Risk-Neutral Pricing of Climate Resilient Debt Clauses and Structures (CRDC/S)

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Abstract

This paper represents Climate Resilient Debt Clauses (CRDCs) as coupon step-down bonds with multiple, periodical tests for step-downs. CRDCs have been suggested as a means to alleviate financial pressures from physical event affected sovereigns, as an increased rate climate-related physical risk are starting to have significant credit implications. Our modelling allows for a risk-neutral pricing framework for CRDCs and determination of 'fair value' pricing. The model allows a calibration of size of coupon reductions - rather than just a full forfeit of the coupon - vis-a-vis expected credit deterioration in absence or presence of the coupon reduction, as well as sensitivity analysis around assumptions about event frequency and credit deterioration and -mitigation post-event and CRDC triggering. We provide an empirical example, showing how Jamaica could achieved similar cash flows benefits through a Climate Resilient Debt Structure (CRDS) compared to the catastrophe bonds triggered after hurricane Melissa in 2025.

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1 Introduction

With an expected increase in frequency of climate change induced physical events, a central question is how these risks will affect sovereign credit debt dynamics, see Beirne, Renzhi and Volz (2021), and in extension of this, the cost of capital and credit rating of countries, see Klusak et al. (2021). As a a means to alleviate some of these pressures, Climate Resilient Debt Clauses (CRDCs) have been proposed. CRDCs are variations in debt contracts and structures such that a disaster hit country is relieved of short-term demands to repay debt and/or interest such that fiscal capacity can be used for emergency and rebuilding efforts in the wake of a disaster. Borensztei, Cavallo and Valenzuela (2009) provide a theoretical framework for how this can be welfare improving. On the investor side, many institutions are less comfortable accelerating debt when the debtor is in non-payment risk due to external, non-controllable factors, compared to situations where the debt has become unsustainable due to endogenous factors, for example see Graves and Wongtrakool (2024).

There are some CRDC structures already in place, e.g. for Barbados, but the construct still has relatively limited uptake. A rich resource on CRDCs is provides by the Sovereign Sustainabilty Debt Hub.[2] Given projections that climate related physical risks are set to increase, as well as an increased government indebtedness, the relevance and practical use of CRDCs going forward is likely to increase. Our paper seeks to increase the practical relevance of CRDCs such that they can be deployed more quickly and efficiently in a changing climate.

Most CRDC discussions have been focused on developing clauses as an explicitly in debt contracts with a legal approach to matter, for example see ICMA (2018). A key question in that discussion is how to integrate CRDCs such that owners of bonds/loans with CRDCs are not put at disadvantage to other lenders that do not have CRDCs. Forms of collective action clauses (CACs) could, for example, be considered to solve this, but would be difficult to implement in practice on an outstanding stock of debt. Eichengreen and Mody (2004) finds that CACs do come with pricing and cost-of-capital implications for the issuers using them.[3] highlighting the importance of developing an understanding of theoretical and empirical evaluation of clause-based changes to standard bond contracts. This papers seeks to explore CRDCs in

[2] https://www.ssdh.net/climate-resilient-debt-clause

[3] Specifically, the paper finds a positive (lowering) cost-of-capital effect for relatively less stressed borrowers, and the opposite for higher risk borrowers.

this pricing spirit.

Another common approach of current CRDCs is the "Net-PV zero"-assumption on ex ante pricing.. This simply means that the CRDC is a redistribution of cash-flows in a bond structure such that the sum of discounted value of cash flows in the CRDC construct is the same as for a vanilla bond. This is quite feasible from an investor point of view, but more difficult from the borrowers perspective. A period of coupon deferrals would generally be met with then higher coupon payment as well a requirement for more aggressive amortization of the bond/loan. However, under an assumption that a CRDC actually decreases repayment risk, it seems reasonable that that improvement (in the form of a lower risky discount factor) should be shared between the investor and the issuer, which is something that this paper develops explicitly.

In this paper, we use a pricing approach to value CRDCs versus the counter-factual: how does a bond with a CRDC function look compared to a vanilla bond, under the assumption that the vanilla bond widens in case of a physical risk event, and the CRDC bond does less so? The novelty in our approach is that we use a standard model for coupon steps – where there are pricing models available (see Erlandsson and Richardson (2024)) to represent a CRDC. This allows for flexibility in terms of design of the instrument: for example, choosing between a full stop on coupon payments, or simply a reduction of coupons to a risk-free, AAA, rate; decisions on how long coupon reductions are active for, and much more.

The model leverages on a key conviction in the discussion: a lower coupon post disaster may increase the credit quality long term such that it compensates for the otherwise wider spread of the bond that an investors would see on a mark-to-market basis and an ex ante risk basis. A bond investor will see a different risk profile of a bond post disaster as probability of default increases and recovery values decrease. It becomes more likely that the bond is never repaid, and there is less to recover if it is not. Decreasing the coupon temporarily will lead to a deterministic reduction of value of the bond that the model will seek to equal to the partially stochastic increase in probability of default and lower recovery value.

An important feature of CRDCs as well as other type of insurance and catastrophe-linked fixed income securities pertains to the dynamics around triggering of post-disaster features: when should the change in a CRDCs be invoked? See, for example, Meenan and Mustapha (2025). To facilitate our

numerical analysis, we will take the triggering process as exogenous and fair, which is a clear simplification of real-life situations. The paper also outlines a number of other extensions of the model to be the topic of future research.

2 The model

We will primarily use risky discount curves to price the CRDC in the context of post-event spread widening as well as risk-reduction through bond coupon deferral. It is useful first to make the connection between defaults, recoveries, credit spreads and implictly risky discount curves.

