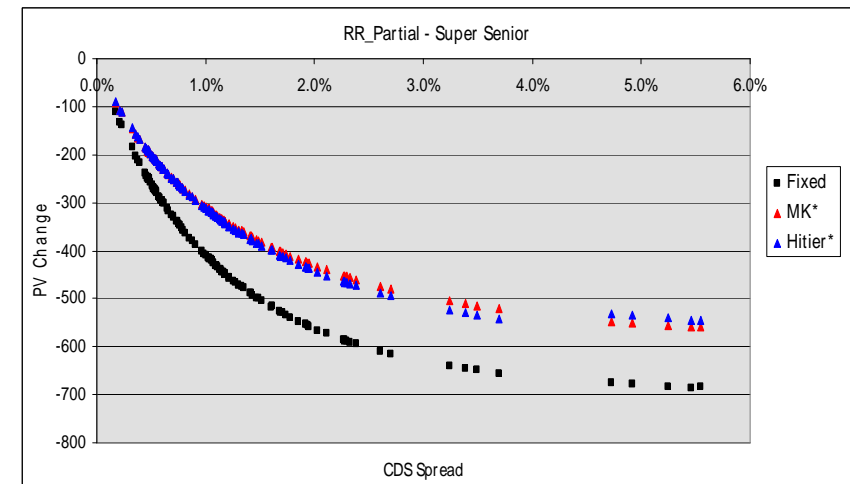
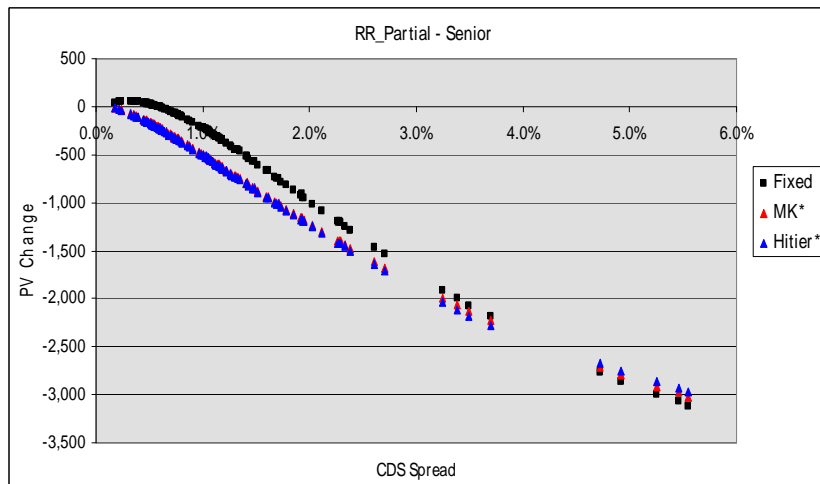
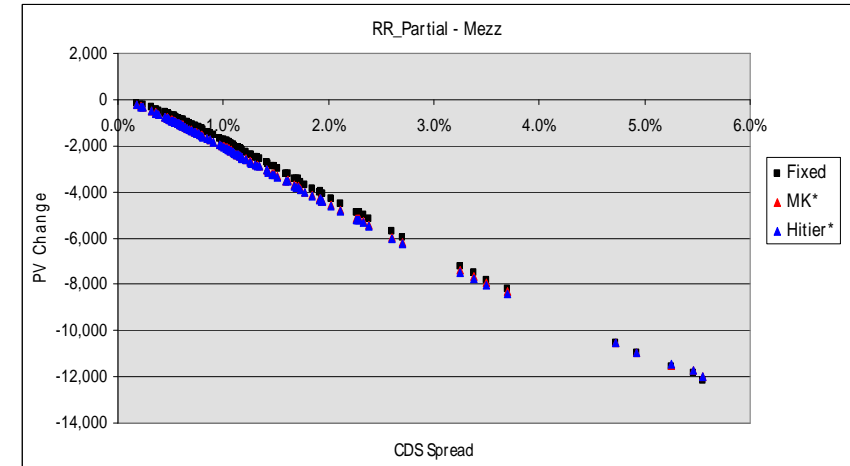
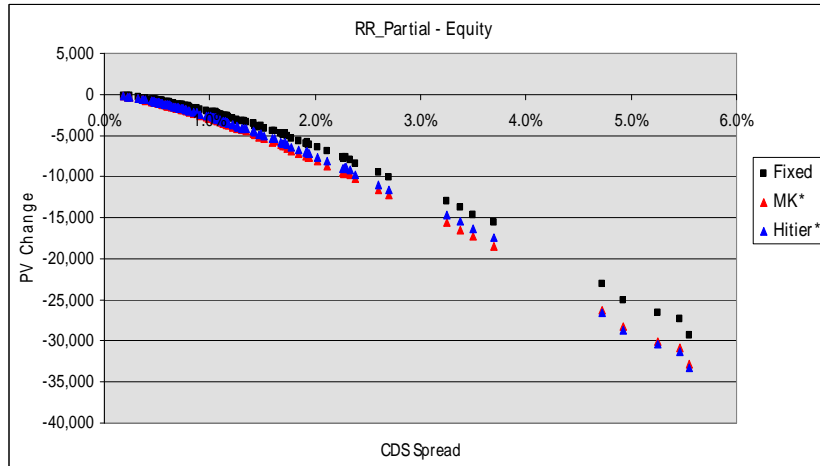
## Sensitivity Analysis – Recovery Risk



