Climate Change Valuation Adjustment (CCVA): using parameterized climate change impacts

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Abstract

We introduce Climate Change Valuation Adjustment to capture climate change impacts on XVA that are currently invisible assuming typical market practice. To discuss such impacts on XVA from changes to instantaneous hazard rates we introduce a flexible and expressive parameterizations to capture the path of this impact to climate change endpoints, and transition effects. Finally we provide quantification of examples of typical interest where there is risk of economic stress from sea level change up to 2101, and from transformations of business models. We find that even with the slowest possible uniform approach to a climate change impact in 2101 there can still be significant XVA impacts on interest rate swaps of 20 year or more maturity. Transformation effects on XVA are strongly dependent on timing and duration of business model transformation. Using a parameterized approach enables discussion with stakeholders of economic impacts on XVA, whatever the details behind the climate impact.

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1 Introduction

Climate change risk comprises physical, transition, and liability risks to assets, companies and sovereign entities[1] (Bank of England 2019; European Central Bank 2020). Credit valuation adjustment (CVA) quantifies expected loss on counterparty default (Green 2015; BCBS 2021), and the costs of funding are captured in funding valuation adjustment (FVA), together XVA. However, XVA are based on extrapolation of credit default swap (CDS) spreads which are typically traded up to 10 year maturity, see Table 1, and inclusion of bond trading where available.

We introduce Climate Change Valuation Adjustment(CCVA) to capture the difference in expected loss and funding between usual credit information extrapolation and the parameterized inclusion of economic stress from climate change endpoints and transition effects. The parameterization we introduce flexibly captures both climate endpoints, and transition effects. We show that climate

[1] https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability

change endpoints, and transition effects, can have significant effects on XVA even if the final climate endpoint is at the end of the century and trades in scope of XVA have 20 to 30 year maturity. We also provide a quantification of the relationship between transition effects and XVA impacts for these trades.

Client transactions, especially project finance for essential infrastructure, can go out 30 years or more so CVA calculation requires extrapolation of CDS spreads. Climate change may impact counterparty default on these timescales (Tol 2018). Many authors have modeled the relationship between climate change and default risk, e.g. (Capasso, Gianfrate, and Spinelli 2020) took a structural approach based on a firm's carbon footprint. (Garnier 2020) models physical and transition risks based on rating level transitions driven by a Gaussian copula. In contrast, we transpose the problem of modeling into estimation of a small number of directly interpretable parameters, see Section 4.

Climate change valuation adjustment will be negative in cases where climate change has favorable outcomes, i.e. lower cost. Examples may include technology providers with long development cycles that address climate mitigation, and regions where there are beneficial effects.

The contributions of this paper are : firstly the introduction of Climate Change Valuation Adjustment to capture climate change impacts on XVA that are currently invisible assuming typical market practice; secondly the introduction of a flexible and expressive parametrization to capture the path of instantaneous hazard rates to climate change endpoints, and for transition effects; and thirdly a quantification of examples of typical interest where there is risk of economic stress from sea level change, or change in business model.

1.1 Data limitations driving market practice

Counterparty default probability is inferred from spreads of traded credit default swaps (CDS), augmented by bonds where available. However, few CDS are traded beyond 5 years and almost none beyond 10 years. Many counterparties, e.g. project finance, have no CDS and so are priced and hedged primarily from CDS proxies. For these cases CDS indices are particularly important. Table 1 shows volumes for CDS indices from a Swaps Data Repository[2]. CDS indices are more traded than single name but not defined beyond 10 years: we see 98% of trading is for maturities up to 5 years.

Given the lack of data, market practice is to use some form of extrapolation beyond 10 years. Ratings may inform bond prices and proxy CDS curves, but corporate ratings typically have a three to five year look ahead (Fitch 2020).

1.2 Probability measures

Since CCVA is based on model predictions rather than tradable instruments it is a $\mathbb{P}$-measure quantity. Standard CVA may be thought of as a $\mathbb{Q}$ measure quantity. However, because of the lack of hedging beyond 5 to 10 years it is a mix between replication-based pricing and a measure represented by the CDS extrapolation. We shall label this measure given by market practice of CDS extrapolation Ξ (Xi for eXtrapolation).

[2]www.dtcc.com

Cumulative percentage by index on DTCC 2021-01-21 to 2021-02-19	CDS maturity rounded to neared year									
	1	2	3	4	5	6	7	8	9	10
Credit:Index:CDX:CDXEmergingMarkets	0%	0%	0%	7%	100%					
Credit:Index:CDX:CDXHY	0%	1%	2%	5%	100%					
Credit:Index:CDX:CDXIG	0%	1%	3%	9%	98%	98%	98%	98%	99%	100%
Credit:Index:iTraxx:iTraxxAsiaExJapan	0%	0%	0%	9%	100%					
Credit:Index:iTraxx:iTraxxAustralia	0%	0%	0%	20%	100%					
Credit:Index:iTraxx:iTraxxEurope	1%	3%	7%	10%	98%	98%	98%	99%	99%	100%
Credit:Index:iTraxx:iTraxxJapan	0%	0%	0%	0%	100%					
Grand Total	**0.5%**	**1.8%**	**3.9%**	**8.5%**	**98.5%**	**98.6%**	**98.8%**	**98.8%**	**99.0%**	**100.0%**

Table 1: Cumulative CDS transaction volume for indices referring to corporates on DTCC over a recent 30-day period, 2021-01-19 to 2021-02-20. DTCC is a US Swaps Data Repository so sees mostly US transaction. CDS indices are more traded than single-name CDS.

To discuss, precisely, the origin of Climate Change Valuation Adjustment, in Section 2.4 we introduce appropriate probability spaces and measures to capture market practice and inclusion of possible climate change endpoints.

