Fine-tuning the equivalent strike framework for bespoke cdo tranches pricing

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Fine-tuning the Equivalent Strike framework for Bespoke CDO Pricing

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Abstract

[1] This paper presents a fine-tuning of some mapping functions used in the Equivalent Strike framework. This new approach provides an equivalent strike that is independent from the index base correlation. This feature is valuable when pricing very junior and senior tranches or when computing index tranches (or index base correlation) sensitivities. Our numerical tests on realistic cases showed that the equivalent correlation provided by this new is pretty close to what is computed with common mapping functions.

Key words: Bespoke CDO pricing, Equivalent Strike framework, Index base correlation extrapolation, Index tranche sensitivities.

JEL classification: C00, C61, C62

1   Introduction

Equivalent strike techniques are widely used in order to price and hedge synthetic bespoke CDO tranches in the base correlation framework. In this framework the attachment and detachment correlations of a bespoke tranche are deduced from base correlations of liquid index tranches via mapping techniques. There are several mapping techniques - of which the advantages and drawbacks have been widely discussed in the literature (see [1], [2], [3]) -

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such as: At The Money or Probability Matching or Expected Tranche Loss. When looking for an equivalent strike - at a given maturity - the common approach consists in solving the following optimization problem:

$$\min_K \phi\left(K, \rho_I(K)\right) \qquad (1)$$

where ϕ is a bivariate function depending on the unknown K and the base correlation curve of the index to which we are mapping $\rho_I : K \mapsto \rho_I(K)$ (to simplify notations, we omit the dependence on maturity throughout the paper). The equivalent strike solution of Problem (1):

$$K^\star = \mathrm{argmin}_K \phi\left(K, \rho_I(K)\right) \qquad (2)$$

clearly depends on the shape of the base correlation curve ρ_I. This behavior should be taken into account when dealing with the situations below:

1. *Pricing very junior or senior tranches*: Since mid-2007, traders are more likely to price very junior tranches detaching below 3% (due to the subordination erosion of some junior tranches present in their book by successive default events) or very senior tranches attaching above 30% in order to hedge the book and take into account new market conditions (it is common now to see quotes for $[60\%, 100\%]$ tranches). For these particular tranches, the equivalent strike $K^\star$ may depend on the extrapolation hypothesis of the base correlation curve ρ_I.

2. *Hedging a bespoke product via liquid index tranches*: Since the Equivalent Strike approach consists in mapping a bespoke tranche to a liquid index tranche market, it is important to compute the sensitivity of the bespoke tranche to the tranches of the liquid index. This is achieved by perturbing the market quotes of each index tranche, bootstrapping the base correlation for each perturbation scenario and finally valuing the bespoke tranche via the Equivalent Strike approach for each index correlation scenario. Since the equivalent strike $K^\star$ depends on the index correlation curve ρ_I, it has to be computed for each index base correlation scenario. The index tranche sensitivity computation time will be impacted by this step.

This paper provides a new equivalent strike approach in order to address the issues mentioned above. The proposed improvement is localized and focuses only on the equivalent strike computation step (see Equation (2))as it keeps many steps in this framework unchanged (choice of the mapping criterion, multi-index mapping methods, term structure handling...). The main

property of the proposed method is that the equivalent strike is independent from the index base correlation ρ_I while the equivalent base correlation $\rho_I(K^\star)$ is close to what is provided by the common approach described by Equation (1). The second section of this paper provides a brief overview of major mapping techniques within the Equivalent Strike framework. The third section is dedicated to the description of the new mapping criterion. The final section gives numerical results and compares our approach to the common approach described by Equation (1).

2 Review of common mapping methods

Although some well-known drawbacks, the base correlation approach is widely used by practitioners in order to price CDO tranches. In this framework a protection leg $[K_1, K_2]$ can be valued as the $[0, K_2]$-protection leg value (using a correlation ρ_2) minus the $[0, K_1]$-protection leg value (using a correlation ρ_1 that may be different from ρ_2). When $[K_1, K_2]$ is a bespoke CDO tranche the attachment and detachment correlations ρ_1 and ρ_2 are deduced from liquid index correlation market data via a mapping technique. For a given bespoke equity tranche $[0, K_B]$ the mapping technique provides an equivalent index equity tranche $[0, K_I^\star]$. The correlation used to price the $[0, K_B]$-tranche is then provided by $\rho_B^\star = \rho_I(K_I^\star)$ (where $\rho_I : K \mapsto \rho_I(K)$ is the base correlation curve of the index used for mapping). In practice, the problem means finding the strike $K_I^\star$ that verifies:

$$\psi(K_I^\star, \rho_I(K_I^\star), \pi^I) = \psi(K_B, \rho_I(K_I^\star), \pi^B) \tag{3}$$

where:

- ψ is the mapping function (it needs to be monotonic of the strike)

- π^I (resp. π^B) is the index (resp. bespoke) portfolio

- K_B is the given bespoke equity tranche strike

- $K_I^\star$ the strike that allow to verify Equation (3)

We review below 3 popular choices for the mapping function ψ: At The Money, Probability Matching and Expected Tranche Loss.

2.1 At The Money (ATM)

This is one of the first and simplest mapping functions that have been used in the Equivalent strike framework. It is defined by:

$$\psi(K, \rho, \pi) = \frac{K}{\mathbb{E}\left[L\left(\pi\right)\right]}$$

where $\mathbb{E}$ is the expectation operator and $L\left(\pi\right)$ is the loss of the portfolio π. This choice of mapping function leads to a simple expression for the equivalent strike (that is not dependant on the shape of the base correlation ρ_I):

$$K_I^\star = K_B \times \frac{\mathbb{E}\left[L\left(\pi^I\right)\right]}{\mathbb{E}\left[L\left(\pi^B\right)\right]}$$

If the bespoke portfolio is tighter than the index portfolio, the bespoke equity tranche will be mapped to a more senior index tranche and conversely. This may lead to a situation (especially in the stochastic recovery framework) where the Equivalent strike $K_I^\star$ is higher than 100%. Other drawbacks of this mapping function are the independence from the portfolios dispersions and non continuity with respect to default settlement. In term of advantages one can mention that the equivalent strike computation is extremely fast (by comparison to other mapping functions) and that $K_I^\star$ is independent from ρ_I which is an appreciable feature when dealing with the two situations mentioned in the introduction.