We start out with the very simple general equation indicating the yield for the sovereign bond of a country A:

$$r_A = r_f + E(L_A) \tag{1}$$

which simply states that the yield of the bons r_A is a function of the risk-free rate r_f and the expected loss $E(L_A)$ which in turn is defined as

$$E(L_A) = PD_A \cdot LGD_A \tag{2}$$

where PD_A is the probability of default of country A and LGD_A is the loss given default. This gives us a straightforward expression for the spread between country As bonds and the risk-free rate:

$$s_A = r_A - r_f = E(L_a) = PD_A \cdot LGD_A \tag{3}$$

Table 1 gives indications for some of the numbers to go into Equation 3. For example, if we have a BBB-rated issuer, and assume that the risk-free AA-rate is for 5 years, as is the BBB-spread, then we have that $r_f = 4.16\%$, $s_A = 1.11\% <=> r_A = 5.27\%$ and $PD = 0.27\% = (1+1.36)^{\frac{1}{5}}\%$. Following this, we could back out that the expected loss given default is $LGD_A = \frac{s_A}{PD_A} = \frac{1\%}{0.27\%} = 410\%$. This is obviously a non-sensible result as any LGD should be capped at 100%. This results stems from the illiquidity premium for the asset class. If the observed risk-premium of credit would actually be fully explained by the bond spread premium (under our assumptions), we would expect the bond premium to be in the range of 0.10-0.20% rather than the observed 1.11%.[4]

[4]Under our assumptions of a five year duration of the index and a recovery rate of 40%. The order of magnitude is insensitive to these assumptions.

Table 1: USD corporate bond yields (1996–2026), spreads, and historical default rates by credit rating. Source: FRED, S&P Global Market Intelligence CreditPro, S&P Global Ratings Credit Research & Insights, Anthropocene Fixed Income Institute.

				Cumulative probability of default				
Rating	Avg. yield (%)	Spread to AA (bps)	Δ spread (bps)	1yr	3yr	5yr	7yr	Total
AAA	4.10	−5.8	—	0.00%	0.13%	0.34%	0.49%	0.86%
AA	4.16	0.0	−5.8	0.02%	0.11%	0.28%	0.45%	0.90%
A	4.56	40.4	40.4	0.05%	0.19%	0.39%	0.65%	1.56%
BBB	5.27	110.9	70.5	0.14%	0.67%	1.36%	2.00%	4.01%
BB	6.66	249.8	138.9	0.56%	3.12%	5.75%	7.94%	13.05%
B	8.40	424.0	174.2	2.93%	10.46%	15.60%	18.90%	25.11%
≤CCC	14.08	992.1	568.1	26.12%	41.32%	46.53%	48.61%	52.30%

This also presents a delicate valuation point. For an investor looking at a potential coupon deferral, doing so based on empirical default rates could be done on a 'cheap' basis as historical defaults and losses are low. To illustrate this, we can represent the bond risk in two different ways: either through the spread risk premium as presented above, or by simply using a tree of default probabilities and risk-free discount rates. We assume a flat risk-free discount zero curve at 2% such that the discount factor for time t is $\phi_\tau = \frac{1}{\gamma_\tau}$ where $\gamma_\tau = \gamma_{\tau-1} \cdot (1 + r^0_\tau)$. With these discount factors, we can build a probability tree as in Table 2, where we have assumed a 1.65% annual default rate (as in the BBB data), and bond coupon of 3% (100bps above the risk-free rate, as in the BBB data), and a 40% recovery rate (as in the BBB data, and the usual market assumption).

We can arrive at the same bond price just using spreads and risky discount factors, as suggested by Equation (3). Indeed, repricing a five year bond with a 100bp spread over the risk-free rate - adding the spread on top of the risk-free zero coupon rates and calculating the relevant discount factors, gives a bond price of exactly 100. The near-equality of bond prices, whether using the probability tree or the risky discount approach, can be verified by using different assumptions on bond coupons. In our example above, using a bond coupon of 5%, yields bonds prices of 108.8 (probability tree) and 109.2 (risky discount) respectively and so on.

Table 2: Pricing a BBB bond using a simple cash flow tree, nominal coupons and recoveries/repayment of notional, adding discounting and default rates.

Scenario	*Cash flow in year*					Probability	Bond price	Prob. wt. bond price
	1	2	3	4	5			
No default	3	3	3	3	103	92.03%	104.713	96.371
Default yr 5	3	3	3	3	40	1.54%	47.652	0.734
Default yr 4	3	3	3	40		1.57%	45.605	0.714
Default yr 3	3	3	40			1.59%	43.518	0.693
Default yr 2	3	40				1.62%	41.388	0.670
Default yr 1	40					1.65%	39.216	0.646
Total						100.00%		99.829

Although mathematically the above relationship between risky discount and probability tree pricing is trivial, the former approach comes with substantial practical advantages. Spreads are readily available through market pricing, whereas default probabilities and loss-given-default numbers are much less so. It is much more within the grasp of a financial analyst to say "we believe event X will lead to a widening of Ybps in country A's bonds" compared to saying "we believe event X will increase the default likelihood (or potential recovery rate) by Y*% for country A." For the purpose of the remainder of this paper, we will discuss the effect of climate related events on bonds in terms of their spread effect, and thus also the risky discount factors.

We now turn to representing CRDC as coupon step-downs in a standard bond structure. The intuition of this is as follows: consider a performance-linked bond which has performance tests every year, and where the test[5] would pertain to the occurrence of a disaster. If the test binds, then a coupon step-down happens, for a pre-set number of coupon payments/years, and then the coupon reverts back to the original one, or alternatively a higher one (a step-up) to PV01 compensate investors.

[5]In the nomenclature of the Sustainability-Linked Bond (SLB) market, this would be market by the Sustainability Performance Target (SPT) and the observation date would be the end of the period covered by the CRDC for an individual coupon payment, see Erlandsson and Richardson (2024).