1.3 Parameterization

To be able to discuss and compare paths of economic stress to climate endpoints we introduce a sigmoid parameterization of the instantaneous hazard rate evolution $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$, Section 4 gives details. This parameterization is expressive enough to cover different paths of economic stress buildup, see Section 4.3. The parameterization flexibly connects the longest traded CDS maturity and level, with the climate change endpoint, by allowing specification of the mid point m of the stress and the width w of the stress buildup. If we specify that instead of ending at a high hazard level the curve returns to the original level, i.e. $1_{\text{has peak}}$ is true, then the same parameterization models transient transition effects.

In this way we capture approach to default and transition with a single set of parameters. These parameters can be specified for each counterparty of a bank for example by by internal risk management, or a regulatory body for all banks, to define climate change scenarios independent of the details of the driving mechanisms.

1.4 Examples

We pick one subset of climate effects defined by endpoints to demonstrate how Climate Change Valuation Adjustment can be calculated and provide a scenario analysis to gage the range of possible impacts on example interest rates swaps with maturities from 10 to 50 years. The climate effects subset we pick is where it is reasonable to expect project finance or sovereign or sub-sovereign to have significant changes in default probability because of sea level change. By sea level change we include frequency of storm effects, and consider that infrastructure may be below ground level. For example tunnel entrances for a port city could be below sea level regularly at the climate end point in 30 to

80 years. Although sea level rise puts the entity below sea level this does not mean the entity will be flooded (Estrada, Botzen, and Tol 2017). Mitigating actions can be taken, but these create economic stress. CCVA captures this additional economic stress beyond market implied from constant CDS extrapolation. Although some aspects of climate change may be contained within a rating assigned to a project, because the CDS only go out 10 years this either misses later effects, or creates a distorted picture by moving risk beyond 10 years to within 10 years.

We pick a second subset of climate effects where there are transition stresses. That is, the corporate experiences a limited duration of economic stress during a transformation of business model. In this case we quantify XVA impacts w.r.t. the mid point of the stress and the width of the stress. As mentioned above this is the same parameterization as the sigmoid curve, but specifying that hazard rates return to normal, rather than ending high.

2 Methods

We will define the CCVA as climate related expected loss and funding that is not already captured by the usual market implied CVA and FVA. Thus CCVA captures the difference between a combined market implied and physical measure expected loss considering the economic impact of climate change, versus a typical bank market implied expected loss from constant CDS extrapolation of hazard rates. In order to make this definition precise we must first describe and define the concepts and probability spaces involved. Before this we recall some aspects of reduced form default modeling and the three lines of defense model typically used within banks for curve marking as well as aspects of the CDS market.

2.1 Source of Climate Change Valuation Adjustment

$\mathrm{CVA}_{\text{Market Implied}}$ does not incorporate climate related risk where this has effect beyond 5 or 10 years because of how $\mathrm{CVA}_{\text{Market Implied}}$ is calculated. $\mathrm{CVA}_{\text{Market Implied}}$ is based on CDS data. CDS data is market-based up to 5 or 10 years and then typically extrapolated flat judging by data from CDS runs (i.e. strips of tradeable CDS quotes) and CDS data providers. We capture the climate change difference of $\mathrm{CVA}_{\text{Climate Change}}$ above market CDS with flat extrapolation using CD.CVA, and the similar effect on FVA by CD.FVA defined below in Sections 2.4 and 3.

$\mathrm{CVA}_{\text{Market Implied}}$ is priced using a market-implied methodology but it is not hedged in practice beyond 10 years judging from trade repository data, e.g. from DTCC[3]. Thus banks face climate change, and other, risks on derivatives over 10 years because banks do not hedge these risks in the CDS market in as much as trade repositories are reflective of trading.

Regulations require that derivative transactions are recorded and this data be publicly available in many jurisdictions, in the US this was a consequence of Dodd-Frank (Congress 2010).

For entities that face no climate change risk CCVA will be zero. For entities where market practice already incorporates climate change risk CCVA will also

[3] `https://www.dtcc.com/`

be zero. Considering CDS market transactions, and market practice detailed below, no information beyond 5 or 10 years is incorporated into CVA nor FVA hence CCVA will be non-zero for trades with entities that face climate related risk outside the 5 or 10 year horizon of market traded CDS data.

2.2 Default modeling: reduced form

We model default and probability of default using a reduced form approach, rather than a structural approach. We use a reduced form approach because it is the standard in the front office and because it is more suitable for pricing, hedging, and risk management (Jarrow 2011). We briefly describe the two approaches below:

reduced form Default is modeled using an exogenous process, usually some form of marked point process.

structural The balance sheet of the entity is modeled and default occurs when liabilities exceed assets.

Reduced form models can be directly calibrated from, and hedged by, market observed Credit Default Swaps where they exist.

2.3 Curve marking and Accounting requirements

Most banks have a three lines of defense system for curve marking where the curves affect PnL or risk. This is part of the market-implied pricing methodology. Thus there are strong controls around curves used for pricing which lock in market assumptions and practice.

- Traders, the first line of defense, are responsible for CDS curve marking for PnL of all positions. They have the responsibility for observing the market and the setting the curve at the place where they believe they can trade.
- Product control, the second line of defense, are responsible for validating that the traders' marks reflect where traders can trade. This involves market surveillance and may include requiring traders to trade to verify that they can trade at the prices where they mark their curves. Product control are also typically responsible for holding reserves against other costs such as bid-ask spread, price impact, etc. If product control are marking price related items then there will be another second line group that validates these marks.
- Internal audit are responsible for monitoring the processes whereby traders mark the curves and product control and other validation groups validates these marks.

