Climate change valuation adjustment using parameterised climate change impacts

Chris Kenyon and Mourad Berrahoui introduce the climate change valuation adjustment to capture the climate change effects on CVA and FVA that are currently invisible in typical market practice

Climate change risk comprises physical, transition and liability risks to assets, companies and sovereign entities (Bank of England 2019; European Central Bank 2020). Credit valuation adjustment (CVA) quantifies expected loss on counterparty default (Basel Committee on Banking Supervision 2021; Green 2015), and the costs of funding are captured in the funding valuation adjustment (FVA); together these adjustments are denoted CVA + FVA. However, CVA and FVA are based on extrapolation of credit default swap (CDS) spreads that are typically traded only up to a ten-year maturity (see table A), and include bond trading where applicable.

We introduce the climate change valuation adjustment (CCVA) to capture the difference in expected loss and funding between the usual credit information extrapolation and the parameterised inclusion of economic stress from climate change. The parameterisation we introduce flexibly captures both climate endpoints and transition effects. Climate endpoints, such as sea level rise, can have significant effects on CVA + FVA even if the climate endpoint is at the end of the century and trades in the scope of CVA + FVA have 20- to 30-year maturities. We also provide a quantification of the relationship between transition effects and CVA + FVA effects, for example trades.

The CCVA will be negative in cases where climate change has favourable outcomes, ie, a lower cost. Examples include technology providers with long development cycles that may address climate mitigation, and regions where there are beneficial effects.

The contributions of this paper are: first, the introduction of the CCVA to capture climate change effects on CVA + FVA that are currently invisible in typical market practice; second, the introduction of a flexible and expressive instantaneous hazard rate parameterisation to capture the path to climate change endpoints and for transition effects; and third, a quantification of examples of typical interest where there is risk of economic stress from sea level change or a change in business model.

Context

We will define the CCVA as climate-related expected loss and funding costs that are not already captured by the CVA and FVA calculated according to usual market practice. Thus CCVA captures the difference between the combined market-implied and physical measure expected loss considering the economic impact of climate change and the typical bank market-implied expected loss from some extrapolation of hazard rates outside the maturity of liquid CDSs. In order to make this definition precise we must first describe and define the concepts and probability spaces involved. Before this we recall the limitations of the CDS market.

■ **Data limitations driving market practice of CVA + FVA.** Market-implied counterparty default probability is inferred from spreads of traded CDSs, augmented by bonds where applicable. However, few CDSs are traded beyond five years, and almost none beyond ten years. Many counterparties, eg, project finance, have no CDSs and so are priced and hedged primarily from CDS proxies. For proxy curves, CDS indexes can be particularly important. Table A shows the volumes for CDS indexes from a swaps data repository (the Depository Trust & Clearing Corporation (DTCC)). CDS indexes are more traded than single names, but few are even defined beyond ten years: we see 98% of reported trading volume on DTCC is for maturities of up to five years.

Given the lack of actual transactions, market practice is to use some form of extrapolation beyond ten years. Ratings may inform bond prices and proxy CDS curves, but corporate ratings typically have only a 3–5-year look ahead (Fitch 2020).

■ **Source of the CCVA.** $\mathrm{CVA}_{\text{Market Practice}}$, because of how it is calculated, does not incorporate climate-related risk where this has an effect beyond five or ten years. $\mathrm{CVA}_{\text{Market Practice}}$ is based on CDS data, which is market-based for up to five or ten years and then typically extrapolated flat judging by data from CDS runs (that is, strips of tradeable CDS quotes) and CDS transaction repositories. Note that CDS data providers typically provide extrapolated CDS values using their own internal models beyond ten years when they have insufficient contributors; obviously, this is not tradeable data. We capture the climate change difference of $\mathrm{CVA}_{\text{Climate Change}}$ versus market CDSs with flat extrapolation using CD.CVA, and the similar effect on FVA by CD.FVA defined in the next section.