Normally, performance-linked bonds such as SLBs only have on observation and test date, but there is little in terms of the pricing theory that makes is different to consider a step-bond with τ number of step dates. In terms of pricing such bonds, the discrete time approach in Erlandsson et al. (2023) is here applied to a single step bond where we first consider the baseline standard (non-step) bond price:

$$P_{DE} = \sum_{t=1}^{T} \frac{C}{(1+r)^t} + \frac{100}{(1+r)^T} \tag{4}$$

and the the price of the step-down bond

$$P_{CD} = \sum_{t=1}^{\tau} \frac{C_{CD}}{(1+r)^t} + (1-p) \cdot \sum_{t=\tau+1}^{T} \frac{C_{CD}}{(1+r)^t} + p \cdot \sum_{t=\tau+1}^{T} \frac{C_S}{(1+r)^t} + \frac{100}{(1+r)^T} \tag{5}$$

where C_{CD} is the coupon of the bond prior to the step, CS is the stepped coupon, and p represents the probability of step. This is fairly straightforward and expressed in continuous time in Mielnik and Erlandsson (2022).

The risk-neutral pricing approach to this is simply to set the coupon $C_C D$, given a predetermined coupon step $C_S - C_{CD}$, such that the price of the step bond equals the price of vanilla bond, i.e. $P_{DE} = P_{CD}$. If there is a coupon step-down $C_S - C_{CD} < 0$, then the starting coupon needs to be higher $C_{CD} > C$ in the step down bond in order to compensate the investor for the probability of lower cash flows in a step-down scenario. Stated differently, a risk-neutral investor would be indifferent between the step-down bond with a higher initial coupon with the price P_{CD} and a vanilla bond with the price P_{DE}. The direct translation, without any further assumptions, into the CRDC framing is that coupon deferrals are costly and investors will seek compensation via higher coupons than if they bought the vanilla bonds, or the coupon step-down should be considered concessionary.

Now consider a step-down bond that steps down by a value k once and then reverts to the original coupon C and where the step-down event happens at time E:[6]

$$P_{CRB} = \sum_{t=1}^{E-1} \phi_t \cdot C + \sum_{t=E}^{E} \phi_t \cdot (C-k) + \sum_{t=E+1}^{\tau} \phi_t \cdot C + \phi_\tau \cdot 100 \tag{6}$$

[6]We here assume that the step happens with certainty, and return to discussing probabilities further down, and move into using discount factors ϕ_i to represent the present value of cash flows from here on.

If we set $k = C$ we get a complete coupon deferral as most commonly assumed in CRDC proposals, such that this illustrates the CRDC structure with no coupon payments post disaster is a special case of the more general step-down model. We can also consider a more flexible multi-period step-down, by i periods/coupon payments, as some CRDC are suggesting longer coupon deferrals, or simply to allow for semiannual coupon payments:

$$P_{CRB} = \sum_{t=1}^{E-1} \phi_t \cdot C + \sum_{t=E}^{max(\tau, E+i)} \phi_t \cdot (C-k) + \sum_{t=max(\tau, E+i+1)}^{\tau} \phi_t \cdot C + \phi_\tau \cdot 100 \quad (7)$$

We now turn to the question of what happens with this type of structure if there is an increased risk in the bond after the event date E. The event simply generates a higher probability of default and/or lower recovery rate = a higher expected loss on the bond after that date. We represent this as introducing a higher discount rate, and conversely a lower discount factor, $\phi^*_{i \geq E} < \phi_{i \geq E}$ than the starting one post the event, such that the price of the non-step bond becomes:

$$P_{DB} = \sum_{t=1}^{E-1} \phi_t \cdot C + \sum_{t=E}^{\tau} \phi^*_t \cdot C + \phi^*_\tau \cdot 100 \quad (8)$$

Note that this means that the discount curve for the disaster bond DB would be the same as for the the CRB up until the event at time E but would then have higher discount rates in the following periods.

The crucial assumption now is that we assume that the step-down bond still prices on the original ϕ_i discounting curve, as the step-down k has been set such that it reduces increased ex post expected losses back to the ex ante expected loss rate. Thus, the pricing equation for P_{CRB} remains as before and in a risk-neutral setting, we would again require

$$P_{CRB} = P_{DB} \quad (9)$$

which with some simple manipulation allows us to write:

$$\phi_E \cdot (C-k) + \sum_{t=E+1}^{\tau} \phi_t \cdot C + \phi_\tau \cdot 100 = \sum_{t=E}^{\tau} \phi^*_t \cdot C + \phi^*_\tau \cdot 100 \quad (10)$$

This equation essentially says that the coupon step-down k is directly related to the differential in the discount factors $\phi_t - \phi^*_t$. If we were given

this differential, it would be trivial to solve the equation for k such that the risk-neutral price equality in Equation (10) holds.

Equation (10) is shown using a known event time E. It it straight forward to extend the pricing equality in (10) for $E = 0, 1...\tau$ where $E = 0$ represents the situation where the event does not happen at all, for which the equilibrium pricing coupon step should be the zero. In terms of the calculator in the next section, the probabilities are represented as the vector $\mathbf{P} = [p_1...p_\tau]$ and where the probability of no event is simply $\mathbf{P'1}$.

In order to find the coupon step-down k, one can the simply numerically optimize such that Equation (9) hold for the probability weighted prices of the climate risk bonds. The key inputs in this will be the probability of disaster, the spread widening on the back of the disaster, and the mitigation factor for that spread widening given by coupon step-down k. These are not easy numbers to quantify, but these are of course numbers that should be specified for any claims that a CRDC represents a balance between lower cash flows for investors (through coupon deferrals) and a significant payment relief for the bond issuer.

3 The calculator

Given the coupon step-model in the previous section, we now proceed to walk through the affiliated calculator[7] for finding risk-neutral pricing relationships based on a variety of assumptions. Note that the calculator is simplified to highlight the main concepts, and real pricing should be conducted using more sophisticated methods. As we will show in the next section, however, some of the core CRDC design considerations can be tested out using it. The calculator is provided as-is and for demonstration purposes only. Any real pricing exercises should rely on independent calculations.