Accounting rules like IFRS 13 (IASB 2016) require banks to price derivatives as other market participants would price them. This is largely based on the idea of exit prices, i.e. what would another bank pay in a non-forced situation for the product?

2.4 Market-implied measure and physical measures

Market data may define a unique market implied measure, but physical measures are always subjective as they derive from a choice of calibration. The results of these calibrations may have to pass regulatory requirements but regulations are subjectively decided by committees.

We want to be able to price CVA and FVA as banks normally price them and to price CCVA. For normal bank pricing we introduce the probability space:

$$X = (\Omega, \mathcal{F}, \mathbb{P})$$

on a set of events $\Omega(t)$ with a filtration $\mathcal{F}(t)$ and corresponding probability measures $\mathbb{P}(t)$. The equivalent probability space with a risk-neutral measure, given that the last traded CDS maturity is T, is

$$Y_{Q\Xi}(T) = (\Omega, \mathcal{F}, [\mathbb{Q}; T; \Xi])$$

on events $\Omega_{\leq T} = \Omega(t) s.t.\ t \leq T$ with filtration $\mathcal{F}_{\leq T} = \mathcal{F}(t)\ s.t.\ t \leq T$ and risk neutral measure $\mathbb{Q}$ on $\mathcal{F}_T$. Note that the risk neutral measure only exists for $t \leq T$. We introduce the measure Ξ for $t > T$ on events $\Omega_{>T} = \Omega(t)\ s.t.\ t > T$ with filtration $\mathcal{F}_{>T} = \mathcal{F}(t)\ s.t.\ t > T$. Ξ is defined as a measure in which non-credit items can be hedged but credit items cannot be hedged but are priced assuming that CDS's are extrapolated flat. We assume independence of credit and non-credit events for simplicity.

Note that Ξ is not $\mathbb{P}$, even for $t > T$. Ξ can be thought of as an extrapolation of $\mathbb{Q}$ following the rule that CDS quotes are extrapolated flat, or according to a Bank's internal methodology.

To capture what may actually happen we introduce the probability space combining the risk neutral measure before T and the physical measure after T:

$$Y_{QP}(T) = (\Omega, \mathcal{F}, [\mathbb{Q}; T; \mathbb{P}])$$

Obviously a bank can roll CDS hedges, but the roll takes place in the conditional risk neutral $\mathbb{Q}_{\omega,C}$ measure (Kenyon 2020). There is a probability space $X_{\omega,C}$ conditioned on events ω up to T in which the client C did not default. $\mathbb{Q}_{\omega,C}$ is the equivalent risk neutral probability measure from T, within the conditional probability space $Y_{\omega,C}$. $\mathbb{Q}_{\omega,C}$ is not equivalent to $\mathbb{P}(t)\ s.t.\ t > T$ because the physical measure includes events where C has defaulted and $\mathbb{Q}_{\omega,C}$ does not.

We define CCVA relative to the usual bank calculation of CVA and FVA not the actual hedging cost requiring repeated purchases of CDS at later dates. Repeated CDS purchases are needed due to the lack of longer-dated liquid CDS when the counterparty portfolio is longer than the liquid CDS. The two prices will not be the same when the CDS curve is not flat assuming same-as-now futures (i.e. the CDS curve in the future looks like the one today).

3 Climate Change Valuation Adjustment

Now we have appropriate probability spaces and measures, we can define valuation adjustments based on market practice, based on including climate change, and then CCVA as the difference between these.

We define CVA and FVA including the measure involved, based on (Burgard and Kjaer 2013) and then specialize these with to define CCVA.

Definition 1 (CVA and FVA under probability space $Y(\Omega, \mathcal{F}, \Gamma)$)**.**

$$\text{CVA}^{Y(\Omega,\mathcal{F},\Gamma)} = \mathbb{E}^{\Gamma}\left[\int_{u=0}^{u=T} L_{GD}(u)\lambda(u)e^{\int_{s=t_0}^{s=u} -\lambda(s)ds} D_{r_F}(u)\Pi^+(u)du\right] \quad (1)$$

$$\text{FVA}^{Y(\Omega,\mathcal{F},\Gamma)} = \mathbb{E}^{\Gamma}\left[\int_{u=0}^{u=T} s_F(t)e^{\int_{s=t_0}^{s=u} -\lambda(u)ds} D_{r_F}(u)\Pi(u)du\right] \quad (2)$$

The usual market implied CVA and FVA based on market practice are:

Definition 2 (Market implied CVA and FVA, CVA_{MI} and FVA_{MI})**.**

$$\text{CVA}_{\text{MI}} = \text{CVA}_{\text{Market Implied}} = \text{CVA}^{Y_{Q\Xi}} = \text{CVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\Xi])} \quad (3)$$

$$\text{FVA}_{\text{MI}} = \text{FVA}_{\text{Market Implied}} = \text{FVA}^{Y_{Q\Xi}} = \text{FVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\Xi])} \quad (4)$$

CVA and FVA including climate change are defined similarly based on probability space used.

Definition 3 (CVA and FVA including climate change, CVA_{CC} and FVA_{CC})**.**

$$\text{CVA}_{\text{CC}} = \text{CVA}_{\text{Climate Change}} = \text{CVA}^{Y_{QP}} = \text{CVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\mathbb{P}])} \quad (5)$$

$$\text{FVA}_{\text{CC}} = \text{FVA}_{\text{Climate Change}} = \text{FVA}^{Y_{QP}} = \text{FVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\mathbb{P}])} \quad (6)$$

Now we can define CD.CVA and CD.FVA as the difference between the versions including climate change and market implied (i.e. flat CDS extrapolation). The sum of the differences is the CCVA.

