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JPMorgan

Trading Credit Curves I

Understanding The Theory Behind Credit Curves

Investment Strategies: No. 19

- In our series '*Trading Credit Curves*' we introduce our framework for understanding the P+L drivers in credit curve trades.
- This first note in the series looks at the theory behind credit curves to set the foundations for our analysis.
- We look back to CDS fundamentals to understand the concepts we will need to look at Slide, Convexity and Breakevens which are important to trading credit curves.
- To understand the shape of the curve we examine some often unaddressed issues about credit curves, namely why they are (mostly) upward sloping – the fact a company has less chance of surviving over a longer period does not on its own mean that credit curves should slope upwards.

Introduction

Credit curve trading has become an important trading strategy for many credit investors as the changing shape of credit curves can give rise to P+L opportunities. However, analyzing how to position for a view that 'the curve of Company A will steepen' has often ignored some of the drivers of P+L in these trades. In this series we examine the concepts involved in curve trading and introduce our analysis framework that fully accounts for Slide and Convexity.

This first note, *Trading Credit Curves I*, focuses on the theoretical underpinning of our analysis of curve trading.

Figure 1: Par CDS Spreads and 1y Forward Spreads

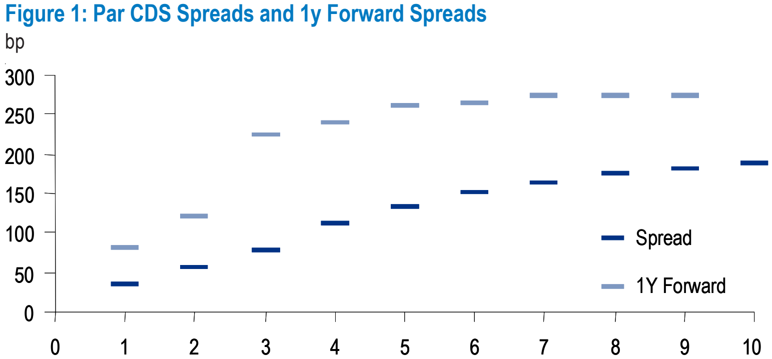

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Table of Contents

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Default Probabilities & CDS Pricing

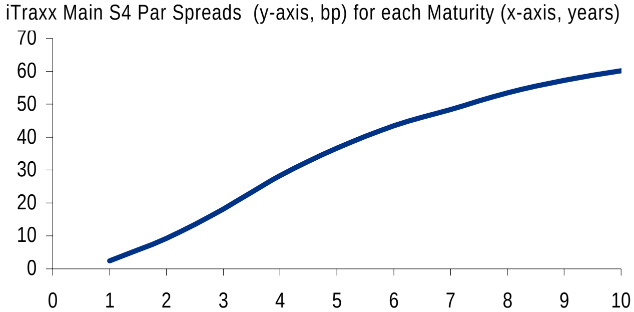
Although taking a view on whether credit curves will flatten or steepen does not necessarily require a full understanding of the theory around how we create curves in credit, any analysis of how these trades actually perform does involve discussing the role of concepts such as Survival Probabilities, Hazard Rates, Forward Rates, Durations and Convexity. In this note we deal with the theory behind these concepts to set up our analysis of curve trading. Readers who know all of this can skip straight to *Trading Credit Curves II* where we look at how to analyse the P+L in curve trades.

Survival Probabilities, Default Probabilities and Hazard Rates.

We talk about credit *curves* because the spread demanded for buying or selling protection generally varies with the length of that protection. In other words, buying protection for 10 years usually means paying a higher period fee (spread) than buying protection for 5 years (making an upward sloping curve). We plot each spread against the time the protection covers (1Y, 2Y,..., 10Y) to give us a credit curve, as in Figure 2.