$\mathrm{CVA}_{\text{Market Practice}}$ is priced using a market-implied methodology but it is not hedged beyond ten years in practice, judging from transaction repository data, eg, from DTCC (www.dtcc.com). Thus banks face climate change, and other, risks on derivatives over ten years because they do not hedge these risks in the CDS market inasmuch as transaction repositories are reflective of trading.

For entities that face no climate change risk, the CCVA will be zero. For entities where market practice already incorporates climate change risk, CCVA will also be zero. Considering CDS market transactions, and the market practices detailed above, no information beyond five or ten years is incorporated into the CVA or FVA; hence, the CCVA will be non-zero for trades with entities that face climate-related risks or benefits outside the five- or ten-year horizon of market-traded CDS data. Where counterparties are on proxy CDS curves, the CCVA can be non-zero for any length of contract where counterparty-specific climate risk is not included in the proxy.

■ **Market-implied measure and physical measures.** Market data may define a unique market-implied measure $\mathbb{Q}$, but physical measures $\mathbb{P}$ are always subjective, as they are derived from a choice of calibrations.

Since the CCVA is based on model predictions rather than tradeable 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

A. Cumulative CDS transaction volume for indexes referring to corporates on DTCC over a recent 30-day period: January 19, 2021–February 20, 2021											
Cumulative notional by index on DTCC 21/01/21–19/02/21	**CDS maturity rounded to nearest year**										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
CDX:CDXEmergingMarkets	0%	0%	0%	0%	7%	100%					
CDX:CDXHY	0%	0%	1%	2%	5%	100%					
CDX:CDXIG	0%	0%	1%	3%	9%	98%	98%	98%	98%	99%	100%
iTraxx:iTraxxAsiaExJapan	0%	0%	0%	0%	9%	100%					
iTraxx:iTraxxAustralia	0%	0%	0%	0%	20%	100%					
iTraxx:iTraxxEurope	0%	1%	3%	7%	10%	98%	98%	98%	99%	99%	100%
iTraxx:iTraxxJapan	0%	0%	0%	0%	0%	100%					
Cumulative percentage	0.0%	0.5%	1.8%	3.9%	8.5%	98.5%	98.6%	98.8%	98.8%	99.0%	100.0%

DTCC is a US swaps data repository so sees mostly US transactions. CDS indexes are more traded than single-name CDSs

five to ten 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).

We want to be able to price the CVA and FVA as banks normally price them and to price the 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 $\Omega_{\leqslant T} = \Omega(t)$ such that (s.t.) $t \leqslant T$ with filtration $\mathcal{F}_{\leqslant T} = \mathcal{F}(t)$ s.t. $t \leqslant T$ and risk-neutral measure $\mathbb{Q}$ on $\mathcal{F}_T$. Note that the risk-neutral measure only exists for $t \leqslant T$. We use 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 CDSs are extrapolated flat (or according to some internal choice). We assume credit and non-credit events are independent for simplicity.

Note that Ξ is not $\mathbb{P}$ 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:

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

Climate change valuation adjustment

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

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

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

$$\mathrm{CVA}^{Y(\Omega,\mathcal{F},\Gamma)} = \mathbb{E}^{\Gamma}\bigg[\int_{u=0}^{u=T} L_{\mathrm{GD}}(u)\lambda(u)\exp\bigg(\int_{s=0}^{s=u} -\lambda(s)\,\mathrm{d}s\bigg) \times D_{r_{\mathrm{F}}}(u)(\Pi(u) - X(u))^{+}\,\mathrm{d}u\bigg] \quad (1)$$

$$\mathrm{FVA}^{Y(\Omega,\mathcal{F},\Gamma)} = \mathbb{E}^{\Gamma}\bigg[\int_{u=0}^{u=T} s_F(t)\exp\bigg(\int_{s=0}^{s=u} -\lambda(u)\,\mathrm{d}s\bigg) \times D_{r_{\mathrm{F}}}(u)(\Pi(u) - X(u))\,\mathrm{d}u\bigg] \quad (2)$$

where $\Pi(u)$ is the value of the portfolio with the counterparty and $X(u)$ is the collateral value.