Definition 4 (Climate Change Valuation Adjustment, CCVA, and climate change differences in valuation adjustments for credit and funding)**.**

$$\text{CCVA} = \text{CD.CVA} + \text{CD.FVA} \quad (7)$$

$$\text{CD.CVA} = \text{CVA}_{\text{Climate Change}} - \text{CVA}_{\text{Market Implied}} = \text{CVA}^{Y_{QP}} - \text{CVA}^{Y_{Q\Xi}} \quad (8)$$

$$\text{CD.FVA} = \text{FVA}_{\text{Climate Change}} - \text{FVA}_{\text{Market Implied}} = \text{FVA}^{Y_{QP}} - \text{FVA}^{Y_{Q\Xi}} \quad (9)$$

These definitions capture what is not in the market implied valuation adjustments. If market practice changes so that climate change is included then, e.g. $\text{CVA}_{\text{Climate Change}} = \text{CVA}_{\text{Market Implied}}$, and the differences will be zero. Here we highlight was is not currently included. Below we estimate the size of CCVA for a particular subset of entities where the calculation may be easiest.

Note that CCVA will be less than zero for cases where climate change has beneficial effects for the entity concerned.

4 Climate economic effect parameterization

We introduce a sigmoid parameterization of how instantaneous hazard rates approach a stressed climate change endpoint, i.e. maximum instantaneous hazard rate. With a very slight adjustment we can use exactly the same parameterization for transition stresses where there is transient increase in economic stress before returning to normal. The parameter $1_{\text{has peak}}$ is True for transition stresses and False for approach to a stressed endpoint. This parameterization enables discussion of how climate change affects counterparty default and calculation of CCVA.

The idea is that a 5 year CDS is available and fixes a constant $\mathbb{Q}$ measure instantaneous hazard rate for the first 5 years, since this is the most liquid instrument. Following this $\mathbb{Q}$-measure section there is a sigmoid approach to default for the $\mathbb{P}$ measure instantaneous hazard rate. We pick a sigmoid as this is common in nature to describe approach to a limit and can express a wide variety of approach to default, see Section 4.3.

4.1 Sigmoid parameterization, stressed endpoint

The sigmoid parameterization is shown in figure 1 with parameters described in Table 2. The resulting curve is $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$.

Note that if the slope of the last section is greater than the slope of the mid section, then $h_{\text{mid end}}$ is reduced so there is a straight line between $(t_{\text{mid start}}, h_{\text{mid start}})$ and $(t_{\text{end}}, h_{\text{end}})$. This is because it is physically reasonable to have a jump in instantaneous hazard rates in the transition from the $\mathbb{Q}$ section to the $\mathbb{P}$ section, but there is no particular justification for such a jump at the end of the $\mathbb{P}$ section. The $\mathbb{Q}$ section is that covered by traded CDS, i.e. $t = 0$ to $t = t_{\text{start}}$. The $\mathbb{P}$ section is the rest, i.e. the sigmoid.

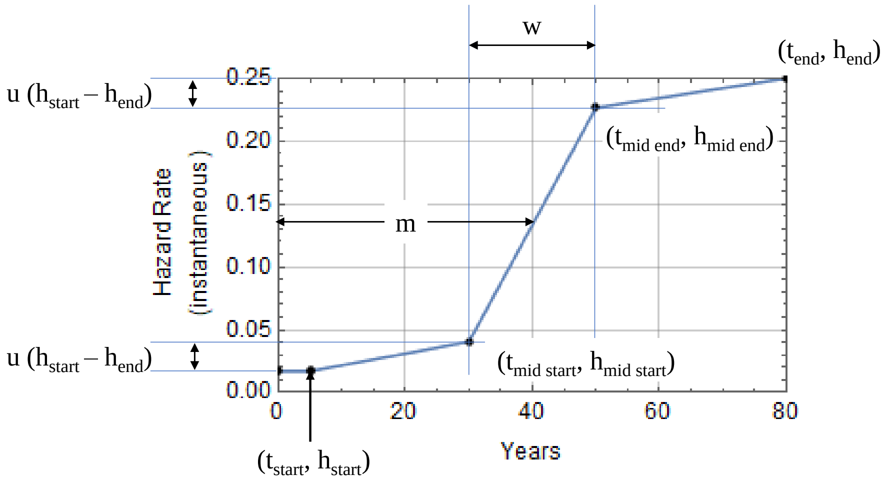

Figure 1: Sigmoid parameterization for the approach of instantaneous hazard rates to default, $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$, with $1_{\text{has peak}}$ False. See Table 2 for details.

4.2 Sigmoid parameterization, transition effects

The sigmoid parameterization for a transition effect where economic stress returns to normal is shown in Figure 2. Parameters described in Table 2, except that $1_{\text{has peak}}$ is now True. The resulting curve is $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$. Figure 2 also defines the parameters

Parameter	Example value	Description
$1_{\text{has peak}}$	False	
m	40 years	time to mid-impact
w	20 years	width of middle section
$(t_{\text{start}}, h_{\text{start}})$	(5, 0.0170)	coordinates of end of $\mathbb{Q}$ measure section and start of $\mathbb{P}$ measure section that approaches default
$(t_{\text{end}}, h_{\text{end}})$	(80, 0.2000)	coordinates of end of impact
u	10%	fraction of impact $(h_{\text{end}} - h_{\text{start}})$ for initial increase, and final approach to h_{end}

Table 2: Sigmoid parameterization for the approach of instantaneous hazard rates to default, $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}});\ m, w; u, (t_{\text{end}}, h_{\text{end}}))$. Note that if the slope of the last section is greater than the slope of the mid section, then $t_{\text{mid end}}$ is reduced so there is a straight line between $(t_{\text{mid end}}),\ h_{\text{mid start}})$ and $(t_{\text{end}}, h_{\text{end}})$. See Figure 1 for graphical view using the example parameters.