2.2 Probability Matching (PM)

In this case the mapping function is the probability that the loss of the portfolio π is below the strike K. The equivalent strike:

$$\psi(K, \rho, \pi) = \mathbb{P}_\rho\left[L\left(\pi\right) \leq K\right]$$

where $\mathbb{P}_\rho$ is the probability operator using correlation value ρ and $L\left(\pi\right)$ is the loss of the portfolio π.

This mapping function addresses some of the drawbacks of the ATM mapping since it is sensitive to portfolios dispersion and is continuous with respect the to default settlement. Under normal market conditions $\psi(0, \rho, \pi) > 0$. Thus, when using this mapping function one can face situations (typically when index portfolio is much tighter than the bespoke one), where there is no strike $K_I^\star$ such as Equation (3) is verified. This mapping function may also produce some "counter-intuitive" behavior: typically, if the bespoke portfolio

has a higher WAS (weighted average spread) than the index portfolio, the intuition is that the equivalent strike of the reference will be lower than the bespoke strike (similar to the ATM case), but this may not be the case as the equivalent strike depends on the dispersion of the portfolio and the index correlation curve level. In a Constant Recovery framework, solving Equation (3) may be numerically unstable (since the portfolio loss cumulative distribution is discrete for a given correlation). Smoothing the cumulative distribution functions allows overcoming this behavior.

2.3   Expected Tranche Loss (ETL)

The mapping function is the proportion of the expected portfolio loss that is embodied in a given equity tranche. It is a monotonic function of the strike:

$$\psi(K, \rho, \pi) = \frac{\mathbb{E}_\rho \left[\min \left(L \left(\pi \right), K \right) \right]}{\mathbb{E} \left[L \left(\pi \right) \right]}$$

where $\mathbb{E}_\rho$ is the expectation operator using correlation value ρ and $L \left(\pi \right)$ is the loss of the portfolio π.

This mapping function takes into account the dispersion of portfolios (similar to the Probability Matching case). It always provides an equivalent strike since: (i) we are dealing with a mapping function that is monotonic of the strike and (ii) we have $\psi(0, \rho, \pi) = 0$ and $\psi(1, \rho, \pi) = 1$ (we assume here that we are dealing with standard portfolios. i.e. containing no short names). This mapping function has also the following drawbacks: (1) Sometimes it take dispersions into account but in a counterintuitive way. This is the case for example, when an issuer of the bespoke portfolio widens idiosyncratically. (2) Another problem is the continuity with respect to default settlement.

This method like the Probability Matching, leads to an equivalent strike that is dependent on the index base correlation curve ρ_I. Particularly, when mapping a junior bespoke tranche to an index portfolio that is much wider than the bespoke one, the equivalent strike is sensitive the extrapolation hypothesis below the lowest market strike (typically 3%). The same thing may also happen, when we map a super-senior tranche on a bespoke portfolio that is extremely tighter than the index one. This time the equivalent strike is sensitive to the extrapolation hypothesis above the biggest market strike.

3   New computation method

As noticed in the previous section, the equivalent strike is commonly computed via Equation (3). The equivalent strike can be regarded as the solution

of the following problem:

$$K^{\star} = \mathrm{argmin}_{K}\varphi\left(K\right)$$

where the function φ is defined via the mapping function ψ by:

$$\varphi\left(K\right) = \left[\psi(K, \rho_{I}(K), \pi^{I}) - \psi(K_{B}, \rho_{I}(K), \pi^{B})\right]^{2} \quad (4)$$

This mean that the equivalent strike is a function of the index correlation curve $\rho_{I} : K \mapsto \rho_{I}\left(K\right)$. We suppose that $\rho_{I} \in \mathcal{C}^{1}[0, 1]$, where $\mathcal{C}^{1}[0, 1]$ is the set of continuously differentiable functions from $[0, 1]$ to $\mathbb{R}$. This set is a Banach Space with respect to the $\mathcal{C}^{1}$-norm defined by:

$$\| f \|_{\mathcal{C}^{1}} = \| f \|_{\infty} + \| f^{'} \|_{\infty}, \ \forall f \in \mathcal{C}^{1}[0, 1]$$

where $\| \bullet \|_{\infty}$ stands for the sup-norm. We also introduce the function $F : \mathcal{C}^{1}[0, 1] \to \mathbb{R}$ such that:

$$K^{\star} = F\left(\rho_{I}\right)$$

We assume that F is Gateaux differentiable at ρ_{I} and we denote $dF_{\rho_{I}}$ its Gateaux derivative at this point. The bespoke equity tranche is valued using the equivalent correlation:

$$\rho^{\star} = \rho_{I}(F(\rho_{I})), \ \rho^{\star} \in [0, 1]$$

Let $h : K \mapsto h\left(K\right)$ be a vector in the Banach space $\mathcal{C}^{1}[0, 1]$. We look at the first order impact of a small perturbation in the direction of h on the equivalent correlation $\rho^{\star}$. Let ε be a real number such as: $0 \leq \varepsilon \ll 1$. We denote $\rho_{\varepsilon}^{\star} = (\rho_{I} + \varepsilon h)(F(\rho_{I} + \varepsilon h))$ and we expand this expression to the first order:

$$\rho_{\varepsilon}^{\star} = \rho^{\star} + \varepsilon\left(\rho_{I}^{'}(K^{\star})dF_{\rho_{I}}(h) + h(K^{\star})\right) + o(\varepsilon) \quad (5)$$