Main inputs in the calculator as shown in Figure 1 are

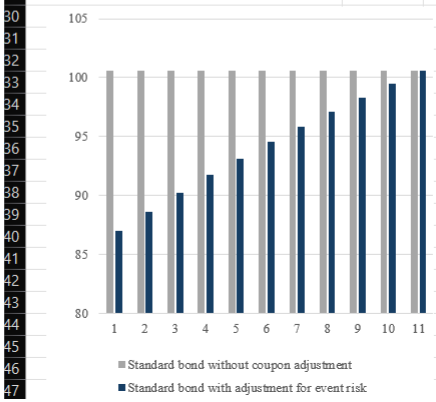
- Risk free curve r_f: row 2, this is found under the tab 'ZeroCurve'.
- Original spread curve s_t, row 3, for purposes of this paper we will assume a flat original spread curve.

[7]The calculator is available for download at https://anthropocene.capital/resources. New versions will be updated continuously.

- Fixed coupon C, row 4, column B.
- Probability vector $\mathbf{P}$, row 5
- Post-disaster spread response function $\mathbf{S}^* = s^*_E, s^*_{E+1}, .., s^*_\tau$, row 9, indicates how spreads move in absolute post a disaster event
- Post-disaster coupons response function $\mathbf{K} = k_E, k_{E+1}, .., k_\tau$, row 11, coupon variations of the event has triggered a coupon change.
- Coupon stepped down risk mitigation vector, row 12, indicates how much spreads move as feedback from the coupon step.

Figure 1: Climate Resilient Bond Structure calculator, available through link. The numbers in the figure/spreadsheet are from Case A below.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Year**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2	Risk-free curve	5.06%	4.64%	4.39%	4.24%	4.14%	4.09%	4.04%	4.03%	4.01%	3.99%	3.99%	3.99%
3	Credit spread curve	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
4	Initial bond coupon	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
5	Spot probability for risk event	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	50%	
6													
7	**Response functions post event / Year t+**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
8	*No spread move post disaster (for testing)*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
9	Disaster widening response function	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
10	*No coupon change (for testing)*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
11	Coupon step after disaster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Coupon stepped down risk mitigation vector	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13													
14													
15	**Probability weighted bond prices (using Spot probability vector)**												
16	Standard bond, no event risk	100.585											
17	Standard bond with adjustment for event risk	97.096	3.49										
18	Standard bond with risk adjustment and coupon ste	97.096				Target function							
19	Standard bond with event risk mitigation and coupo	97.096		Optimized differential		0.000							
20													
21	**Sample bond prices**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
22	Maturity	10.00											
23	Disaster year	5											
24	*Standard bond without coupon adjustment*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	
25	*Standard bond with adjustment for event risk*	*87.03*	*88.66*	*90.22*	*91.72*	*93.16*	*94.53*	*95.85*	*97.11*	*98.31*	*99.47*	*100.58*	
26	*Standard bond with coupon step only*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	*100.58*	
27	*Standard bond with risk adjustment and coupon ste*	*87.03*	*88.66*	*90.22*	*91.72*	*93.16*	*94.53*	*95.85*	*97.11*	*98.31*	*99.47*	*100.58*	
28	*Standard bond with event risk mitigation and coupo*	*87.03*	*88.66*	*90.22*	*91.72*	*93.16*	*94.53*	*95.85*	*97.11*	*98.31*	*99.47*	*100.58*	



The main outputs of the sheet are the probability weighted bond prices P_{CRB} and P_{DB}, and more specifically:

- Standard bond price, row 16 and 24, prices a bond without the event risk and any coupon adjustement
- Adjustment for event risk, row 17 and 25, prices the bond with the spread widening assumption
- Adjustment for event risk and coupon step, row 18 and 27, prices the bond with spread widening and coupon step
- Event risk mitigation and coupon step, row 19 and 28, prices the bond with spread widening, coupon step down, and spread/risk mitigation based on coupon step.

The cell row 19, column F, is generally used as a target function to numerically optimize such that the risk-neutral price equality e.g. in Equation (9) holds. Optimization is conducted using the Solver function, which may sometimes need constraints in order to find the target value.

Core to the calculator are the VBA functions calculating bond prices under various assumptions.[8] The most general function DisasterSDRMBondZero() takes the inputs: risk-free curve, spread curve, baseline coupon, widening response vector, coupon response vector, year in which the disaster happens and maturity of the bond in years. The function then returns the bond price under assumption that the disaster strikes in the given year. If the disaster year exceeds the maturity of the bond, the bond is calculated as if no disaster strikes. This means, as in the calculator rows 24-28, that you can obtain a vector of bond prices (columns B-L) for when disaster strikes in year 1...10 and then finally (column L) the price if it does not happen (year 11). This vector is then simply multiplied with the probability vector and the sum-product then becomes the probability-weighted bond price.

4 Model application

Armed with the step-down pricing model in the previous sections we now turn to some example applications as possible to track in the attached spreadsheet model. The individual applications are indicated by 'Case' and have

[8] Ensure that the option 'Iterative calculations' is turned on in order to obtain meaningful results.

cross-referencing tabs in the Calculator that replicate the results. Price data is as of 24 February 2026.

Case A, as seen in 1), relies on a few assumptions in order to calculate bond prices. Climate-related physical risks are assumed to be exogenous and not currently in the risk-premium of the issuer. We assume a risk-free rate curve r_f based on the USD SOFR rate, and a steady-state spread between the risk-free rate and the issuer yield s of 2% (200bps), meaning that the baseline discount curve is at 6-7% over the time of the bond. We also assume a 6% fixed coupon C on the bond (before any steps).