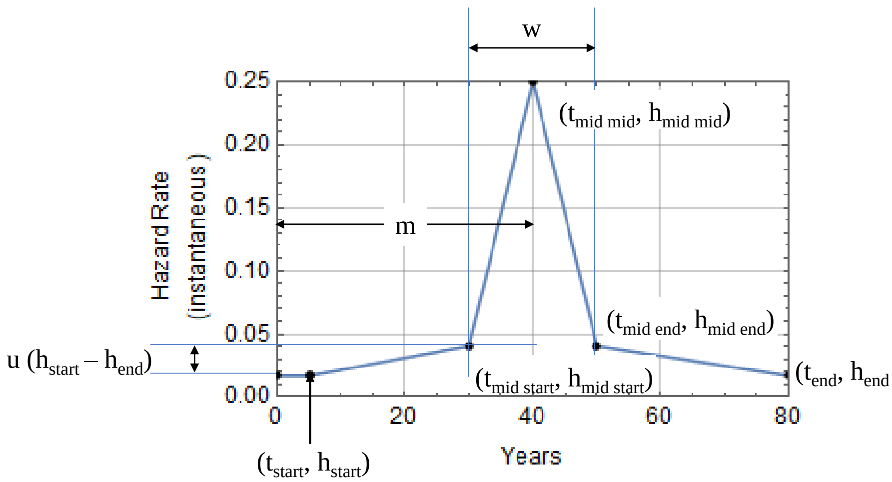

Figure 2: Sigmoid parameterization for modeling of transition stress uses the same parameters, $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}});\ m, w; u, (t_{\text{end}}, h_{\text{end}}))$, but now with $1_{\text{has peak}}$ True. See Table 2 and Section 4.2 for details. Now $h_{\text{end}} = h_{\text{start}}$, $h_{\text{mid end}} = h_{\text{mid start}}$ and $t_{\text{mid mid}} = m = (t_{\text{mid start}} + t_{\text{mid end}})/2$.

4.3 Expressivity

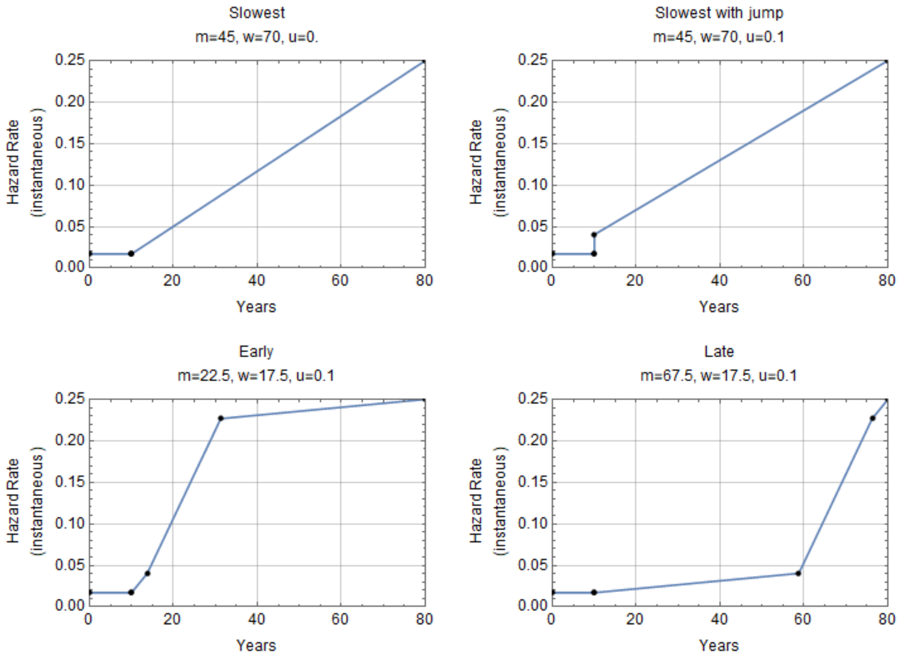

Figure 3: Examples of sigmoid parameterization expressivity. Subfigure titles, e.g. "Slowest", refer to the build up of economic stress expressed as instantaneous hazard rates. See text for details.

Different parameter settings of $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$ give different ways that instantaneous hazard rates can approach default when $1_{\text{has peak}}$ is False. I.e. $S(1_{\text{has peak}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{end}}))$ parameterizes the link between physical and economic climate change effects for the entity under consideration.

The range of possibilities displayed in Figure 3 is described below.

Slowest Set: $m = (t_{\text{end}} + t_{\text{start}})/2$ and $w = w_{\max} = (t_{\text{end}} - t_{\text{start}})/2$, with $u = 0$. Economic stress increases continuously at slowest possible continuous rate.

Slowest with jump Set: $m = (t_{\text{end}} + t_{\text{start}})/2$ and $w = w_{\max} = (t_{\text{end}} - t_{\text{start}})/2$, with $u > 0$. There is a jump in economic stress on changing from $\mathbb{Q}$ measure to $\mathbb{P}$ measure and then economic stress increases continuously at slowest possible continuous rate.

Early Set $w < w_{\max}$ and $m < (t_{\text{end}} + t_{\text{start}})/2$ with $u \geq 0$. Economic stress builds up earlier and then reaches a limit that can be close to default.

Late Set $w < w_{\max}$ and $m > (t_{\text{end}} + t_{\text{start}})/2$ with $u \geq 0$. Economic stress builds up later and then reaches a limit that can be close to default.

When $1_{\text{has peak}}$ is True m moves the mid point of the stress in time, and w changes the duration of the transition stress.