The term $\varepsilon\rho_{I}^{'}(K^{\star})dF_{\rho_{I}}(h)$ is due to the fact that in the common Equivalent Strike framework, $K^{\star}$ depends on the index correlation curve ρ_{I}. This term disappears when the mapping function is not dependent on the correlation curve ρ_{I} like in ATM approach. The second term $\varepsilon h(K^{\star})$ is not peculiar to the Equivalent Strike framework and will always exist. We propose in this section, to change the Equivalent strike computation method, in order to remove the dependance on the index correlation curve ρ_{I} while keeping sensitivity to the bespoke and index portfolios dispersions. We will see in the next section that this new approach provides similar results to the common market practice. We propose instead of minimizing the function φ introduced in Equation (4) to minimize the function χ defined by:

$$\chi\left(K\right) = \int_{0}^{1} \left[\psi(K, \rho, \pi^{I}) - \psi(K_{B}, \rho, \pi^{B})\right]^{2} d\rho \quad (6)$$

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The new equivalent strike is then computed as the solution of the following problem:

$$\hat{K} = \mathrm{argmin}_K \chi(K)$$

and the correlation used to price the equity bespoke tranche is $\hat{\rho} = \rho_I(\hat{K})$. If we look as earlier at the first order impact of a small perturbation in the direction h where $h \in \mathcal{C}^1[0,1]$ on the correlation $\hat{\rho}$, the perturbed correlation $\hat{\rho}_\varepsilon$ (where the real ε verifies $0 \leq \varepsilon \ll 1$) is given by:

$$\hat{\rho}_\varepsilon = \hat{\rho} + \varepsilon h(K^\star) + o(\varepsilon) \tag{7}$$

In practice, we will use the following objective function:

$$\chi_D(K) = \frac{1}{N} \sum_{i=1}^{N} \left[\psi(K, \rho_i, \pi^I) - \psi(K_B, \rho_i, \pi^B) \right]^2 \tag{8}$$

where N is the number of correlation levels. The quantities $\psi(K_B, \rho_i, \pi^B)$, $i \in <1, N>$ are totally known and they can be pre-computed and stored when looking for $\hat{K}$. This will reduce computation time. If we apply this approach to the Probability Matching method the objective function defined by Equation (8) becomes:

$$\chi_D(K) = \frac{1}{N} \sum_{i=1}^{N} \left[\mathbb{P}_{\rho_i} \left[L\left(\pi^I\right) \leq K \right] - \mathbb{P}_{\rho_i} \left[L\left(\pi^B\right) \leq K_B \right] \right]^2 \tag{9}$$

Whereas when we apply this approach to the Expected Tranche Loss Matching method the objective function defined by Equation (8) becomes:

$$\chi_D(K) = \frac{1}{N} \sum_{i=1}^{N} \left[\frac{\mathbb{E}_{\rho_i} \left[\min\left(L\left(\pi^I\right), K\right) \right]}{\mathbb{E}\left[L\left(\pi^I\right) \right]} - \frac{\mathbb{E}_{\rho_i} \left[\min\left(L\left(\pi^B\right), K_B\right) \right]}{\mathbb{E}\left[L\left(\pi^B\right) \right]} \right]^2$$
$$\tag{10}$$

In the next section, we will study the behavior of this new approach with respect to the number of correlation levels N, the portfolios WAS (Weighted Average Spread)... . The results will be compared to those obtained in the common Equivalent Strike framework.

4   Numerical tests:

In this section, we mainly focus on the ETL mapping (since it is more used by practitioners than Probability Matching or any other mapping function). We define the ratio:

$$\omega = \text{Index portfolio WAS/Bespoke portfolio WAS}$$

where the WAS is given by:

$$\text{WAS} = \sum_{m=1}^{M} w_m D_m S_m \Big/ \sum_{m=1}^{M} w_m D_m$$

with: M the number of issuers and D_m, S_m, w_m are respectively the risky duration, the market spread and the weight of the issuer m, $m = 1, ..., M$ in the portfolio.

4.1 Impact of the ratio ω

We use the mapping function (10) with 10 correlation levels $\rho_i = i/9$; $i = 0, ..., 9$ and we compare both approaches for $\omega \in \{0.25, 0.5, 2, 4\}$. We also consider 2 different index base correlation curves C_1 (low correlation environment) and C_2 (high correlation environment):
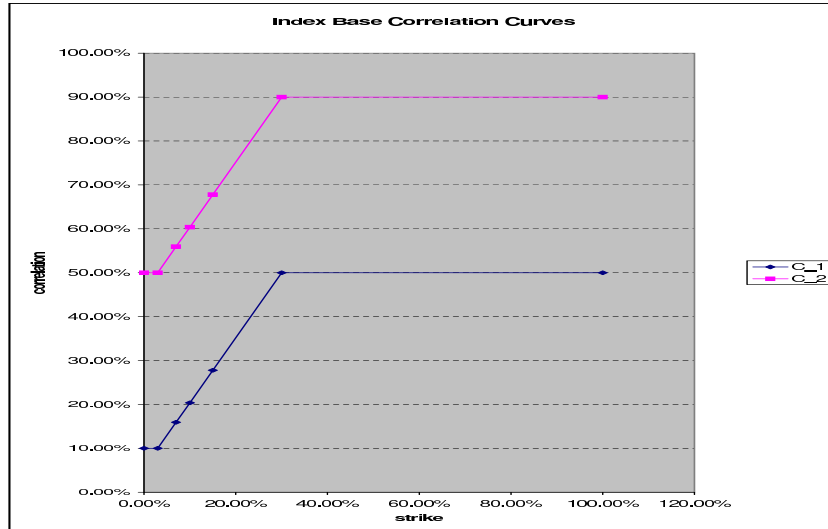
Figure 1: 5-years index base correlation