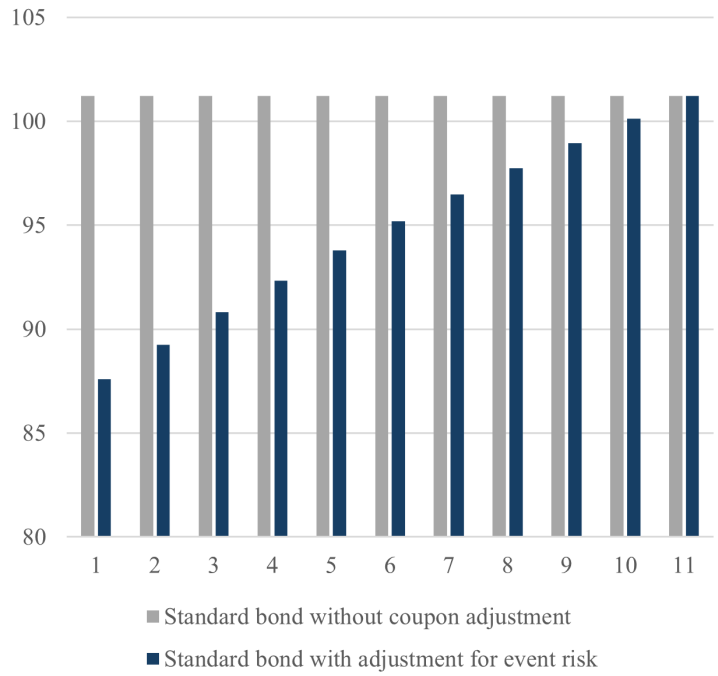
This initial fixed spread may already be pricing in some physical event risk, and for the purposes of this paper we will assume that they disaster event is additional to current expectations, e.g. knowledge that future disasters will be more damaging than currently being priced in. Alternatively, we can use the differential to represent different lenders/investors with views on whether climate change is either happening or has the predicted detrimental effects on the credit worthiness of the underlying countries.

First, we assume that the investor will see a 200bps widening of the bond following a disaster until maturity (i.e. a 'permanent' shock). This move would more than the expected spread move of a rating letter change between BBB to BB (159.9bps) or BB to B (183bps) as seen in Table 1. We also assume a flat probability (hazard rate) of 5% per annum for disaster to strike. What is the risk-neutral price of this bond, relative to a bond without the exogenous risk?

We price this in Figure 2, case A, where the dark-blue bars show the lower bond prices for the disaster struck bond as a function of the year in which the disaster strikes, e.g. a bond where we expect the disaster to strike in year 1 is worth only 87.03 cents on the dollar. If the disaster does not strike (indicated as year 11), then the bond price is the same as for the non-disaster risk bond (100.58).

We then simply weigh the bond prices by year by the probability by year that disaster strikes, i.e. a 5% probability for each year and a resultant 50% probability that disaster does not strike at all. The bond price is then 97.10 (cell B1), or 3.49 cents lower than for the standard bond. If we have an investor that start to 'believe' in disaster risk of this type, they would then be willing to forgo some of that \$3.5 price differential in order arrive at a marginally better outcome than losing it all.

Figure 2: Simple bond pricing, case A.



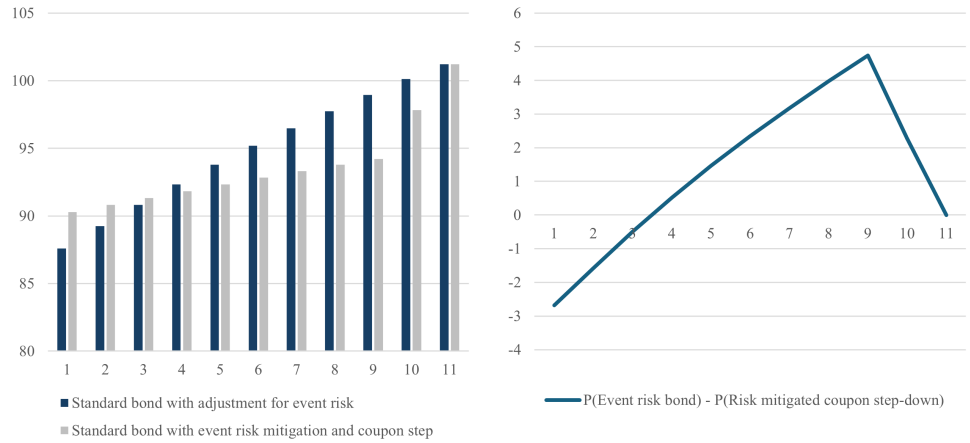
We now assume that we add some sort of climate risk debt contingency into the bond such that the credit quality of the issuer is improved and we do not see a credit widening of the bond post a contigency trigger. As discussed above, this argument can stand on two feet: first, the debt contingency reduces cash flow risk in the short term, when for example tax collection may not be operational. Second, the investments in rebuilding post-disaster are made in a resilient way such that expected losses are lower in the future.

In this first iteration, we assume that there – in case of a disaster – a step-down of 6% of the coupon of the bond for the year when it hits and the next (a $i = 2$yr stepdown, case B.1). We will call this a Climate Resilient Debt Structure (CRSD). Effectively, the borrower would pay no coupon in the two years following a disaster, and on the flip-side, the post-disaster credit quality would not change.

The valuation of the two different bonds in this case is available in Figure 3 (left). In the right hand graph we also plot the price differential between the bonds, where we can see that the step-down bond is more valuable (higher

price) when the disaster hits early (yr 1-3), and the straight bond is more valuable in yr (4-10), as there is less time at which the bond trades at the higher discount factor.

Figure 3: Comparison of disaster bond (+2% flat) vs step-down bond (6%, 2yrs), no final maturity adjustment. Case B.1.



Pricing these bonds at a flat 5% annual probability, the step-down bond prices at 89.70 (case B.1, cell B26), 2.67 cents higher than the disaster-priced straight bond. This simply illustrates the basic logic of the CRDC discussion: a substantial temporary reduction of the bond coupon which neutralizes the credit negative impact of a physical event can be well motivated to invest in.