The usual market-implied CVA and FVA based on market practice are defined as follows.

Definition 2 (Market-implied CVA and FVA: $\mathrm{CVA}_{\mathrm{MP}}$ and $\mathrm{FVA}_{\mathrm{MP}}$)

$$\begin{aligned}\mathrm{CVA}_{\mathrm{MP}} &= \mathrm{CVA}_{\text{Market Practice}} \\ &= \mathrm{CVA}^{Y_{Q\Xi}} = \mathrm{CVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\Xi])} \quad (3)\end{aligned}$$

$$\begin{aligned}\mathrm{FVA}_{\mathrm{MP}} &= \mathrm{FVA}_{\text{Market Practice}} \\ &= \mathrm{FVA}^{Y_{Q\Xi}} = \mathrm{FVA}^{Y(\Omega,\mathcal{F},[\mathbb{Q};T;\Xi])} \quad (4)\end{aligned}$$

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

Definition 3 (CVA and FVA including climate change: $\mathrm{CVA}_{\mathrm{CC}}$ and $\mathrm{FVA}_{\mathrm{CC}}$)

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

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

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

Definition 4 (CCVA and climate change differences in valuation adjustments for credit and funding)

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

$$\begin{aligned}\mathrm{CD.CVA} &= \mathrm{CVA}_{\text{Climate Change}} - \mathrm{CVA}_{\text{Market Practice}} \\ &= \mathrm{CVA}^{Y_{QP}} - \mathrm{CVA}^{Y_{Q\Xi}} \quad (8)\end{aligned}$$

$$\begin{aligned}\mathrm{CD.FVA} &= \mathrm{FVA}_{\text{Climate Change}} - \mathrm{FVA}_{\text{Market Practice}} \\ &= \mathrm{FVA}^{Y_{QP}} - \mathrm{FVA}^{Y_{Q\Xi}} \quad (9)\end{aligned}$$

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

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

Climate economic effect parameterisation

To be able to discuss and compare paths of economic stress to climate endpoints we introduce a sigmoid parameterisation of the instantaneous hazard rate, $\lambda(t)$:

$$\lambda(t) = S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$$

For parameter details see table B and figures 1 and 2. This parameterisation is expressive enough to cover different paths of economic stress buildup. The parameterisation flexibly connects the longest traded CDS maturity and level, with the climate change endpoint, by allowing specification of the midpoint 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, that is, $1_{\text{transient}}$ is true, then the same parameterisation models transient transition effects.

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

Custom $\lambda(t)$ models can be specified by credit departments using integrated assessment models (IAMs). IAMs take climate scenarios, micro- and macroeconomic transmission channels and deliver economic impact scenarios (Nordhaus 2017). Typically, there might be a two-step approach, where an initial assessment by a credit department working with the relationship manager to produce sigmoid parameters that are then refined by reference to IAM scenarios based on Network for Greening the Financial System (2020), or vice versa.

The hazard curve for a counterparty including climate effects consists of two parts:

- a hedgeable section with $\mathbb{Q}$-measure $\lambda(t)$ from traded CDS levels, up to five or ten years; and
- a sigmoid section in $\mathbb{P}$-measure, where:

$$\lambda(t) = S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$$

Sigmoid parameterisation, stressed endpoint. This sigmoid parameterisation is shown in figure 1 with parameters described in table B. The resulting curve is $S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$, with $1_{\text{transient}} = \text{true}$.

CDS spreads and survival probabilities are given in table C.