The following figure provides the behavior of Common TLE and New TLE as function of the ratio ω when using the curve C_1:
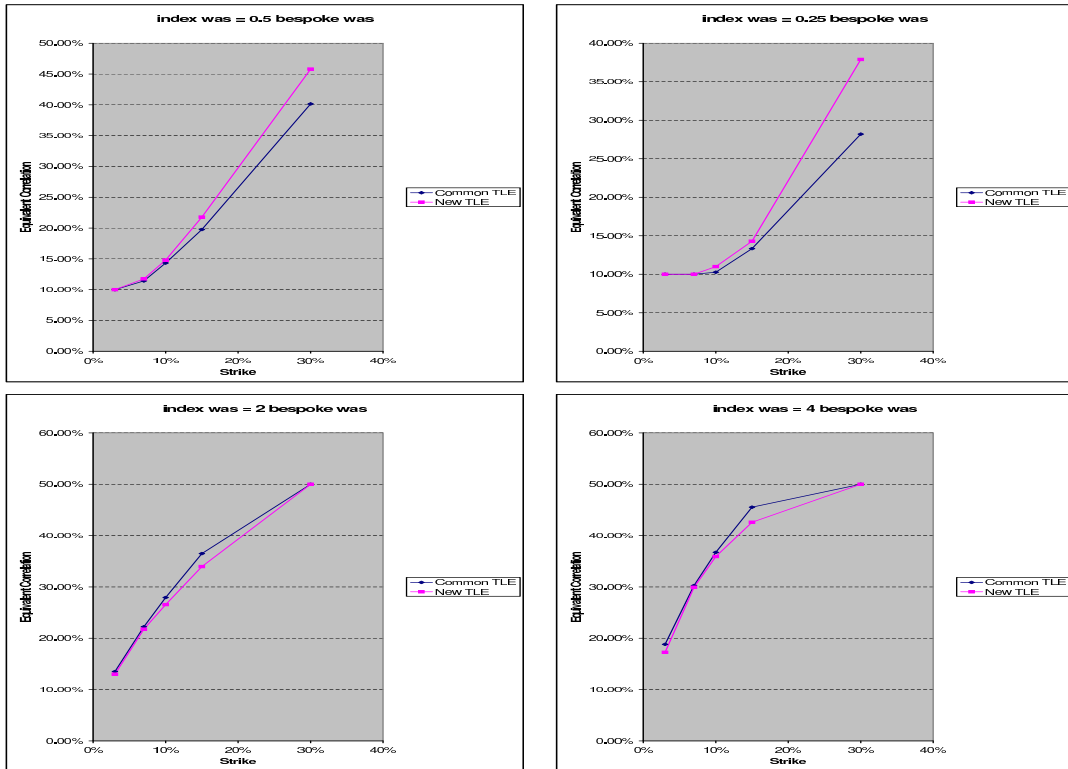
Figure 2: Common TLE and New TLE with low index base correlation

We notice that when index portfolio's WAS is smaller (respectively bigger) than bespoke portfolio's WAS, the equivalent base correlation provided by Common TLE is below (respectively above) the one provided by New TLE. The difference between both methods is bigger when $\omega = 0.25$ or 4 than when $\omega = 0.5$ or 2. We also notice that new and Common TLE are closer for junior tranches (see graphs for $\omega = 2$ or 4).

We now look at the the behavior of Common TLE and New TLE as a function of the ratio ω in high correlation environment (i.e. using the curve C_2):
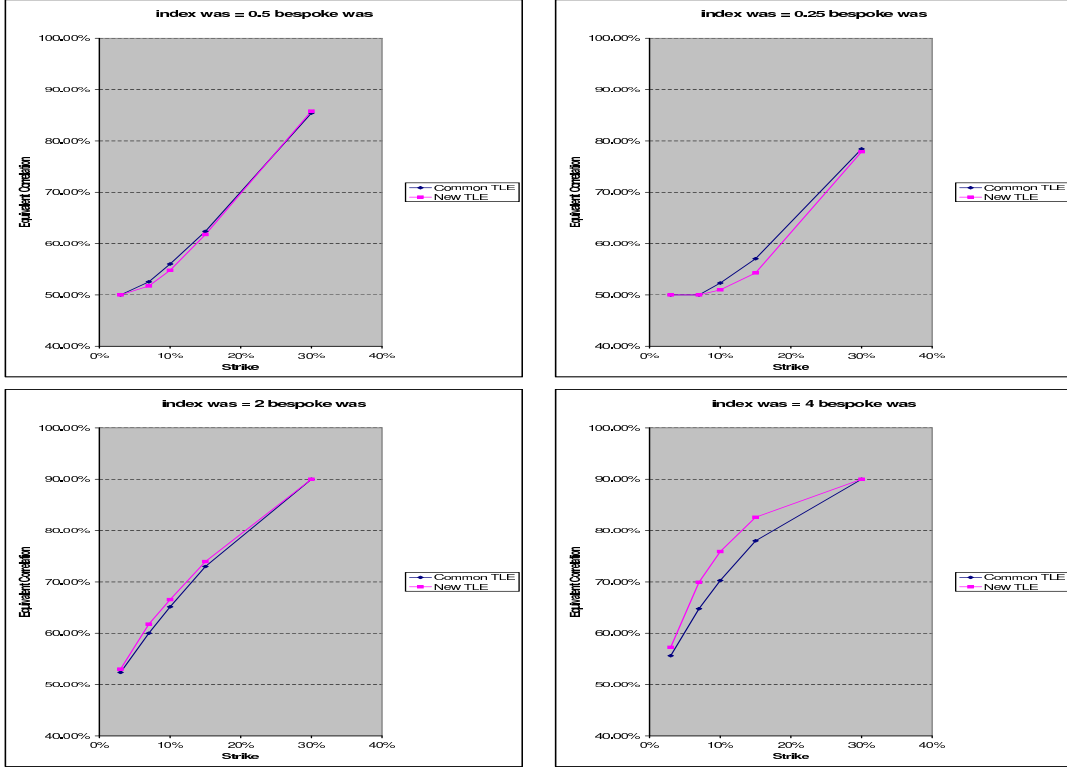
Figure 3: Common TLE and New TLE with high index base correlation