What is the coupon step-down that under these assumption would provide an investor with a risk-neutral proposition vis-a-vis the disaster bond? It is trivial to search for the coupon step-down using the pricer (case B.2), in this case, the 'cost' of a coupon step-down of 5.02% for two years while mitigating the disaster risk (cell B19) would equal the expected loss on the disaster bond with no mitigation (cell B17). This serves to suggest that rather than complete coupon deferrals, the coupons can be stepped down such that they are calibrated to the investors' perceived fundamental risk exposure. Also note the flexibility in being able to decide on longer or shorter coupon reductions (either just for the year or the event, of being able to cover a multi-year build-back process explicitly).

In the right-hand figure of Figure 3 we plot the price differentials. Note the kink in the curve in year 10, due to the fact that there is only one coupon

step down as the bond then matures at the same time. We will return to this assumption below, recognizing that it is reasonable for a CRSB to have features where nominals should not be repaid following disasters.

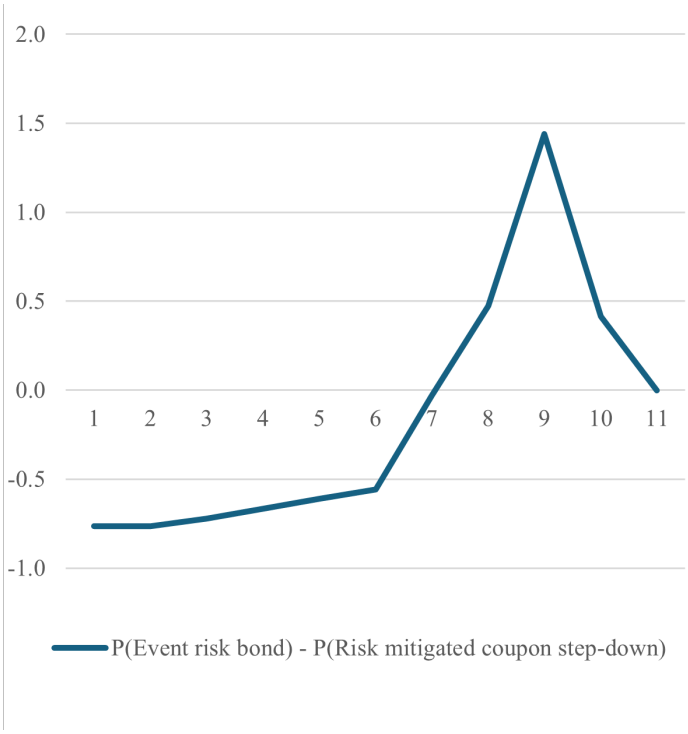
One important point comes through in the graph in terms of time-value in the two alternatives: if disaster probability is back-loaded, for example if we expect increased probabilities for risk events in the later years, then you would rather hold the disaster bond than the step-down bond. If we assume that annual probability starts out at 5% but then increase by 1% per annum, then the price differential between the disaster bond and the step-down bond increases, such that the risk-neutral acceptable step-down becomes 4.51% (case C, cell B11) rather than 5.07% (case B.2). More generally, the point will be that the probability curve matters for how to view the CRSB versus a straight bond.

Another variation of the assumptions is to let the spread response function post disaster not be a constant but time-varying. In Case D, we set the spread widening versus the original spread at E to be 400bps, $E+1$ 300bps, then 200bps, 100bps for year 4 and 5, and then the spread reverts back to the earlier one. We again assume a flat probability curve and that a CRSD mitigates the spread widening fully. The resulting bond pricing is available in Figure 4, and the risk-neutral pricing allows in this case to have a coupon step-down of 4.60% (case D, cell B11) for two years.

As noted above, there are CRDCs prevalent in the market that are generally structured as PV01-neutral, which from our understanding of the structures does not assume a spread-widening in the PV01 calculations. As seen in World Bank (2024): *To achieve PV neutrality and maintain the loan's original weighted average maturity of about 13 years, the loan payments post-deferral would be repaid over a shorter timeframe (by 18 years of the remaining maturity instead of the original 20 due to the 2-year deferral period).* Effectively, lenders recover their 'value' from allowing a deferral by quicker amortization of the bond, including repayments of the deferred coupon, in order to make the whole package PV01 neutral. This might seem counter-intuitive to what is the modus operandi in debt restructurings (such as Greece in 2012) where debt maturities are extended in order to lighten the burden for the borrower, but one should recognize that most CRDCs are proposed as liquidity solutions, not financial support.

In case E, we represent the 20-year structure in World Bank (2024) instead as a bond with a full coupon step-down for two years after the occurrence of

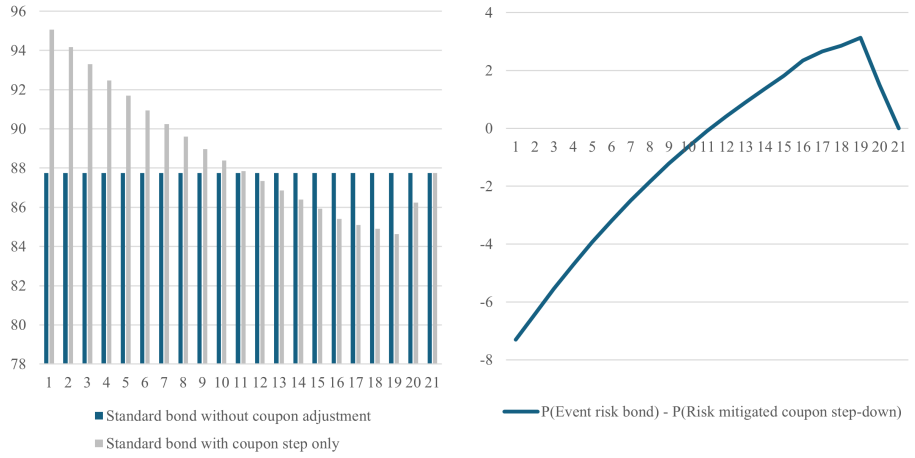
Figure 4: Comparison of bond prices assuming a receding spread widening after the event, Case D.



a 'natural' disaster, and then with an automatic coupon step-up after the deferral period. This is a similar way to represent the PV01s in the bond with the benefit of not changing maturities (which is problematic for investors as well as borrowers), and with perhaps greater transparency as it show how much higher the interest becomes post deferral. This is shown as Case E in the calculator.