Figure 2: The Shape of the Credit Curve

iTraxx Main S4 Par Spreads (y-axis, bp) for each Maturity (x-axis, years)



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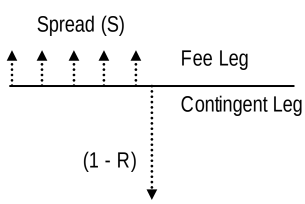
Each point along this credit curve represents a spread that ensures the present value of the expected spread payments (Fee Leg) equals the present value of the payment on default (Contingent Leg), i.e. for any CDS contract:

$$\text{PV(Fee Leg)} = \text{PV(Contingent Leg)}$$

Figure 3: CDS Fee and Contingent Leg



Source: JPMorgan

Given the spread will be paid as long as the credit (reference entity) has not defaulted and the contingent leg payment (1—Recovery Rate) occurs only if there is a default in a period, we can write for a Par CDS contract (with a Notional of 1):

$$\underbrace{S_n.\sum_{i=1}^{n}\Delta_i.Ps_i.DF_i + Accrual\ on\ Default}_{\text{PV(Fee Leg)}} = \underbrace{(1-R).\sum_{i=1}^{n}(Ps_{(i-1)} - Ps_i).DF_i}_{\text{PV(Contingent Leg)}} \qquad [1]$$

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Where,
S_n = Spread for protection to period n
Δ_i = Length of time period i in years
Ps_i = Probability of Survival to time i
DF_i = Risk-free Discount Factor to time i
R = Recovery Rate on default

$$\text{Accrual on Default} = S_n.\sum_{i=1}^{n}\frac{\Delta_i}{2}.(Ps_{(i-1)} - Ps_i).DF_i$$

Three Default Probabilities
There are actually three measures commonly referred to as 'default probabilities':

1. The Cumulative Probability of Default – This is the probability of there having been any default up to a particular period. This increases over time.

2. Conditional Probabilities of Default or Hazard Rates – This is the probability of there being a default in a given period, conditional on there not having been a default up to that period. I.e. Assuming that we haven't defaulted up to the start of Period 3, this is the probability of then defaulting in Period 3.

3. Unconditional Default Probabilities – This is the probability of there being a default in a particular period as seen at the current time. In our current view, to default in Period 3 we need to survive until the start of Period 3 and then default in that period. This is also the probability of surviving to the start of the period minus the probability of surviving to the end of the period.

Building Survival Probabilities from Hazard Rates
We typically model Survival Probabilities by making them a function of a Hazard Rate. The Hazard Rate (denoted as λ) is the conditional probability of default in a period or in plain language 'the probability of the company defaulting over the period given that it has not defaulted up to the start of the period'. For the first period, i=1, the Probability of Survival (Ps) is the probability of not having defaulted in the period, or (1 – Hazard Rate). So, we can write:

For i=1, $$Ps_1 = (1-\lambda_1)$$

Where, λ_1 is the hazard rate (conditional default probability) in period 1.

For the next period, i=2, the Probability of Survival is the probability of surviving (not defaulting in) period 1 **and** the probability of surviving (not defaulting in) period 2, i.e.:

For i=2, $$Ps_2 = (1-\lambda_1) . (1-\lambda_2)$$

(See Footnote 1 for a formal treatment of hazard rates.)

The probability of default (Pd) (as seen at time 0) in a given period is then just the probability of surviving to the start of the period minus the probability of surviving to the end of it, i.e.:

For i=2, $$Pd_2 = Ps_1 - Ps_2 = (1-\lambda_1) . \lambda_2$$

This shows how we can build up the Probabilities of Survival (PS_i) we used for CDS pricing in Equation [1].

In theory, that means we could calculate a CDS Spread *from* Probabilities of Survival (which really means from the period hazard rates). In practice, the Spread is readily observable in the market and instead we can back out the Probability of Survival to any time period implied by the market spread, which means we can back out the Hazard Rates (conditional probabilities of default) for each period using market spreads.

[1] Formal treatment of Survival Probabilities is to model using continuous time, such that the probability of survival over period δt, $Ps_{(t,\, t+\delta t)} = 1-\lambda_t\,\delta t \approx e^{-\lambda_t \delta t}$. So, for any time t, $Ps_t = e^{-\int_0^t \lambda u du}$.