In high correlation environment, the equivalent base correlation curves relative positions is the opposite of what is observed the low correlation environment. When index portfolio's WAS is smaller (respectively bigger) than bespoke portfolio's WAS the equivalent base correlation provided by Common TLE is above (respectively below) the one provided by New TLE. Here too, the difference between both methods is bigger when $\omega = 0.25$ or 4 than when $\omega = 0.5$ or 2. We also notice that for $\omega = 0.5$ or 2 base correlation curves are close in high correlation environment that in low correlation environment.

4.2 Impact of the number of correlation levels

We use the mapping function (10) with a number of correlation levels $N \in \{2, 5, 10, 20, 50\}$ and we compare both approaches for $\omega \in \{0.5, 2\}$. We also consider as in the previous paragraph the curves C_1 and C_2.

The following figure provides the impact of the number of correlation levels on the equivalent strikes and base correlations obtained with New TLE

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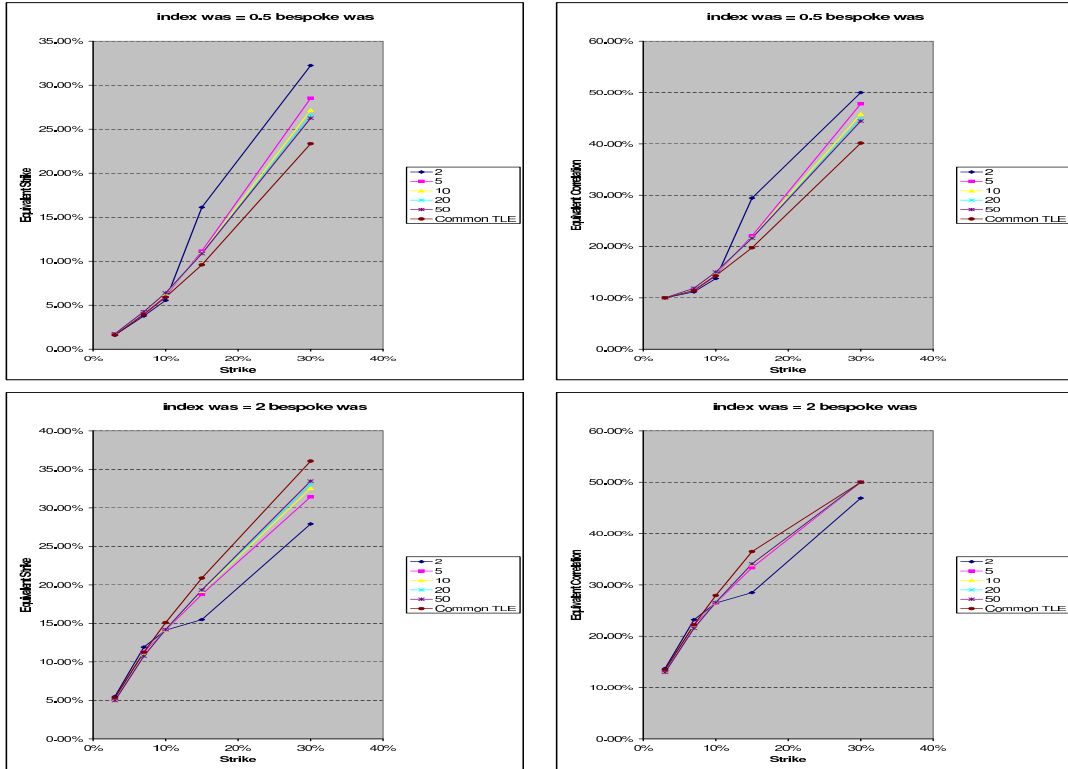
when using the curve C_1:

Figure 4: Impact of correlation levels number on New TLE with low index base correlation

We notice a convergence of the equivalent strike from $N = 10$. Except for $N = 2$, we observe that the equivalent strike obtained by New TLE decreases as the N increases when the index portfolio is tighter than the bespoke one. The equivalent strike obtained with Common TLE is higher than those obtained by New TLE. Conversely, when the index portfolio is wider than the bespoke one the equivalent strike decreases as N increases (Except for $N = 2$). The equivalent strike obtained with Common TLE is lower than those obtained by New TLE.