We also show the bond price calculations in Figure 5, where we have assumed a 2% base probability for an event, which then is increasing by 0.25% per annum over the 20yr maturity of the bond. The coupon has been set to 5% to match a 200bps spread versus the risk-free curve, and we have assumed no increase in the spread following a climate risk event. Optimizing for risk-neutrality, the step-up becomes 1.69% (case E, cells D11:U11) above the baseline coupon after the two years of deferral. This is the coupon step-up that would, on a probability weighted equivalent basis, give the same PV01 neutrality as the amortizing, shortened CRDC structure.

Figure 5: Representing the World Bank (2024) CRDC as a step-down bond with fixed 20yr maturity, Case E.



Further development of CRD structures based on the step-down pricing model should be straightforward. We would consider a number of possible additions:

- Maturity extension: a CRDS where the maturity of the bond extends in case the disaster event happens near the end of the life of the bond, such that the issuer is protected also from nominal repayments while in rebuilding stage.

- Variable step-ups: a CRDS where there is a compensating step-up coupon after the coupon step-downs/deferrals and where the size of that coupon is a function of the remaining life of the bond. Longer left, lower step-ups. One could consider this a representation of CRDCs where there is amortization of the deferred coupons such as the structure in World Bank (2024).

- Multiple event structures: a limitation of the above model, and the CRDCs in the market, is the restriction to only one climate risk event in the life of the bond. Extending the CRDS model, however, to account for multiple events is straightforward from a cash-flow discounting perspective. The difficulty rather lies in estimating the probability thereof, which will rest upon defining the correlation between multiple events in time "auto-correlation". From a practical standpoint, one needs to decide if step-downs would be cumulative or simply just extend over time in case of multiple events, but again this would not be hard to price if given a probability thereof.

- Portfolio effects: an investor holding a portfolio of CRDS bonds would need to price it using assumptions on correlation between events happening simultaneously in time. For example, a portfolio of Caribbean country CRDS might have a high correlation, with an elevated risk for step-downs in several bonds at the same time whereas a global portfolio might have lower correlation than the equivalent non-CRDS portfolio. We would suggest using pricing methodology from the collateralized debt obligation (CDO) space as an approach to pricing CRDS portfolios, see Lando (2004) for example.

5 Case study: Jamaica CRDS

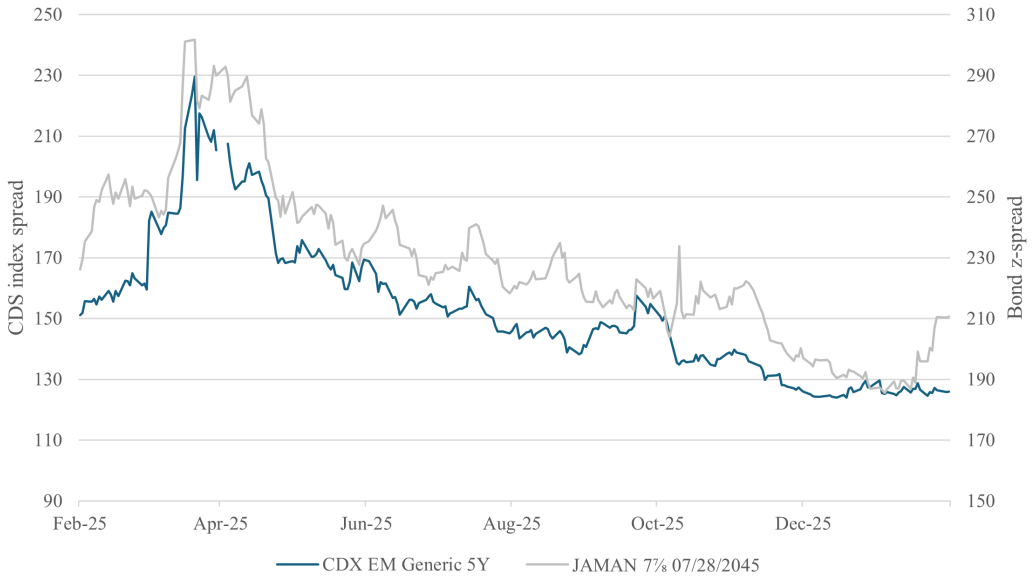
With CRDCs most often being mentioned in relation to island nations with high hurricane risks, we use Jamaica as an illustrative case study Jamaica is rated BB, BB-, Ba3 from S&P, Fitch and Moody's respectively, and the 5yr CDS trades at around 128bps, almost exactly the same as the MarkIt CDX.EM 5yr index at the time of writing.[9] The z-spread of the JAMAN 2045 maturity bond versus the generic CDX.EM index is plotted in Figure 6.

Note the high correlation of spreads generally, expect for a brief period in late October-26, at which time Jamaica was hit by category 5 Hurricane

[9]Pricing as of 18 Feb 2026 unless stated otherwise.

Melissa, see WMO (2025). Estimates of losses from the hurricange range between 28-32% of 2024 GDP (USD19.3bn → USD5.4-6.2bn of losses), according to Reuters. The event was also significant as it triggered a full payout on a USD150mn World Bank Catastrophe Bond, see World Bank (2025) and Artemis (2025). The bond in question was issued in 2024 with a 3.7yr maturity and a 7% risk premium, priced off a 2.46% per annum loss probability (CHECK 'attachment' probability) and a 1.61% p.a. expected loss.