# Partial Recovery Risk\*

(Also recovery markdown parameter is bumped)

## Sensitivity Analysis – Recovery Risk

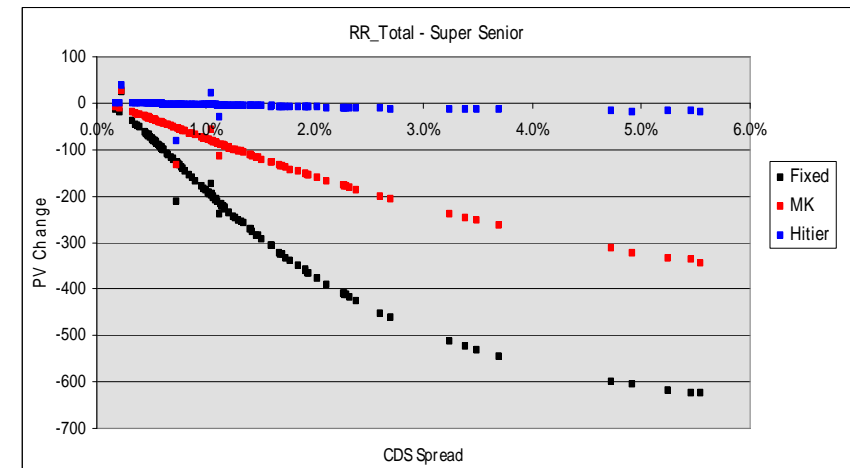
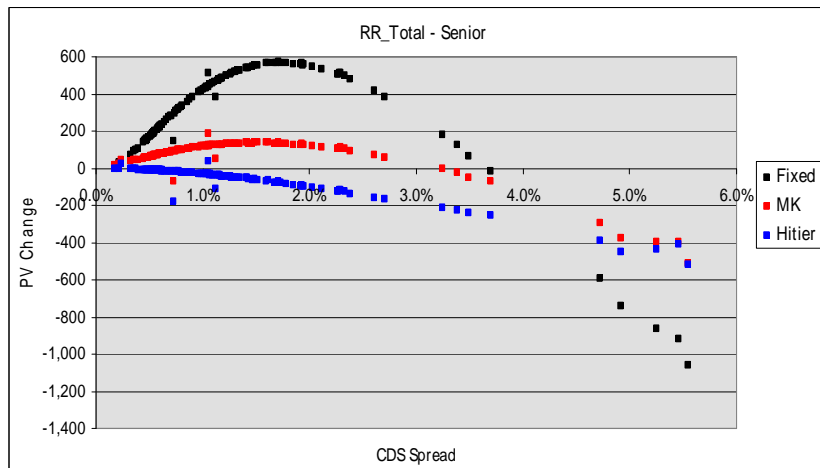
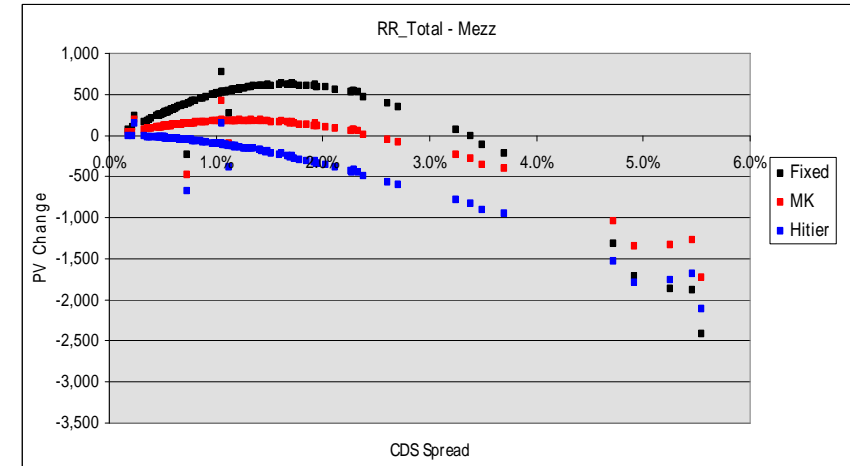
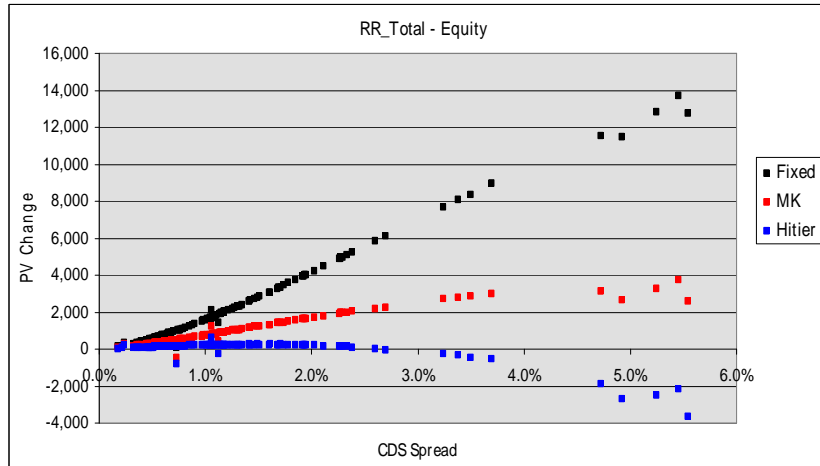


# Interpretation

- Effect of stochastic recovery rates
  - Senior tranche:  
The recovery bump has for the stochastic recovery models less impact than for fixed recovery model. Think of an 55%-100% tranche: It would be worthless after the 5% recovery bump in a fixed recovery model, but still has a value in a SR model !
  - Equity Tranche:  
To compensate this effect, the PV Change must be larger.
- In general: Recovery volatility makes super senior tranches expensive and equity tranches cheap
- Effect of recovery markdown in Recovery reduction:
  - For a fixed recovery markdown of 0%, there is more risk in super senior tranches than in the MK model, since also the recovery variance is increased in Recovery reduction due to the bump.
  - If recovery markdown is also bumped by 5%, the results are similar to MK model