5 Numerical Examples

We consider climate change end point test cases using the sigmoid parameterization of approach to default of instantaneous hazard rates. The first set of cases we quantify are those where the entity has reasonable expectation of default from continually increasing economic stress caused by rising sea level. Examples of such entities include low-lying coastal cities, and associated special purpose vehicles (SPVs) used for essential infrastructure, such as roads, bridges, tunnels, housing, etc.

The second set of cases we consider are transition risks where the economic stress of the transition occurs from 20 to 70 years in the future and has a duration of 1 to 10 years. We do not need to consider transition stresses within 10 years because we assume that CDS are traded to 10 years and that the Bank can fully hedge XVA up to 10 years.

5.1 General setup

We quantify effects on at the money (ATM) USD interest rate swaps (IRS) using the setup below:

- first context: IRS associated with an entity with reasonable expectation of default from rising sea level. Examples of such entities include low-lying coastal cities, and associated special purpose vehicles (SPVs) used for essential infrastructure.
- second context: IRS associated with an entity that transforms its business model in response to climate change and so has transient elevated economic stress from the transition.
- uncollateralized trade. This is typical for infrastructure projects via SPVs.
- climate change end points considered: 30 to 80 years (to 2101)
- maximum instantaneous hazard rate at climate change endpoint: 2500 basis points (bps). This roughly corresponds to a forward CDS level of 20%. It is rare to observe entities with CDS above 20% for extended periods.
- recovery rate on CDS, 40%. This may appear strange if the climate change endpoint results in negative relative sea level effects. However, as we demonstrate below, economic stress (probability of default) will probably result in earlier default and at these earlier default times there may still be significant positive recovery.
- IRS length: 20 to 50 years. Thirty years may be a reasonable maximum for SPVs, we include longer maturities in case these are associated with sovereign or sub-sovereign entities.
- Funding spread is 100bps, flat
- We assume traded CDS out to 10 years, flat, at 100 bps.

maturity	CDS(linear hazard) (bps)	survival(linear hazard)	survival(flat hazard)
0.5	100.0	99.17	99.17
1.0	100.0	98.35	98.35
2.0	100.0	96.72	96.72
3.0	100.0	95.12	95.12
4.0	100.0	93.55	93.55
5.0	100.0	92.00	92.00
7.0	100.0	88.99	88.99
10.0	100.0	84.65	84.65
15.0	114.0	74.64	77.88
20.0	138.0	60.55	71.65
30.0	180.0	31.04	60.65
40.0	203.0	11.40	51.34
50.0	212.0	3.00	43.46
60.0	214.0	0.57	36.79
70.0	215.0	0.08	31.14
80.0	215.0	0.01	26.36

Table 3: CDS rates implied from slowest uniform approach of instantaneous hazard rate to climate change endpoint in 80 years, starting from CDS of 100 bps up to 10 years. shown in Figure 4. The flat CDS extrapolation is 100bps for all times. Survival probabilities are to the maturity in the first column.

5.2 Slowest approach to endpoint at 2051 to 2101

Here we consider CCVA for the slowest possible approach to a default instantaneous hazard rate that is reached by 2050 to 2100. We first consider the most benign example where the climate change endpoint is reached in 80 years, and then a range of endpoint dates.

5.2.1 Endpoint reached in 80 years

Figure 4 shows an example of slowest uniform approach of instantaneous hazard rate to climate change endpoint in 80 years starting from CDS of 100bps up to 10 years, and the derived average hazard rates, and survival probabilities. The derived CDS rates are shown in Table 3. Note that we have ignored IMM dates as these have little effect on results.

We see from Figure 4 and Table 3 that even in one of the most benign examples we can create, i.e. start from 100 bps up to 10Y, approach climate change endpoint in 80Y, there are significant consequences for survival probabilities at 20Y and by 50Y the survival probability has almost reached zero. In as much as there are earlier economic consequences adapting to distant (80Y) future climate endpoints can have significant earlier effects.

Although the CDS spreads only double at 40Y to 80Y, this is deceptive. The reason that the CDS spreads do not increase further is that both the fee and protection legs effectively cease to exist around 50Y, so further quotes carry no information.

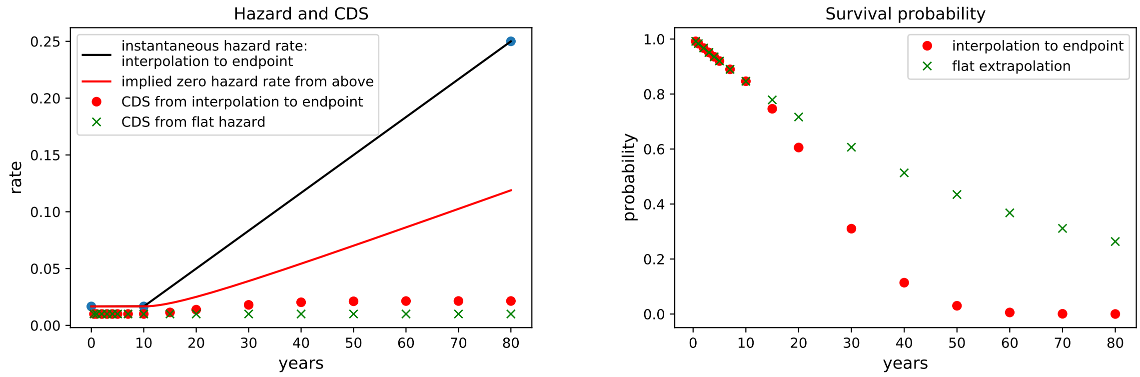

Figure 4: Slowest uniform approach of instantaneous hazard rate to climate change endpoint in 80 years, starting from CDS of 100bps up to 10 years on LEFT above, and derived zero (average) hazard rate. On RIGHT the derived survival probabilities.