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Bootstrapping Credit Curves

We call the hazard rate we derive from market spreads the 'Clean Spread'[2]. In terms of pricing a CDS contract, we could in theory solve Equation [1] using a single hazard rate. However, we can also *bootstrap* a hazard rate implied for each period from the market-observed credit curve. To do this we use the Period 1 Spread to imply the hazard rate for Period 1. For Period 2 we use the Period 1 hazard rate to calculate the survival probability for Period 1 and use the Spread observed for Period 2 to calculate the hazard rate for Period 2. In that way, we are using the market pricing of default risk in Period 1 when we price our Period 2 CDS contract (i.e. when we back out the survival probability for Period 2). Continuing this process, we can *bootstrap* the hazard rates (a.k.a 'clean spreads') implied for each period.

We use these bootstrapped hazard rates whenever we Mark-to-Market a CDS position as we use our hazard rates to build the Survival Probabilities used in calculating our Risky Annuity (see Grey Box), where:

Risky Annuity = PV(Fee Payments + Accruals on Default[3])

$$RiskyAnnuity \approx 1.\sum_{i=1}^{n} \Delta_i.Ps_i.DF_i + 1.\sum_{i=1}^{n} \frac{\Delta_i}{2}(Ps_{(i-1)} - PS_i).DF_i \qquad [2]$$

The MTM of a CDS contract is (for a seller of protection) therefore:

$$MTM = (S_{Initial} - S_{Current}) \;.\; Risky\ Annuity_{Current} \;.\; Notional \qquad [3]$$

In practice, CDS unwinds are sometimes calculated with flat curves for conveniance.

Risky Annuities and Risky Durations (DV01)

Many market participants use the terms Risky Duration (DV01) and Risky Annuity interchangeably. In reality they are not the same but for CDS contracts trading at Par they are very close, which is why Risky Duration is sometimes (inaccurately) used instead of Risky Annuity. Appendix I formally shows how to equate Risky Duration (DV01) and Risky Annuity and why the approximation is fair for small spread movements when looking at a Par CDS contract.

We define the terms as follows:

Risky Annuity is the present value of a 1bp risky annuity as defined in Equation [2] above. We use the Risky Annuity to Mark-to-Market a CDS contract as shown in Equation [3].

Risky Duration (DV01) relates to a trade and is the change in mark-to-market of a CDS trade for a 1bp parallel shift in spreads. We mainly use Risky Duration for risk analysis of a trade for a 1bp shift in spreads and therefore it is used to Duration-Weight curve trades.

Appendix I shows that for a Par CDS trade and a small change in spreads Risky Annuity ≈ Risky Duration (DV01). However for a contract trading away from Par and for larger spread movements this approximation becomes increasingly inaccurate. We will mostly be talking about Risky Annuities when we discuss Marking-to-Market a CDS position and when we move on to discuss Convexity.

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[2] Clean Spreads are analogous to zero rates that we derive from bootstrapping risk-free interest rates in the sense that we derive a rate from the market curve that we use in pricing other instruments.

[3] Risky Annuity is sometimes defined without the Accruals on Default. This is really just a matter of convention and the Accruals part is much less significant in terms of pricing.

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The Shape of Credit Curves

The concepts of Survival Probability, Default Probability and Hazard Rates that we have seen so far help us to price a CDS contract and also to explain the shape of credit curves.

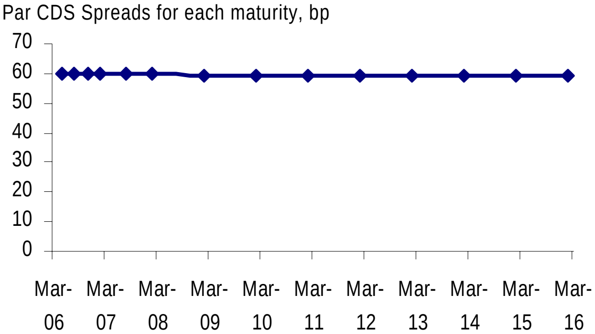
Why do many CDS curves slope upwards?