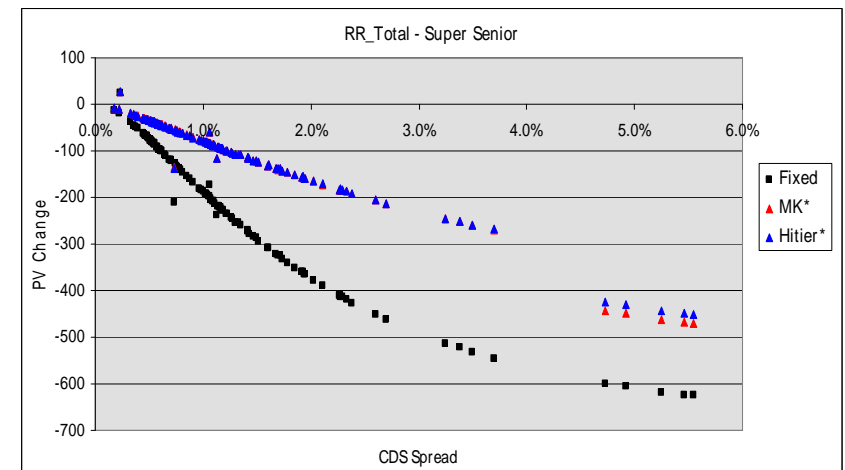
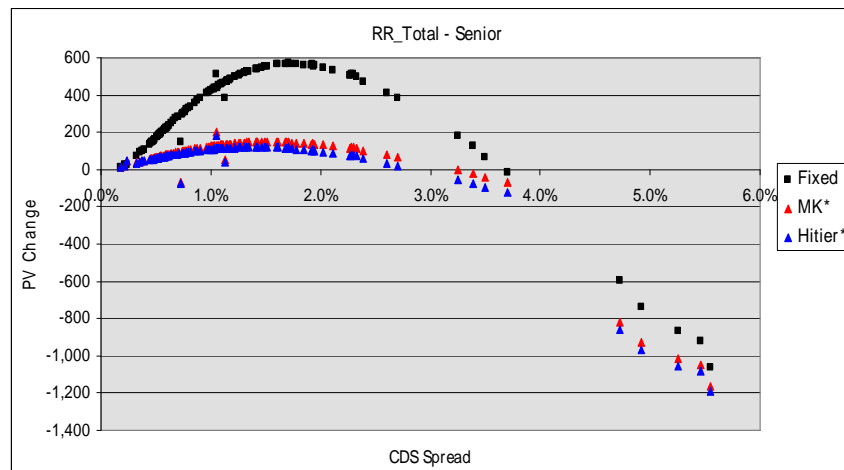
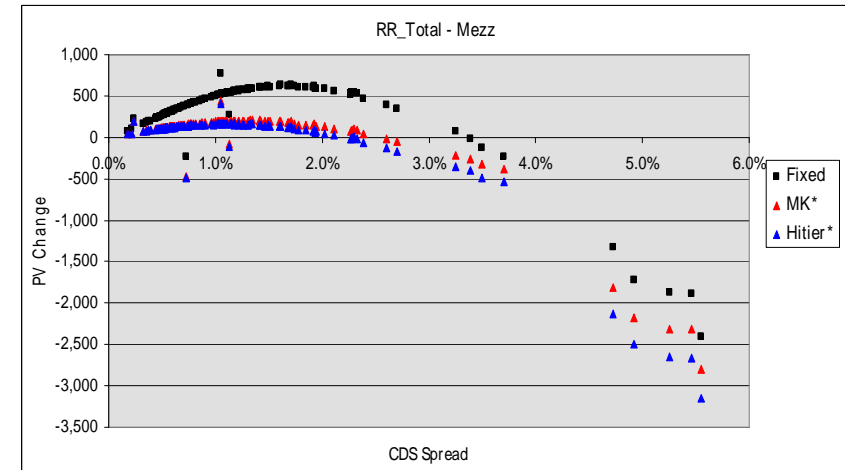
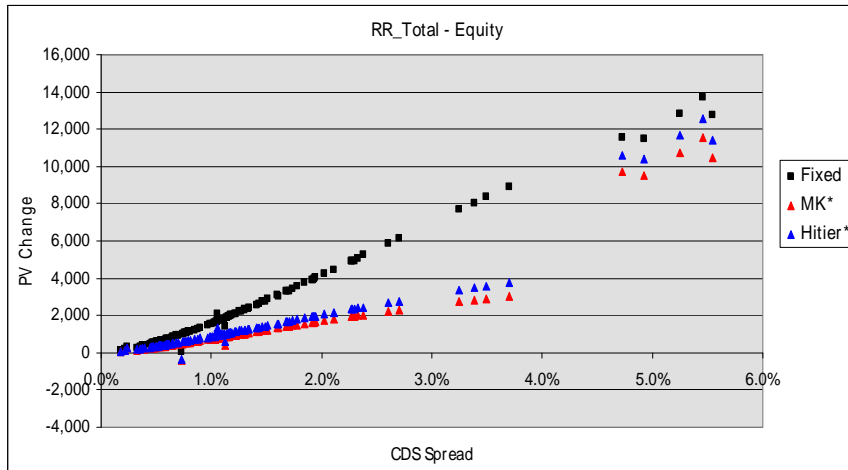
# Complete Recovery Risk\* (with CDS-Recalibration)