5.2.2 Climate change endpoint reached in 30 to 80 years

Here we give the XVA changes considering climate change endpoints at 30 to 80 years against IRS of 20 to 50 year maturities. Here the instantaneous hazard rates increase at the slowest uniform rate, i.e. a straight line from the end of the traded CDS at 10 years to the climate change endpoint. Hazard rates are kept constant once reaching the maximum level of 2500bps.

We observe in Table 4 that there are significant effects on the CVA for all IRS, even as short as 20 years given a climate change endpoint in 2101 (i.e. 80 years from 2021), of an increase of 23%. The decrease in FVA, because funding costs are paid for less time partly mitigates this increase, and the overall effects is roughly a 10% increase in CVA+FVA, i.e. CCVA is roughly 10% of the value ignoring climate change. This is the most benign case.

With increasing IRS length and shorter time to climate change endpoint the overall effect is still always an increase in XVA, of up to 70% for long IRS and shortest time to endpoint, i.e. 2051.

5.3 Impact around midpoint to 2101

Here we assume that the impact on the instantaneous hazard rate is around the mid point of the time to the climate change endpoint. We also assume that there is a 5% build-up, and approach to maximum instantaneous hazard rate, i.e. $u = 0.05$.

Results are shown in Table 5. We see that the effects are much milder than with a uniform build up of economic stress, essentially because we are assuming a delay on the economic impact.

Figure 5 compares plots of the instantaneous hazard rates. Note that because $u = 5\%$, i.e. there is a build-up, there is also a jump in instantaneous hazard rate at the switch from $\mathbb{Q}$ to $\mathbb{P}$ for the slowest increase.

IRS length (years) width (years)	change in CVA % 20	30	40	50
20	71.0	141.0	140.0	130.0
30	51.0	113.0	117.0	113.0
40	39.0	93.0	100.0	100.0
50	32.0	80.0	88.0	90.0
60	27.0	69.0	78.0	81.0
70	23.0	61.0	70.0	74.0

IRS length (years) width (years)	change in FVA % 20	30	40	50
20	-4.0	-18.0	-19.0	-21.0
30	-3.0	-13.0	-15.0	-16.0
40	-2.0	-11.0	-12.0	-14.0
50	-2.0	-9.0	-10.0	-12.0
60	-1.0	-8.0	-9.0	-10.0
70	-1.0	-7.0	-8.0	-9.0

IRS length (years) width (years)	change in XVA % 20	30	40	50
20	37.0	67.0	73.0	73.0
30	26.0	54.0	62.0	64.0
40	20.0	45.0	53.0	57.0
50	17.0	39.0	47.0	51.0
60	14.0	34.0	42.0	47.0
70	12.0	30.0	38.0	43.0

Table 4: Slowest uniform increase in hazard rate results. Changes in CVA (top), FVA (mid), and CVA+FVA (bottom), i.e. relative sizes of CD.CVA, CD.FVA, and CCVA compared to flat CDS extrapolation. Notice that increased hazard rates is beneficial for FVA but not so for CVA. FVA and CVA are different sizes so the overall result is not a simple average.

IRS length (years) width (years)	change in CVA %, 30Y IRS 20	30	40	50
1	2.0	8.0	10.0	16.0
10	3.0	9.0	11.0	18.0
20	3.0	10.0	14.0	24.0
30	4.0	13.0	19.0	31.0
40	6.0	19.0	29.0	40.0
50	8.0	32.0	44.0	53.0
60	18.0	54.0	64.0	69.0
70	42.0	82.0	88.0	89.0

IRS length (years) width (years)	change in FVA %, 30Y IRS 20	30	40	50
1	-0.0	-1.0	-1.0	-1.0
10	-0.0	-1.0	-1.0	-1.0
20	-0.0	-1.0	-1.0	-2.0
30	-0.0	-1.0	-2.0	-2.0
40	-0.0	-2.0	-2.0	-3.0
50	-0.0	-3.0	-4.0	-5.0
60	-1.0	-6.0	-6.0	-8.0
70	-2.0	-10.0	-11.0	-13.0

IRS length (years) width (years)	change in XVA %, 30Y IRS 20	30	40	50
1	1.0	4.0	5.0	9.0
10	1.0	4.0	6.0	11.0
20	2.0	5.0	8.0	14.0
30	2.0	6.0	11.0	18.0
40	3.0	9.0	16.0	24.0
50	4.0	16.0	24.0	31.0
60	9.0	26.0	34.0	40.0
70	22.0	39.0	46.0	50.0

Table 5: Impact around mid point to 2101 for instantaneous hazard rate, and $u = 0.05$. Changes in CVA (top), FVA (mid), and CVA+FVA (bottom), i.e. relative sizes of CD.CVA, CD.FVA, and CCVA compared to flat CDS extrapolation. Notice that increased hazard rates is slightly beneficial for FVA but not so for CVA. FVA and CVA are different sizes so the overall result is not a simple average.