The answer many would give to this is that investors demand greater compensation, or Spread, for giving protection for longer periods as the probability of defaulting increases over time. However, whilst it's true that the cumulative probability of default does increase over time, this by itself does not imply an upward sloping credit curve – flat or even downward sloping curves also imply the (cumulative) probability of default increasing over time. To understand why curves usually slope upwards, we will first look at what flat spread curves imply.

What do Flat Curves Imply?
A flat spread curve, as in Figure 4, does imply a declining Probability of Survival over time (and therefore an increasing Probability of Default), as shown in Figure 5. So, in order to justify our thought that the probability of default increases with time, we don't need an upward sloping spread curve.

Figure 4: Flat Spread Curve

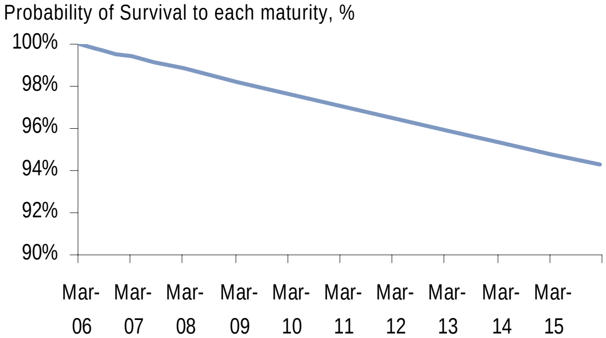
Par CDS Spreads for each maturity, bp



Source: JPMorgan

Figure 5: Probability of Survival for Flat Spread Curve

Probability of Survival to each maturity, %



Source: JPMorgan

The key to understanding why we have *upward sloping* curves, is to look at the hazard rate implied by the shape of the curve: *flat curves imply* ***constant*** *hazard rates* (the conditional probability of default is the same in each period). In other words, if the hazard rate is constant, spreads should be constant over time and credit curves should be flat[4].

If the hazard rate (λ) is constant, then we can show that:

For i=n, $$Ps_n = (1-\lambda)^n$$

This formula shows that to move from the Probability of Survival (in Figure 5) in one period to the next we just multiply by (1- Hazard Rate).

[4] For flat curves we can also calculate the hazard rate as: $\lambda = \dfrac{S}{(1-R)}$

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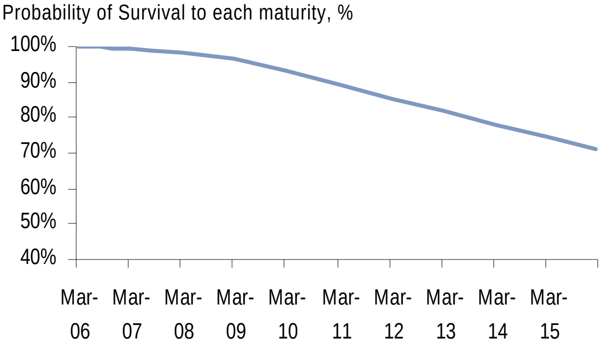
So What Does an Upward-Sloping Curve Imply?
For curves to slope upwards, we need the hazard rate to be *increasing over time*. Intuitively, this means that the probability of defaulting in any period (conditional on not having defaulted until then) increases as time goes on. Upward sloping curves mean that the market is implying not only that companies are more likely to default with every year that goes by, but also that the likelihood in each year is ever increasing. Credit risk is therefore getting increasingly worse for every year into the future[5].