## Sensitivity Analysis – Recovery Risk



# Complete Recovery Risk\*

## Sensitivity Analysis – Recovery Risk





# Interpretation

- General effect of stochastic recovery rates
  - Effect of recovery bump goes in the same direction as in the partial case, i.e. senior tranches more- and equity less risky relative to the fixed recovery model.
- Effect of recovery markdown in Recovery reduction:
  - For a fixed markdown recovery of 0%, almost no PV effect in equity and super senior tranches.
  - If recovery markdown is also bumped by 5%, results similar to MK model
- Effect of fixed recovery (Hitier) / uncorrelated recovery (MK)
  - Recovery Risk is similar to the fixed recovery model in equity tranche

# AGENDA

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- Model Overview
    - Recovery reduction
    - Krekel model
  - Recovery Distribution
    - Historical Distribution
    - Model Distributions
  - Sensitivity Analysis
    - Correlation Skew
    - Credit Risk
    - JTD Risk
    - Recovery Risk
  - Conclusion
-

# Comparison of stochastic recovery models

Conclusion

Characteristics	MK Model	Recovery Reduction Model
Recovery distribution conditional on the market factor	Discrete recovery distribution with fixed pillars, only probabilities change	Single recovery rate within in range [0,1]
Marginal distribution	stable	<ul style="list-style-type: none"> <li>▪ not stable, shape depends on correlation</li> <li>▪ the larger the correlation, the larger the variance of the distribution</li> </ul>
Recovery distribution	Allows to control the recovery correlation and shape of the recovery distribution separately	Distribution rather arbitrary, does not allow to choose a specific shape
Calculation time for bucketing approximation (e.g. Hull)	MK faster, since recovery distribution is based on fixed pillars	needs a very fine grid since recoveries are arbitrary
Calculation time moment matching approximation of loss distribution	4 probabilities needs to be calculated	Recovery reduction faster, since only two probabilities needs be calculated per name

## How these models should be applied

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Conclusion

- 1) Jump-to-Default risk should be simulated with fixed recoveries**
  - ☐ consistent with CDS-JTD
  - ☐ stable CDS-Hedge Ratios
  - ☐ sensitivities are rather model-independent
- 2) The recovery markdown parameter of the Recovery reduction should be bumped by the same amount as the mean recovery**
  - ☐ Otherwise recovery variance is increased, which has side-effects on sensitivities
  - ☐ Otherwise complete recovery risk almost zero for equity and super senior tranches
  - ☐ Recovery Risk very close to MK model and closer to Fixed Recovery Model
- 3) For distressed names stochastic recovery might be disabled**
  - ☐ Convergence to JTD-Risk when spreads are increasing  
(but there will be anyway a P&L-Jump after the auction date)
  - ☐ Non-negative JTD-Risk in super-senior tranches  
(but super senior JTD-Risk rather small in terms of tranche notional)

## Your contacts

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### **Imprint**

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