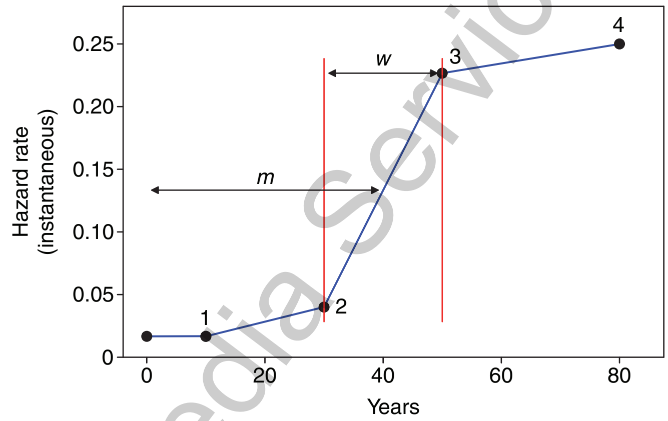
Sigmoid parameterisation, transient transition effects. The sigmoid parameterisation for a transient transition effect where the economic stress returns to normal is shown in figure 2. The parameters are as described in table B, except that $1_{\text{transient}}$ is now true. The resulting curve is $S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$. Figure 2 also defines the parameters.

CDS spreads and survival probabilities are also given in table C.

Numerical examples

We consider climate change test cases using the sigmoid parameterisation quantifying effects on at-the-money (ATM) US dollar interest rate swaps (IRSs) for two sets of cases.

1 Sigmoid parameterisation for the approach of instantaneous hazard rates to default, $S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$, with $1_{\text{transient}} = \text{false}$



See table B for details

B. Sigmoid parameterisation and point definition for the approach of instantaneous hazard rates to default, $S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$

Parameter	Example value	Description
$1_{\text{transient}}$	False	
m	40 years	Time to mid-impact
w	20 years	Width of middle section
$(t_{\text{start}}, h_{\text{start}})$	(10, 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, 0.2500)	Coordinates of end of impact
u	10%	Fraction of impact $(h_{\text{end}} - h_{\text{start}})$ for initial increase, and final approach to h_{max}

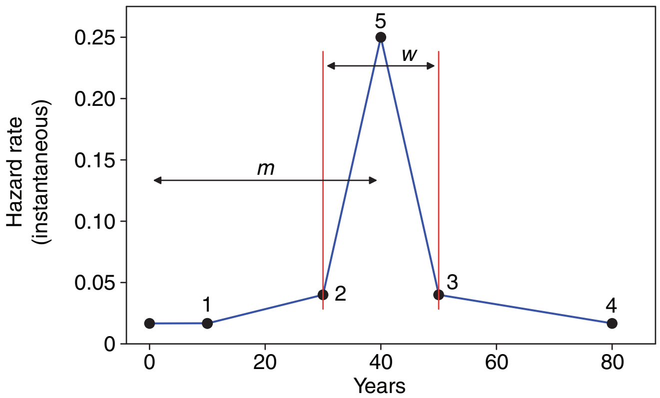
Point	Definition	
1	$(t_{\text{start}}, h_{\text{start}})$	
2	$(m - w/2, h_{\text{start}} + u \times (h_{\text{max}} - h_{\text{start}}))$	
3	$(m + w/2, h_{\text{max}} - u \times (h_{\text{max}} - h_{\text{start}}))$	If $1_{\text{transient}} = \text{false}$
	$(m + w/2, h_{\text{start}} + u \times (h_{\text{max}} - h_{\text{start}}))$	If $1_{\text{transient}} = \text{true}$
4	$(t_{\text{end}}, h_{\text{max}})$	If $1_{\text{transient}} = \text{false}$
	$(t_{\text{end}}, h_{\text{start}})$	If $1_{\text{transient}} = \text{true}$
5	(m, h_{max})	Only present if $1_{\text{transient}} = \text{true}$

Note that if the slope of the last section is greater than the slope of the mid section, then point 2 is removed so there is a straight line between point 2 and point 4. See figure 1 for a graphical view using the example parameters

- In the first set of cases, the entity has a reasonable expectation of default from continually increasing economic stress caused by rising sea level. Examples of such entities include low-lying coastal cities and the associated special purpose vehicles (SPVs) used for essential infrastructure, such as roads, bridges, tunnels or housing.
- The second set of cases involves transient transition risks, where the midpoint economic stress of the transition occurs between 15 and 75 years in the future and has a duration of one to ten years. We do not need to consider transition stresses within ten years because we assume single-name CDSs are traded to ten years and that the bank can fully hedge CVA + FVA up to ten years.