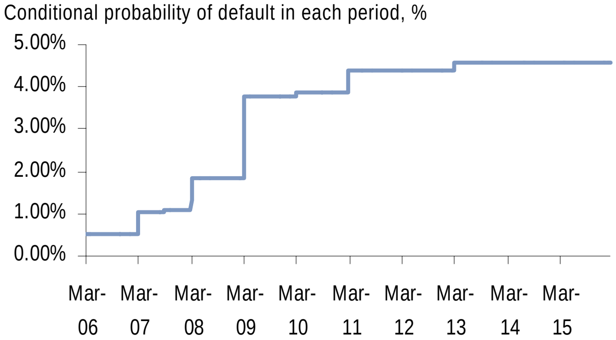
An upward sloping curve, such as in Figure 2, implies a survival probability as shown in Figure 6, which declines at an increasing rate over time. This means that we have an increasing hazard rate for each period as shown in Figure 7.

Figure 6: Probability of Survival for Upward Sloping Spread Curve



Source: JPMorgan

Figure 7: Hazard Rates for Upward Sloping Spread Curve



Source: JPMorgan

As Figure 7 shows, we tend to model hazard rates as a step function, meaning we hold them constant between changes in spreads. This means that we will have constant hazard rates between every period, which will mean Flat Forwards, or constant Forward Spreads between spread changes. This can make a difference in terms of how we look at Forwards and Slide.

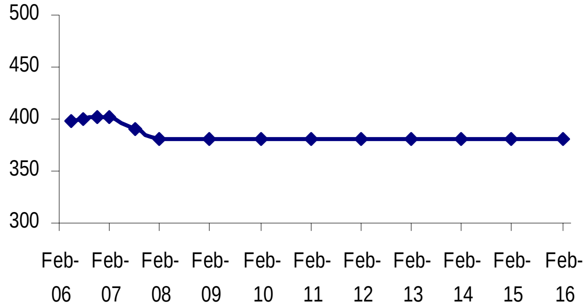
Downward Sloping Credit Curves

Companies with downward sloping curves have decreasing hazard rates, as can be seen when looking at GMAC (see Figure 8). This does not mean that the cumulative probability of default decreases, rather it implies a higher conditional probability of default (hazard rate) in earlier years with a lower conditional probability of default in later periods (see Figure 9). This is typically seen in lower rated companies where there is a higher probability of default in each of the immediate years, but if the company survives this initial period then it will be in better shape and less likely to (conditionally) default over subsequent periods.

[5] One explanation justifying this can be seen by looking at annual company transition matrices. Given that default is an 'absorbing state' in these matrices, companies will tend to deteriorate in credit quality over time. The annual probability of default increases for each rating state the lower we move and so the annual probability of default increases over time.

Figure 8: Downward Sloping Par CDS Spreads

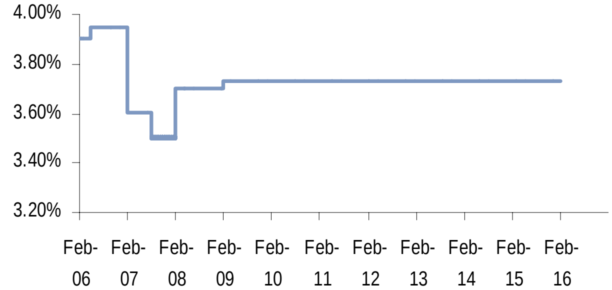
GMAC Curve, bp



Source: JPMorgan

Figure 9: Bootstrapped Hazard Rates

%



Source: JPMorgan

Having see what the shape of credit curves tells us, we now move on to look at how we calculate Forward Spreads using the curve.

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Forwards in Credit

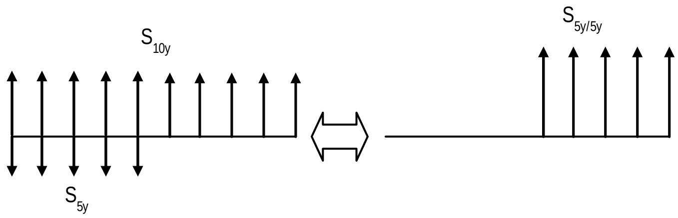
Forward rates and their meaning

In CDS, a Forward is a CDS contract where protection starts at a point in the future ('forward starting'). For example, a 5y/5y Forward is a 5y CDS contract starting in 5 years[6]. The Forward Spread is then the fair spread agreed today for entering into the CDS contract at a future point.