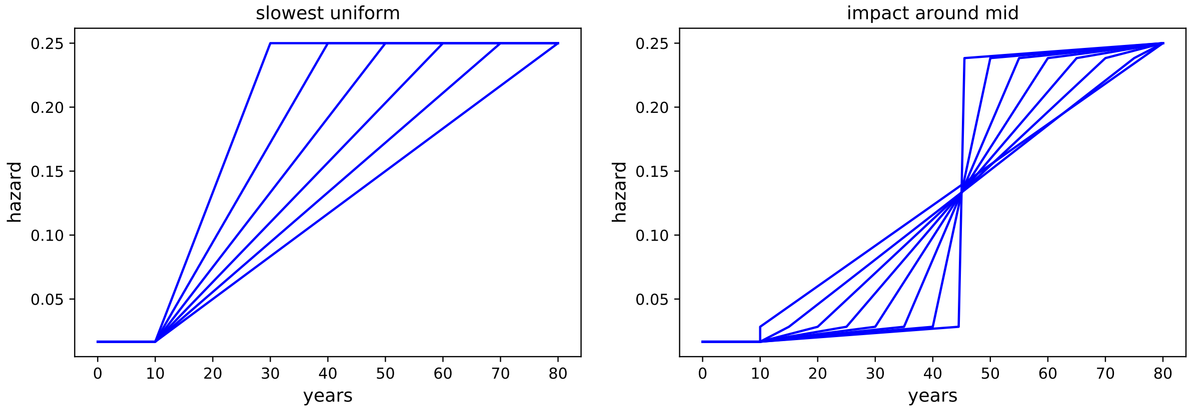

Figure 5: Slowest uniform test case approaches of instantaneous hazard rate to climate change endpoint, starting from CDS of 100bps up to 10 years on LEFT above. On RIGHT test cases when the impact is around the mid point from now to 2101. XVA impacts are given in Sections 5.2.2 and 5.3.

5.4 Transition quantification

Table 6 shows the effect on XVA and survival probabilities within the transition stress $t_{\text{mid start}}$ to $t_{\text{mid end}}$, with $u = 0.05$ and the peak hazard rate at 2500bps, for a 30 year IRS. We consider mid-transition from 15 years in the future to 75 years in the future, and transition durations of 1 to 10 years. The counterparty has a traded CDS level of 100bps, and we imagine that the counterparty experiences economic stress from changing their business model to adapt to climate change. We further assume that if they overcome the transition period then they have the same risk level as at the start, i.e. 100bps.

We observe that there are significant impacts to XVA pricing if the transition stress occurs up to the end of the IRS, i.e. within 30 years, but almost no effect there after. Of course there is no effect from any transition actions up to 10 years because the XVA risk is assumed fully hedged up to then.

The lowest table in Table 6 provides the change in survival probability over the transition period, whether this is 1, 5, or 10 years. This change in probability provides another way to understand the impact of the transition timing and duration relative to the effects on XVA.

time to mid width	change in CVA % 15.0	 25.0	 35.0	 45.0	 55.0	 65.0	 75.0
1	47.0	26.0	10.0	8.0	6.0	5.0	4.0
5	112.0	54.0	11.0	8.0	6.0	5.0	4.0
10	161.0	81.0	13.0	9.0	6.0	5.0	4.0

time to mid width	change in FVA % 15.0	 25.0	 35.0	 45.0	 55.0	 65.0	 75.0
1	-7.0	-2.0	-1.0	-1.0	-1.0	-0.0	-0.0
5	-19.0	-4.0	-1.0	-1.0	-1.0	-1.0	-0.0
10	-29.0	-6.0	-1.0	-1.0	-1.0	-1.0	-0.0

time to mid width	change in XVA % 15.0	 25.0	 35.0	 45.0	 55.0	 65.0	 75.0
1	22.0	13.0	5.0	4.0	3.0	2.0	2.0
5	52.0	27.0	6.0	4.0	3.0	2.0	2.0
10	73.0	41.0	6.0	4.0	3.0	3.0	2.0

time to mid width	percent change in survival probability 15.0	 25.0	 35.0	 45.0	 55.0	 65.0	 75.0
1	-9.0	-7.0	-5.0	-4.0	-3.0	-3.0	-2.0
5	-34.0	-27.0	-21.0	-16.0	-13.0	-10.0	-8.0
10	-51.0	-40.0	-31.0	-24.0	-19.0	-15.0	-12.0

Table 6: Impact of transition stress for 30 year IRS, depending on timing (mid point) and duration (width). Changes in CVA (top), FVA (mid-upper), and CVA+FVA (mid-lower), and change in default probability over the transition period (1, 5, or 10 years), i.e. relative sizes of CD.CVA, CD.FVA, and CCVA compared to flat CDS extrapolation.

6 Discussion

We introduce Climate Change Valuation Adjustment to capture currently invisible economic impact on credit losses and funding from climate change in as much as this is different to market implied XVA using current CDS extrapolation. We also provide a rigorous basis both in terms of probability spaces and measure, and in terms of contrast of potential climate change effects with market practice.

In addition to mathematical formalism we introduce a sigmoid parameterization of the impact of climate change on instantaneous hazard rates. This provides a way to discuss economic impacts in a uniform way, whatever the source of modeling of the economic developments. This parameterization can capture approach to a stressed endpoint, e.g. negative relative sea level, and also transient transition stresses, e.g. from transformation of business model to adapt to climate change.

Surprisingly, we find that even for climate change endpoints as far away as 2101, if there is the slowest possible uniform increase of hazard rates then there are significant credit impacts even on 20y IRS. We also see that the effect on FVA is opposite in sign to the effect of CVA, simply because increased default probability means less time to pay funding costs. However, the overall effect is still an increase of XVA.

Transition effects, unsurprisingly, depend on when they occur and their duration. Our modeling enables this to be captured with a few clearly interpretable parameters that can then form the basis of discussion with stakeholders, e.g. the risk department, or regulators.

The contributions of this paper are: firstly the introduction of Climate Change Valuation Adjustment to capture climate change impacts on XVA that are currently invisible assuming typical market practice; secondly the introduction of a flexible and expressive sigmoid parameterization to capture the path of instantaneous hazard rates to climate change endpoints and transition modeling; and thirdly a quantification of examples of typical interest where there is risk of economic stress from sea level change or business model transformation.

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