Figure 6: Jamaica USD bond spreads (20yr) vs CDX.EM spreads (5yr). Source: Bloomberg.



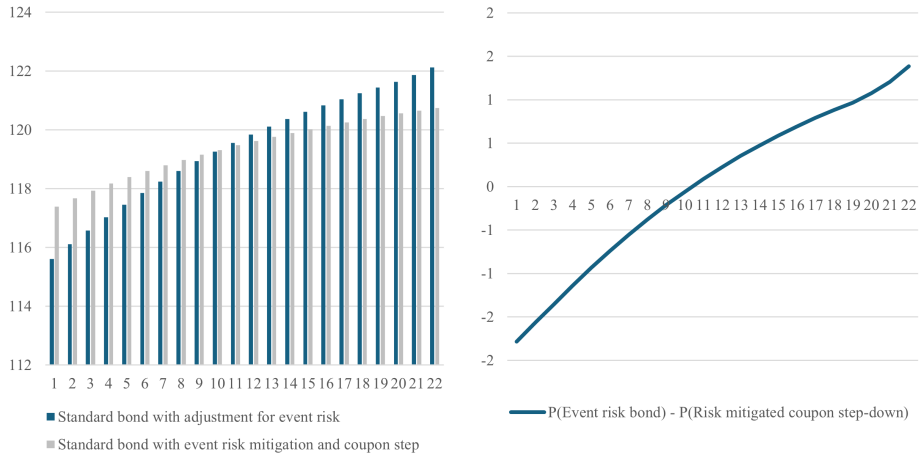
Around the Melissa event, spreads on the JAMAN 2045s widened by about 30bps, at a time when EM spreads as measure by the index tightened 10bps, generating an estimated 40bps underperformance that we will assume was fully driven by the event. Jamaica has approximately USD4.9bn of debt outstanding with and average maturity around 11.4 years. The weighted coupon rate is 7.76%, meaning that the sovereign is facing average bond payments of USD380mn a year. Back of the envelope, the spread widening (+40bps) across the average debt would have meant mark-to-market losses for investors of USD4.9bn x (0.4% x 7.5) = USD147mn.[10]

[10]Based on the average bond structure, we estimate the duration of of the 'average' bond to be 7.5.

A CRDS example for Jamaica is available in the calculation spreadsheet. We have modelled the CRDS on the current outstanding JAMAN 2045 bond that was issued in 2015. With a high-coupon relative to today's spread/perceived riskiness of Jamaica, the bond trades a substantial premium with cash price of around 120.

In order to price the CRDS, we make assumptions around the spread widening incurred in case an event afflicts happens: we assume an instantaneous spread widening of 80bps, which is twice the widening seen around the Melissa event. This assumption barbells two different perspectives: the Melissa incurred a 40bps instantaneous widening and retraced fully after a few months, with the support of cat bond write-off of USD150mn. On the flip side, the cost in %-age terms to GDP was substantial of almost a third of annual output. To contextualize that GDP hit into bond spread changes, Hadzi-Vaskov and Ricci (2016) estimate that a 10% increase in debt-to-GDP leads to a half notch credit rating downgrade and increases spreads by 100-120bps, and more in times of domestic distress. Our assumption of an immediate 80bps effect, then decaying to 40bps over five years, and then staying at 40bps wider permanently, seeks to strike a balance between the two perspectives.

Figure 7: A CRDS structure for Jamaica 2045 bonds.



We furthermore assume, as in the CAT bond pricing, a probability of an event to strike at 2.68% per annum, and let it stay fixed over the life of the bond. The pricing as in the calculation sheet as well as in Figure 7 assumes a single coupon step-down under these assumption, and finds an equilibrium

step-down k of 5.3% (case Jamaica, cell B11). This would represent a reduced coupon payment in the event year of USD97mn, which is lower than the USD150mn CAT bond capital depreciation, but on the other carries a much lower cost through the life of the bond,[11] suggesting that a coupon step-down structure could be better for the issuer on an expectations basis. Further capital reliefs would of course come if also other bonds on the JAMAN curve had CRDS features.

Our example above is rather simplistic and could be extended to include more bonds, longer coupon step-down periods as well as differing assumptions on the the credit risk mitigation on the basis of cash flow relief. The calculator should be able to accommodate that with some adjustments. The point of the example is to illustrate that a rather standard bond technology, coupon steps, can facilitate dynamics provided by less standard instruments such as cat bonds and bonds with CRDCs in a way that is arguably more digestible for mainstream investors. For example, Bloomberg (2025) index methodology allows coupon step bonds for bond index inclusion.

6 Conclusions

This paper has represented CRDCs in a coupon-step down framework, allowing for a direct analysis of the assumption of risk-mitigation through coupon step-downs/deferrals and the expected increase in credit risk post a climate disaster event. It highlights the key assumptions that need to be made with a CRDC/CRDS for investors to consider it a non-concessionary investment: the probability of an event happening, the expected risk increase post event and the expected risk mitigation through a coupon adjustment. We show in a hopefully easy-to-access framework how these factors are interconnected, allowing for adjustments in the coupon step-down size (or length of deferrals) to price bonds in a risk-neutral fashion that should be attractive to both investors and issuers.

We argue that the coupon step structure do have some practical advantages: rather than relying on contractual overheads that may be difficult to input in investor systems, the coupon step structures are generally already implemented among investors. It also is good for illustrating the pay-back of coupon deferrals in current CRDCs through back-end higher coupon payments, as such structures in the current market standards are usually not

[11] The JAMAN 2045 spread at around 200bps over swaps versus the cat-bonds 700bps.

concessionary. Index inclusion may be another benefit of the CRDS structures.

The generalization of the above model to multiple events and coupon steps should be straightforward but remains the topic of future analysis. Especially for long-dated bonds, just allowing for one coupon step-down/deferral may not be reflective of the actual risk as perceived by borrowers.

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