The Forward is priced so that the present value of a long risk 5y/5y Forward trade is equivalent to the present value of selling protection for 10y and buying protection for 5y, where the position is default neutral for the first 5 years and long credit risk for the second 5 years, as illustrated in Figure 10.

Figure 10: Forward Cashflows For Long Risk 5y/5y Forward

Spreads, bp



Source: JPMorgan

Deriving the Forward Equation

The Forward Spread is struck so that the present value of the forward starting protection is equal to the present value of the 10y minus 5y protection.

Given the default protection of these positions is the same (i.e. no default risk for the first 5 years and long default risk on the notional for the last 5y), the present value of the fee legs must be equal as well. We can think of the Forward as having sold protection for 10y at the Forward Spread and bought protection for 5y at the Forward Spread. The fee legs on the first 5 years net out meaning we are left with a forward-starting annuity.

Given that the present value of a 10y annuity (notional of 1) = $S_{10y} \, . \, A_{10y}$

Where,
S_{10y} = The Spread for a 10 year CDS contract
A_{10y} = The Risky Annuity for a 10 year CDS contract

We can write:

$$S_{10y} \, . \, A_{10y} - S_{5y} \, . \, A_{5y} = S_{5y/5y} \, . \, A_{10y} - S_{5y/5y} \, . \, A_{5y}$$

6 See also, *Credit Curves and Forward Spreads* (J Due, May 2004).

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Where,
$S_{t1,\,t2}$ = Spread on t_2-t_1 protection starting in t_1 years time

Solving for the Forward Spread:

$$S_{5y/5y} = \frac{S_{10y}.A_{10y} - S_{5y}.A_{5y}}{A_{10y} - A_{5y}}$$

For example, Table 1 shows a 5y CDS contract at 75bp (5y Risky Annuity is 4.50) and a 10y CDS contract at 100bp (10y Risky Annuity is 8.50).

$$\text{The Forward Spread} = \frac{(100 \times 8.5) - (75 \times 4.5)}{8.5 - 4.5} = 128bp$$

Table 1: 5y/5y Forward Calculations

	5y	10y
Spread (bp)	75	100
Risky Annuity	4.5	8.5
		5y/5y
Forward Spread (bp)		128

Source: JPMorgan

For a flat curve, Forward Spread = Par Spread, as the hazard rate over any period is constant meaning the cost of forward starting protection for a given horizon length (i.e. 5 years) is the same as protection starting now for that horizon length. We can show that this is the case for flat curves, since $S_{t2} = S_{t1} = S$:

$$S_{t1,\,t2} = \frac{S_{t2}.A_{t2} - S_{t1}.A_{t1}}{A_{t2} - A_{t1}} = \frac{S.(A_{t2} - A_{t1})}{A_{t2} - A_{t1}} = S$$

We refer to an equal-notional curve trade as a Forward, as the position is present value equivalent to having entered a forward-starting CDS contract. To more closely replicate the true Forward we must strike both legs at the Forward Spread. In practice, an equal-notional curve trade for an upward-sloping curve (e.g. sell 10y protection, buy 5y protection on equal notionals) will have a residual annuity cashflow as the 10y spread will be higher than the 5y. Market practice can be to strike both legs with a spread equal to one of the legs and to have an upfront payment (the risky present value of the residual spread) so that there are no fee payments in the first 5 years. In that sense replicating the Forward with 5y and 10y protection is not truly ‘forward starting’ as there needs to be some payment before 5 years and protection on both legs starts immediately.