The details of the setup are as follows: as-of-date January 29, 2020 for the US dollar yield curve; a single curve approach with normal volatility, flat

2 The sigmoid parameterisation for modelling transition stress uses the same parameters, $S(1_{\text{transient}}, (t_{\text{start}}, h_{\text{start}}); m, w; u, (t_{\text{end}}, h_{\text{max}}))$, but now with $1_{\text{transient}}$ = true



See table B and the previous section for details

C. CDS and survival probabilities for the two examples in figures 1 and 2

Maturity	$1_{\text{transient}}$ = false		$1_{\text{transient}}$ = true		Flat CDS, 100bp
(years)	CDS (bp)	Survival	CDS (bp)	Survival	Survival
10	100	84.65	100	84.65	84.65
20	114	67.55	114	67.55	71.65
30	132	47.97	132	47.97	60.65
40	163	20.07	178	11.14	51.34
50	180	3.30	188	2.64	43.46
60	183	0.33	188	1.84	36.79
70	183	0.03	188	1.39	31.14
80	183	0.00	188	1.13	26.36

at 20 basis points; an uncollateralised trade (this is typical for infrastructure projects via SPVs); a maximum instantaneous hazard rate of 2500bp at the climate change endpoint; a recovery rate on the CDS of 40%; the length of the IRS length is 20–50 years; the funding spread is 100bp, flat; we assume a traded CDS out to ten years, flat, at 100bp.

■ **Slowest approach to endpoint at 2051–2101.** Here we consider CCVA for the slowest possible approach to a default instantaneous hazard rate that is reached by 2050–2100. We consider first the most benign example, where the climate change endpoint is reached in 80 years, and then a range of endpoint dates.

■ **Endpoint reached in 80 years.** Figure 3 shows an example of the slowest uniform approach by the instantaneous hazard rate towards the climate change endpoint in 80 years, starting from a CDS of 100bp up to ten years, as well as the derived average hazard rates and survival probabilities. The derived CDS rates are shown in table D. Note that we have ignored International Monetary Market (IMM) dates, as these have little effect on our results.

We see from figure 3 and table D that even in one of the most benign examples we can create, that is, starting from 100 bp up to 10Y and approaching the climate change endpoint in 80Y, there are significant consequences for survival probabilities at 20Y, and by 50Y the survival probability has almost reached zero. Inasmuch as there are earlier economic consequences, the effects of adapting to distant (80Y) future climate endpoints can occur significantly earlier.

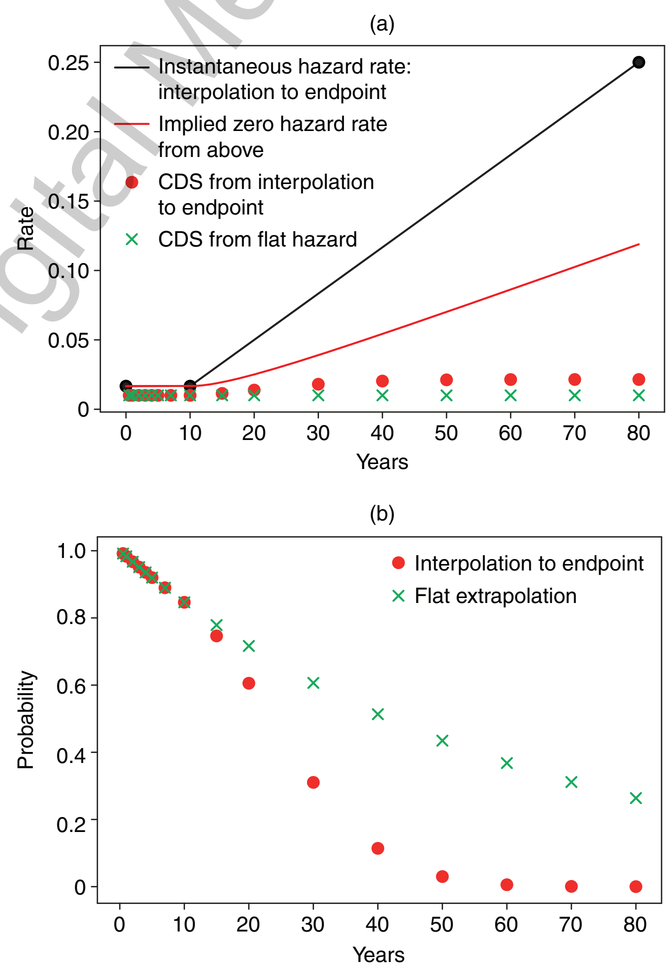
Although the CDS spreads only double at 40Y to 80Y, this is deceptive. The reason that the CDS spreads do not increase further is that both the fee