The following figure provides the impact of the number of correlation levels the equivalent strikes and base correlations obtained with New TLE when using the curve C_2:
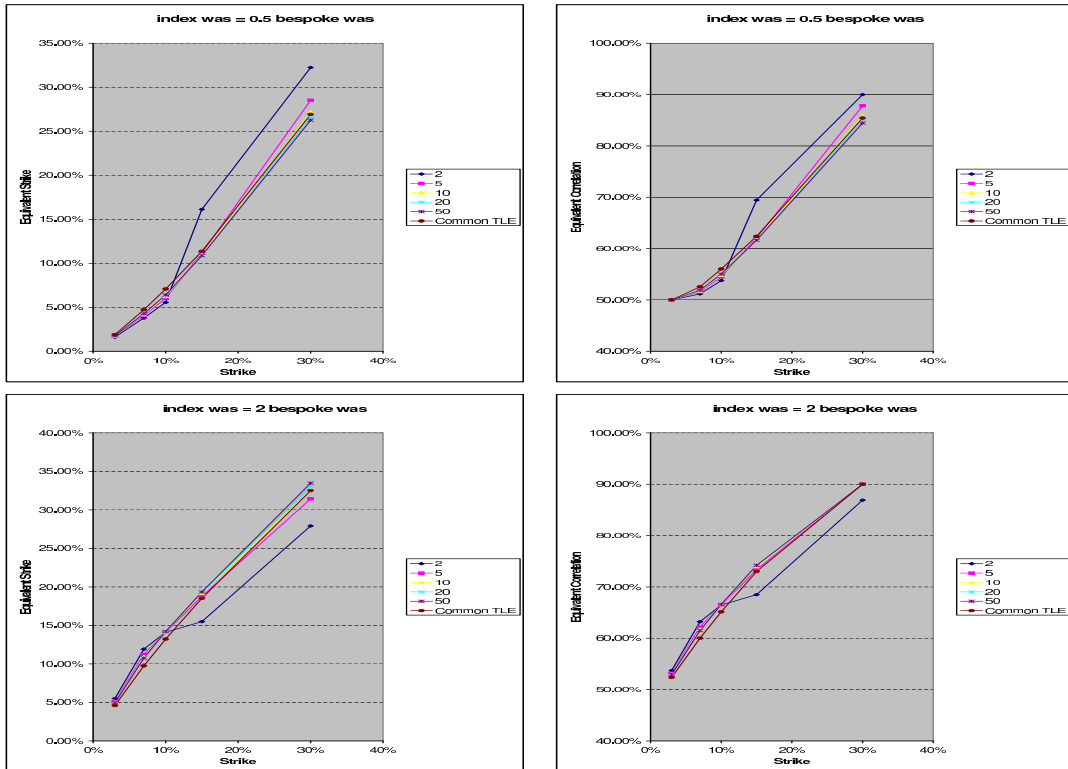
Figure 5: Impact of correlation levels number on New TLE with high index base correlation

By construction, New TLE gives the same equivalent strikes as with C_1. We notice that the equivalent strikes obtained via Common TLE are closer to the one obtained with New TLE.

4.3 Comparison of PM and ETL mapping

In this paragraph, we compare the results obtained by the common and new approaches for PM and ETL mappings using the same conditions as in paragraph 4.1. We provide below the equivalent correlations for the curves C_1 and C_2:
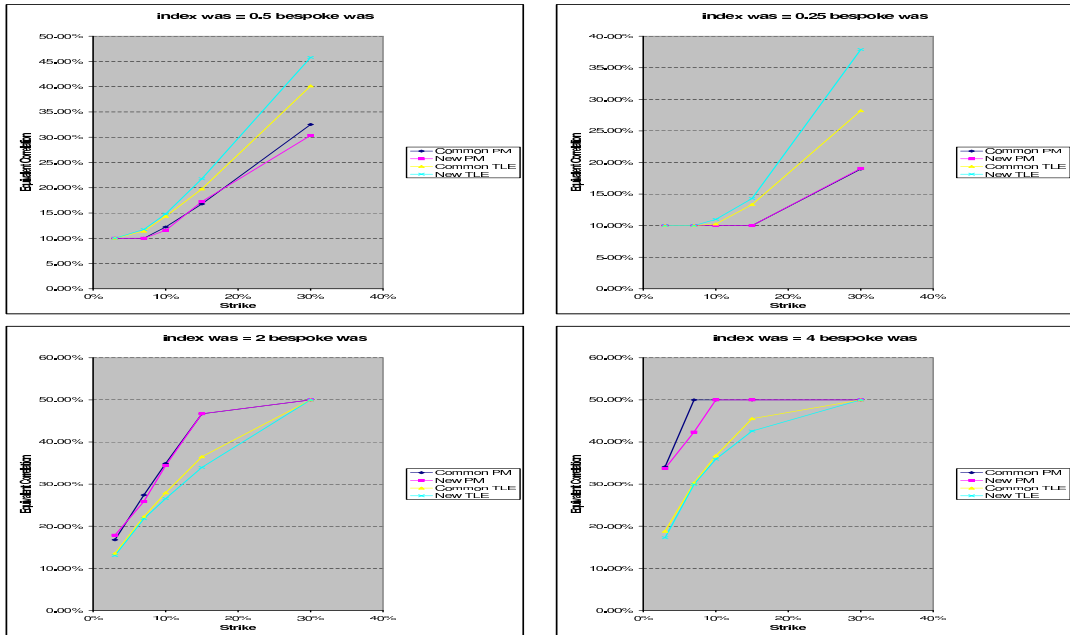
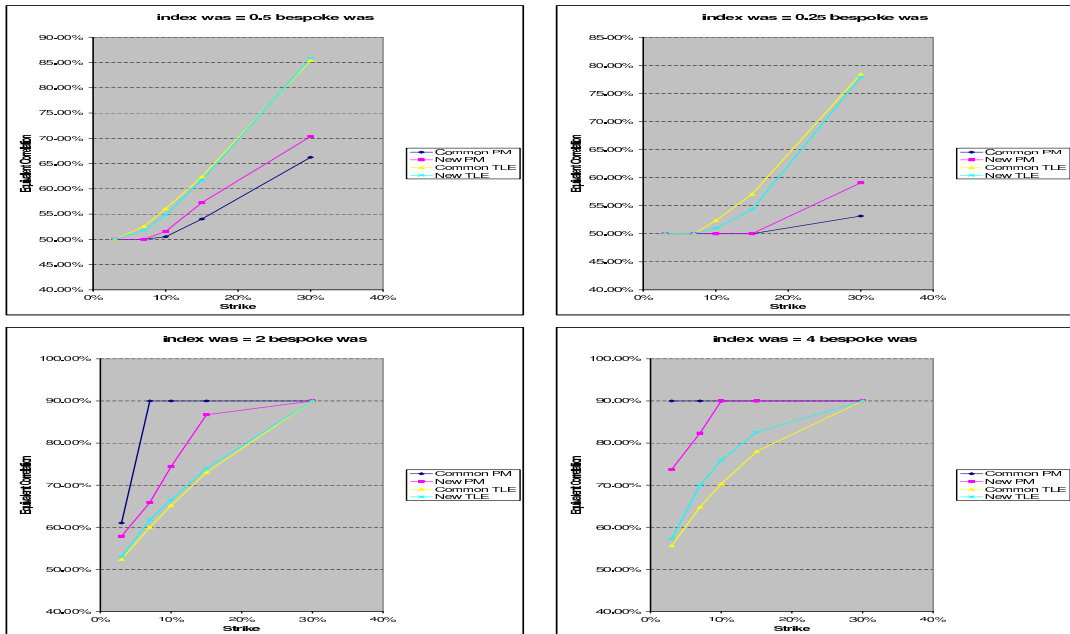Figure 6: PM and TLE with low index base correlation