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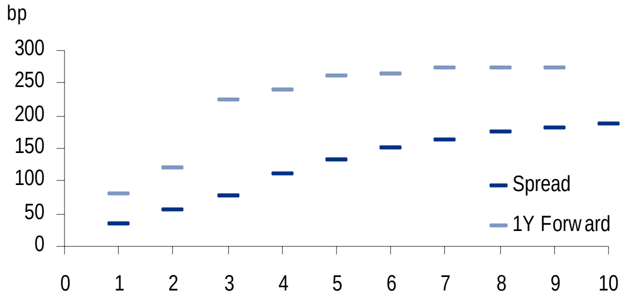
What do forward rates actually look like?

When we model forward rates in credit we use Flat Forwards meaning we keep the forward rate constant between spread changes (see Figure 11). This is a result of the decision to use constant (flat) hazard rates between each spread change.

Figure 11: Par CDS Spreads and 1y Forward Spreads



Source: JPMorgan

This can be important when we look at the Slide in our CDS positions (and curve trades) which we discuss in *Trading Credit Curves II.*

Summary

We have seen how we can understand the shape of the credit curve and how this relates to the building blocks of default probabilities and hazard rates. These concepts will form the theoretical background as we discuss our framework for analysing curve trades using Slide, Duration-Weighting and Convexity. The next note in the series, *Trading Credit Curves II*, moves on to outline our curve trading analysis framework and to apply it to common curve trading strategies.

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Appendix I: Risky Annuities and Risky Durations (DV01)

This Appendix shows how we accurately treat Risky Annuity and Risky Duration (DV01) and the relationship between the two. We define Risky Annuity and Risky Duration (DV01) as follows:

Risky Annuity is the present value of a 1bp risky annuity stream:

$$RiskyAnnuity = A_s \approx 1.\sum_{i=1}^{n} \Delta_i.Ps_i.DF_i + 1.\sum_{i=1}^{n} \frac{\Delta_i}{2}(Ps_{i-1} - PS_i).DF_i$$

where A_s = Risky Annuity for an annuity lasting n periods, given spread level S

Risky Duration (DV01) relates to a trade and is the change in mark-to-market of a CDS trade for a 1bp parallel shift in spreads.

The Mark-to-Market for a long risk CDS trade using Equation [3], (Notional = 1) is:

$$\mathrm{MTM}_{S_{current}} = (\mathrm{S_{Initial}} - \mathrm{S_{Current}}) \ . \ \mathrm{A}_{S_{current}}$$

$$MTM_{1bp\ shift} = (S_{Initial} - S_{Current\ +1bp}) \ . \ A_{S_{current\ +1bp}}$$

Given, $DV01\ (Risky\ Duration) = MTM_{1bp\ shift} - MTM_{S_{current}}$

$$DV01 = [\ (S_{Initial} - S_{Current\ +1bp}) \ . \ A_{S_{current\ +1bp}}\ ] - [(S_{Initial} - S_{Current}) \ . \ A_{S_{current}}\ ]$$

Using,

$$S_{Current\ +1bp} \ . \ A_{S_{current\ +1bp}} = S_{Current} \ . \ A_{S_{current\ +1bp}} + 1bp \ . \ A_{S_{current\ +1bp}}$$

We can show that:

$$DV01 = -\ A_{S_{current\ +1bp}} + (S_{Initial} - S_{Current}) \ .(A_{S_{current\ +1bp}} - A_{S_{current}})$$

For a par trade $S_{Initial} = S_{Current}$, and since Risky Annuities do not change by a large amount for a 1bp change in Spread, we get:

$\mathrm{DV01} = -\ \mathrm{A}_{\mathrm{Scurrent\ +1bp}} \approx -\ \mathrm{A}_{\mathrm{Scurrent}}$ I.e. Risky Duration $\approx$ Risky Annuity

This approximation can become inaccurate if we are looking at a trade that is far off-market, where $S_{Initial} - S_{Current}$ becomes significant, causing the Risky Duration to move away from the Risky Annuity.

Also, as we start looking at spread shifts larger than 1bp, the shifted Risky Annuity will begin to vary more from the current Risky Annuity (a Convexity effect) and therefore we need to make sure we are using the correct Risky Annuity to Mark-to-Market and not the Risky Duration (DV01) approximation.

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