D. CDS rates implied by the slowest uniform approach of the instantaneous hazard rate to a climate change endpoint in 80 years, starting from a CDS of 100bp up to ten years, shown in figure 3

Maturity	CDS (linear hazard) (bp)	Survival (linear hazard)	Survival (flat hazard)
10	100	84.65	84.65
20	138	60.55	71.65
30	180	31.04	60.65
40	203	11.40	51.34
50	212	3.00	43.46
60	214	0.57	36.79
70	215	0.08	31.14
80	215	0.01	26.36

The flat CDS extrapolation is 100bp for all times. Survival probabilities are to the maturity in the first column

3 The slowest uniform approach of instantaneous hazard rate to the climate change endpoint in 80 years, starting from a CDS of 100bp up to ten years



(a) The derived zero (average) hazard rate. (b) The derived survival probabilities

and protection legs effectively cease to exist around 50Y, so further quotes carry no information.

■ **Climate change endpoint reached in 30–80 years.** Here we give the CVA + FVA changes considering climate change endpoints of 30–80 years against IRSs of 20–50-year maturities. Here the instantaneous hazard rates

E. The slowest uniform increase in hazard rate results

Width (years)	Change in CVA (%) IRS length (years)				Change in FVA (%) IRS length (years)			
	20	30	40	50	20	30	40	50
20	71	141	140	130	−4	−18	−19	−21
30	51	113	117	113	−3	−13	−15	−16
40	39	93	100	100	−2	−11	−12	−14
50	32	80	88	90	−2	−9	−10	−12
60	27	69	78	81	−1	−8	−9	−10
70	23	61	70	74	−1	−7	−8	−9

Width (years)	CDS slope (bp/year)	Extrapolation of CDS level after 80 years (bp)	Change in CVA + FVA (%) IRS length (years)			
			20	30	40	50
20	125	8,333	37	67	73	73
30	83	5,611	26	54	62	64
40	63	4,250	20	45	53	57
50	50	3,433	17	39	47	51
60	42	2,889	14	34	42	47
70	36	2,500	12	30	38	43

Changes in CVA (top), FVA (middle) and CVA + FVA (bottom), ie, the relative sizes of CD.CVA, CD.FVA and CCVA compared with a flat CDS extrapolation. Notice that increased hazard rates are beneficial for FVA but not for CVA. FVA and CVA are different sizes, so the overall result is not a simple average

increase at the slowest uniform rate, that is, a straight line from the end of the traded CDSs at ten years to the climate change endpoint. Hazard rates are kept constant once they reach the maximum level of 2500bp.

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

■ **Impact around midpoint to 2101.** Here we assume the impact on the instantaneous hazard rate is around the midpoint of the time to the climate change endpoint. We also assume there is a 5% build-up and approach to the maximum instantaneous hazard rate, that is, $u = 0.05$.