Figure 7: PM and TLE with high index base correlation

We notice that with either common or new approach, TLE mapping is smoother than PM mapping (PM gives an equivalent correlation of which the shape is as discontinuous as the index base correlation). We also notice that TLE provides lower (resp. higher) equivalent base correlations then PM when the ration $\omega > 1$ (resp. $\omega < 1$). We also observe that Common and New TLE equivalent base correlation are more close than Common and New PM ones. More generally, we notice that the equivalent base correlation shape and behavior mainly depends on the mapping function (PM vs ETL) rather than the fine-tuning approach (Common vs New).

4.4 Stability of Common and New ETL mapping

In this section we look at the equivalent base correlation sensitivity behavior. Thus, we consider the following extreme example of 2 discontinuous index base correlation curves C_1 and C_2:
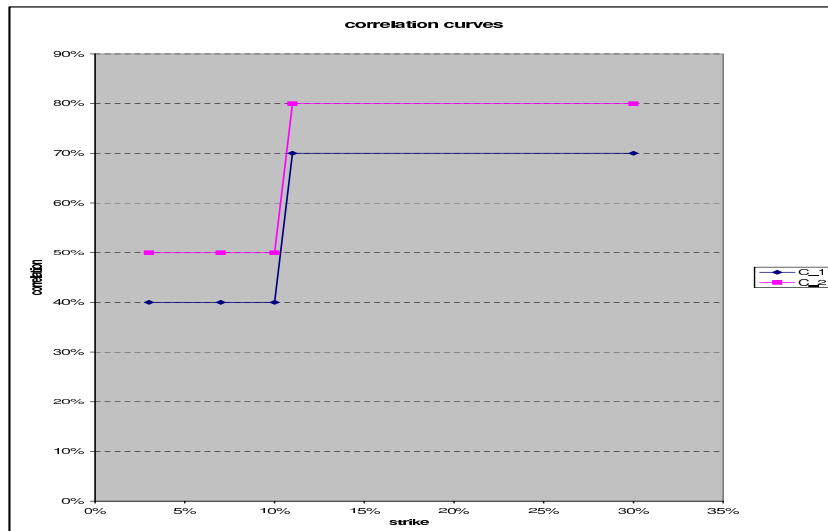

Figure 8: 5-years index base correlation

We also consider an index portfolio with a WAS of 150 bp and bespoke one with a WAS of 175 bp. We then look at the 5-years equivalent base correlation in the neighborhood of the strike 10.5% using either index base correlation curves C_1 or C_2 for both TLE methods (i.e. Common and New)
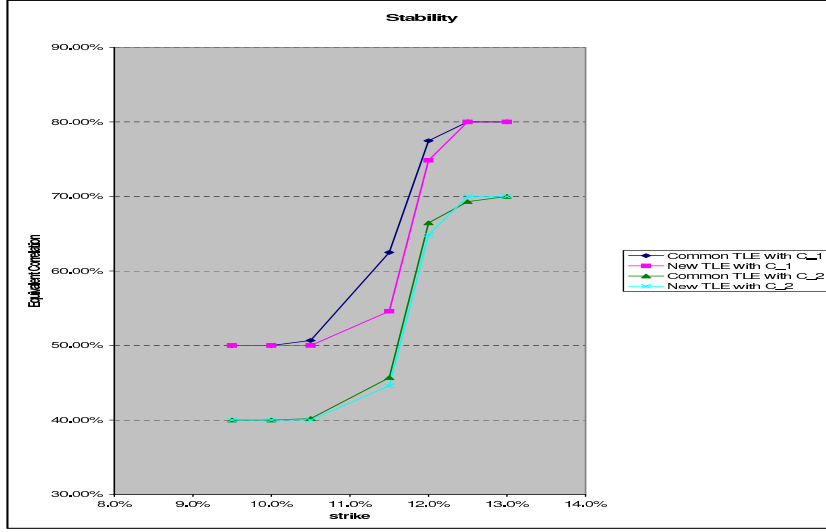
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Figure 9: Stability of the equivalent correlation sensitivity w.r.t. strike

When using New TLE, we notice that a bump in the index base correlation of 10% leads to a bump in the equivalent strike of a 10% as expected from Equation (7). When using Common TLE, we notice that the equivalent correlation variation is 16.8% which is much higher (The extra bump of 6.8% is associated to the term $\varepsilon \rho'_I(K^\star) dF_{\rho_I}(h)$ appearing in Equation (5)). Besides, we notice a "discontinuity" of the equivalent base correlation variation around the strike 10.5% (with Common TLE, the equivalent base correlation variation is close to 10% at strikes 10% and 11%).