The results are shown in table F. 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 4 compares plots of the instantaneous hazard rates. Note that because $u = 5\%$, that is, 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.

■ **Transition quantification.** Table G shows the effect on CVA + FVA 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 2500bp, for a 30-year IRS. We consider mid-transitions from 15 years in the future to 75 years in the future, and transition durations of 1–10 years. The counterparty has a traded CDS level of 100bp, 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, that is, 100bp.

The bottom panel in table G provides the change in survival probability over the transition period, whether this be one, five or ten years. This change in probability provides another way to understand the impact of the transition timing and duration relative to the effects on CVA + FVA.

F. The impact around the midpoint until 2101 for the instantaneous hazard rate and $u = 0.05$

Width (years)	Change in CVA (%), 30Y IRSs IRS length (years)			
	20	30	40	50
1	2	8	10	16
10	3	9	11	18
20	3	10	14	24
30	4	13	19	31
40	6	19	29	40
50	8	32	44	53
60	18	54	64	69
70	42	82	88	89
Width (years)	**Change in FVA (%), 30Y IRSs IRS length (years)**			
	20	30	40	50
1	−0	−1	−1	−1
10	−0	−1	−1	−1
20	−0	−1	−1	−2
30	−0	−1	−2	−2
40	−0	−2	−2	−3
50	−0	−3	−4	−5
60	−1	−6	−6	−8
70	−2	−10	−11	−13
Width (years)	**Change in CVA + FVA (%), 30Y IRSs IRS length (years)**			
	20	30	40	50
1	1	4	5	9
10	1	4	6	11
20	2	5	8	14
30	2	6	11	18
40	3	9	16	24
50	4	16	24	31
60	9	26	34	40
70	22	39	46	50

Changes in CVA (top), FVA (middle) and CVA + FVA (bottom), that is, the relative sizes of CD.CVA, CD.FVA and CCVA compared with a flat CDS extrapolation. Notice that increased hazard rates are slightly beneficial for FVA but not for CVA. FVA and CVA are different sizes, so the overall result is not a simple average

Discussion

We introduce the CCVA to capture the economic impact on credit losses and funding from climate change, which is currently invisible inasmuch as this is different from market-implied CVA+FVA using current CDS extrapolation. We also provide a rigourous basis both in terms of probability spaces and measures, and in terms of contrasting potential climate change effects with market practice.

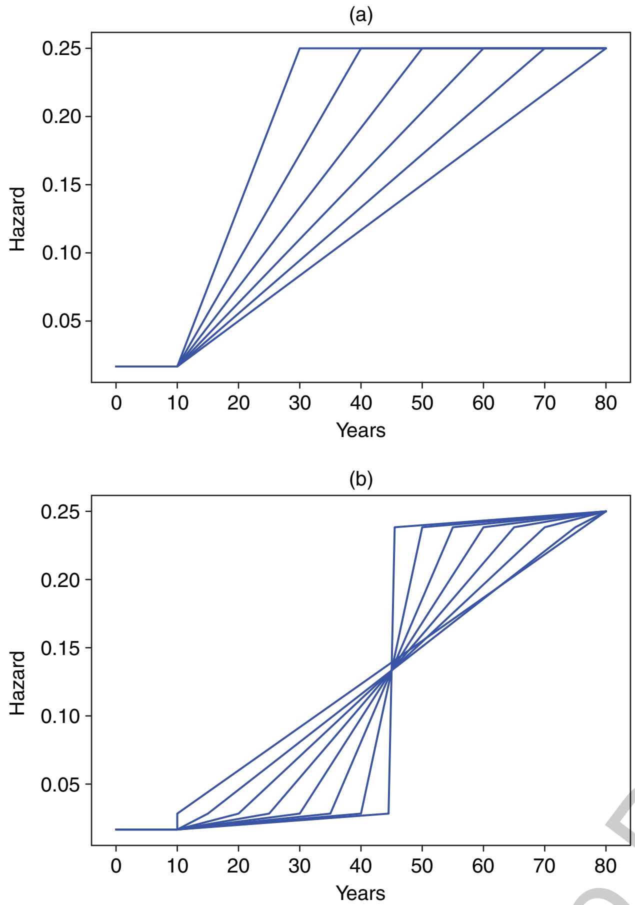
Surprisingly, we find that, even for climate change endpoints as far away as 2101, if there is the slowest possible uniform increase in hazard rates, then there are significant credit effects, even on a 20Y IRS. We also see that the effect on FVA is opposite in sign to the effect on CVA, simply because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

Transition effects, unsurprisingly, depend on when they occur and their duration.

The parameterised approach we introduce for the instantaneous hazard rate curve enables a simple comparison and communication of climate change economic impacts whatever the details of the upstream models. ■

Chris Kenyon is the global head of quant innovation and the global head of XVA quant modelling at MUFG in London. Mourad Berrahoui is head of coun-

4 The slowest uniform test case approaches of the instantaneous hazard rate up to the climate change endpoint



(a) Starting from a CDS of 100bp up to ten years. (b) When the impact is around the midpoint between now and 2101. CVA + FVA impacts are given in the previous section

G. The impact of transformation stress for a 30-year IRS, depending on timing (midpoint) and duration (width)

Width (years)	Change in CVA % Time to mid (years)						
	15	**25**	**35**	**45**	**55**	**65**	**75**
1	47	26	10	8	6	5	4
5	112	54	11	8	6	5	4
10	161	81	13	9	6	5	4
Width (years)	**Change in FVA % Time to mid (years)**						
	15	**25**	**35**	**45**	**55**	**65**	**75**
1	−7	−2	−1	−1	−1	−0	−0
5	−19	−4	−1	−1	−1	−1	−0
10	−29	−6	−1	−1	−1	−1	−0
Width (years)	**Change in CVA + FVA % Time to mid (years)**						
	15	**25**	**35**	**45**	**55**	**65**	**75**
1	22	13	5	4	3	2	2
5	52	27	6	4	3	2	2
10	73	41	6	4	3	3	2
Width (years)	**Percent change in survival probability Time to mid (years)**						
	15	**25**	**35**	**45**	**55**	**65**	**75**
1	−9	−7	−5	−4	−3	−3	−2
5	−34	−27	−21	−16	−13	−10	−8
10	−51	−40	−31	−24	−19	−15	−12

This table shows changes in CVA (top), FVA (mid-upper) and CVA + FVA (mid-lower) as well as the change in default probability over the transformation period (one, five or ten years), that is, the relative sizes of CD.CVA, CD.FVA and CCVA compared with a flat CDS extrapolation

terparty credit risk modelling at Lloyds bank in London and an executive MBA student at Henley Business School. The authors gratefully acknowledge discussions with Robert Wendt, Cathyrn Kelly, Nicholas Amery, Shaoti Zeng and Astrid Leuba.
Email: chris.kenyon@mufgsecurities.com,
mourad.berrahoui@lloydsbanking.com.

REFERENCES

Bank of England, 2019
Enhancing banks' and insurers' approaches to managing the financial risks from climate change
Supervisory Statement 3/19, www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability

Basel Committee on Banking Supervision, 2021
The Basel framework, section 50
Report, available at www.bis.org/basel_framework

Burgard C and M Kjaer, 2013
Funding strategies, funding costs
Risk 26(12), page 82, www.risk.net/2310207

European Central Bank, 2020
Supervisory expectations relating to risk management and disclosure
Guide on climate-related and environmental risks

Fitch, 2020
Corporate rating criteria
Report, available at www.fitch.com

Green A, 2015
XVA: Credit, Funding and Capital Valuation Adjustments
Wiley

Network for Greening the Financial System, 2020
Guide to climate scenario analysis for central banks and supervisors
Report, available at www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_scenario_analysis_final.pdf

Nordhaus W, 2017
Integrated assessment models of climate change
NBER Reporter 3, pages 16–20