4.5 Impact of extrapolation on ETL mapping

In this paragraph, we look at the impact of the extrapolation method for ETL mapping. We consider a bespoke and index portfolios such us $\omega = 2$ and we focus on the left side extrapolation. We consider the curve C_2 introduced in paragraph 4.1 with 3 extrapolations:

$\mathcal{E}_1$ Flat extrapolation after the strike 30%

$\mathcal{E}_2$ Linear extrapolation after the strike 30% with a slope equal to the slope between 15% and 30%

$\mathcal{E}_3$ Linear extrapolation after the strike 30% with a slope twice bigger than the slope between 15% and 30%

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We then look at the equivalent strike and correlations associated with a bespoke strike of 30% for the 3 extrapolations introduced above:

Equivalent strike as a function of the left extrapolation slope:

slope	0	1	2
Common TLE	32.51%	32.22%	31.98%
New TLE	32.53%	32.53%	32.53%

Equivalent correlation as a function of the left extrapolation slope:

slope	0	1	2
Common TLE	90%	92.22%	93.97%
$\rho_I(32.51\%)$	90%	92.51%	95.01%
New TLE	90%	93.53%	95.05%

The difference between the equivalent correlation provided by Common TLE and $\rho_I(32.51\%)$ is mainly due to the dependance of the Common TLE on the index curve ρ_I. This leads to the following break-even for the $[30\%, 100\%]$ super-senior tranche:

Break-even spread as a function of the left extrapolation slope:

slope	0	1	2
Common TLE	0.62%	0.67%	0.72%
$\rho_I(32.51\%)$	0.62%	0.68%	0.75%
New TLE	0.62%	0.68%	0.75%

We see that extrapolation $\mathcal{E}_3$ impact in Common TLE is about 3 bps.

4.6   Real case

We present in this paragraph the equivalent 5-years base correlation curve of CDX HY S9 using CDX IG S9 as a reference index as of 06/01/2011:
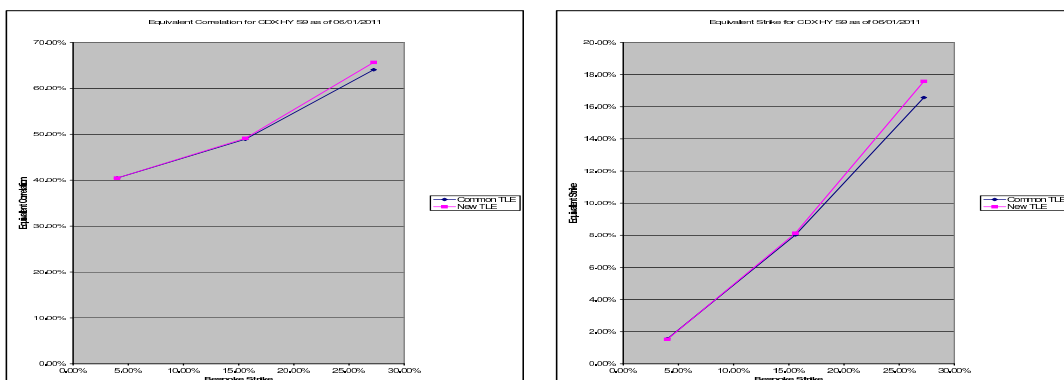
Figure 10: CDX HY S9 mapped via Common and New TLE to CDX IG S9

We notice that both methods give very close results. We did many tests with other portfolios. They all showed that Common and New TLE results are close.

4.7   Index tranche sensitivities

We consider a 100 Mio USD, 5-years [3.981%, 15.609%]-tranche on CDX HY S9. We first, price this tranche (regarded as bespoke) as of 06/01/2011 with Common and New TLE using CDX IG S9 as a reference index. We provide in the following table the prices given by both TLE approaches [2] :

TLE	Price in USD	Eq. att. strike	Eq. att. correl.	Eq. det. strike	Eq. det. correl
Common	44,034,611	1.348%	43.887%	7.071%	50.524%
New	44,036,069	1.290%	43.887%	7.070%	50.521%

Table 1: Pricing outputs

We then, provide the hedge in Mio of USD of this bespoke tranche with junior 5Y tranches of CDX IG S9

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[2]The equivalent attachment correlations in Common and New TLE are the same even if equivalent attachment strikes are different, because the 5Y-CDX IG S9 correlation is extrapolated flat below the strike 2.36 %

TLE	[0- 2.36]	[2.36 - 6.49]	[6.49 - 9.59]	[9.59 - 14.76]	[14.76 - 30.25]	Total
Common	24,572,935	92,400,206	12,522,328	0	0	129,495,469
New	22,092,188	88,177,749	11,926,527	0	0	122,196,464

Table 2: Tranche notional of hedging CDX IG S9 5Y tranches

Both approaches provide similar hedging figures (even if the hedge with New TLE is slightly below the one provided by Common TLE). The advantage of New TLE approach is that it is faster than Common TLE approach. Actually, when computing the hedges above, one has to compute the equivalent correlations (and thus strikes) for different perturbation scenarios of the CDX IG S9 tranches market up-front quotes (and thus for different perturbation scenarios of the 5Y-CDX IG S9 base correlation curve). In the New TLE approach the equivalent strike are computed only once (when computing the price) which reduces the computation time. We provide below the computation time for these 2 approaches using a computation grid[3]:

TLE	Computation Time
Common	110 sec
New	76 sec

Table 3: Index tranche hedging batch computation time

5   Conclusion

We presented a fine-tuning of some mapping functions used in the Equivalent Strike framework. In this approach, the equivalent strike is independent from the index base correlation shape. Our numerical tests showed that the new approach is more stable than the common one. For realistic cases, the equivalent correlations obtained via New or Common TLE approaches are very close.

Fine-tuned mapping functions behave similarly to the common ones as functions of portfolios dispersions and ratio of portfolio WAS. Nevertheless, they have the advantage of providing an equivalent strike independent from the index base correlation shape. In particular, equivalent strikes are not sensitive to extrapolation (and even interpolation) hypothesis. This feature

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[3]The durations provided above take into account hedge computation time as well as data transfer on the grid.

makes the index tranche hedging computation of a bespoke tranche with the new approach faster than what it can be achieved with the common approach.

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