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Parametric Insurance: A Mechanism to Finance Disaster Resilience and Transitioning to a Low-Carbon Economy in the Caribbean

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Abstract: Caribbean small island developing states (SIDS) are being disproportionately affected by climate change. While no country wants to accept legal liability for their emissions, the Caribbean region faces an urgent need to mobilize financing to address loss and damage. This study proposed a voluntary insurance to address the loss and damage from climate change. Voluntary insurance can be used to pool risk across countries and make a payout to cover the loss from extreme weather events. The insurance payout could be parametric, which can eliminate the trouble assessing of losses in indemnity insurance. The key features affecting the trigger for the payout could be the occurrence of the named peril, and meteorological data such as precipitation. The size of the payout would be determined by estimating the loss and damage of Caribbean SIDS from extreme weather events. The premium could be based on solidarity and thus can be the average cost of the total payout per annum. Wavelet coherence could be used to measure the dependence between the precipitation and loss and damage estimate rather than correlation. Payouts to governments provide crucial financial resources for rebuilding infrastructure more sustainably.

Keywords: loss and damage, climate change, Caribbean SIDS, parametric insurance

1. Introduction

In 2019, Hurricane Dorian hit the Bahamas. It was the first Category Five hurricane to hit the Grand Bahama Island. Additionally, 2019 marked the 4th consecutive year in which at least 1 Category Five hurricane developed in the Atlantic [1]. The hurricane caused flooding and mass destruction on the northwest islands of Abaco and Grand Bahama. Homes were destroyed, power lines were brought down, the airport and the hospital sustained damage, and public utilities were disrupted. Additionally, over 2,500 people were declared missing by September 12, 2019 [2].

Further recent examples of hurricanes impacting the region include Hurricane Dorian, Hurricane Isaias, Hurricane Grace, and Hurricane Ian [3–5]. These extreme weather events cause billions in damage to the affected countries.

The aforesaid examples show the physical risk associated with extreme weather events. For the Caribbean, this is also a manifestation of climate change as it is experiencing an increase in the frequency and intensity of extreme weather events [6–8]. Sartzetakis [9] notes that apart from physical risks, climate change is associated with liability risks and transitional risks.

These risks (physical, liability, and transitional) are all present in the Caribbean. For instance, the physical risk of Hurricane Isaias can be seen in the approximately US$225 million in damages that were incurred by the Caribbean region [10].

The liability risk can also be seen as no high greenhouse gas (GHG)-emitting industrialized country wanted to be held liable for the hurricane damage. Although industrialized countries pledged to give US$100 billion per year in climate funding starting in 2020 at the fifteenth session of the Conference of the Parties (COP 15) [11], the bureaucracy surrounding climate finance makes it very difficult to access by small island developing states (SIDS).

There is also some transitional risk as the hurricanes damaged infrastructure and disrupted economic activity. The need to frequently replace essential public infrastructure makes it more difficult for Caribbean countries to put aside extra funding to invest in renewable energy and other low-carbon technologies.

Given these risks in the Caribbean, there is an urgent need to raise funding to tackle the damage and loss from climate change. Disaster insurance emerges as a potential solution as it can mobilize funding for Caribbean countries affected by loss and damage from climate change without assigning legal liability to any country.

Particularly, the use of weather insurance to compensate SIDS for damage and loss from climate change complements climate change mitigation action and the transition to the low-carbon economy as it helps builds resilience. It helps mobilize finance to rebuild sustainably so that future production activities would produce less GHG emissions.

The objective of this study is to investigate the mechanics of a parametric insurance framework to mobilize damage and loss

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finance for Caribbean SIDS. The corresponding research question for this objective is:

1) How to structure the payout and the premium for the proposed parametric insurance for loss and damage for Caribbean SIDS?

This study is structured as follows. Section 2 provides a literature review on the evolution of the idea of insurance to compensate SIDS for loss and damage from climate change. It also reviews the literature on the application of insurance to compensate stakeholders for adverse weather events. Section 3 explores the disaster insurance options presently available in the Caribbean. Section 4 examines the mechanics of the proposed damage and loss insurance for Caribbean SIDS. Section 5 concludes this study.

2. Literature Review on the Application of Insurance to Address Weather Events

The principle of loss and damage from climate change stems from the idea that some climate change impacts are so great they go beyond activities covering adaptation and mitigation. These effects range from slow-onset occurrences like sea level rise, desertification, and glacier melting to extreme weather events like hurricanes, erratic storms, sporadic flooding, and random droughts [12].

The Alliance of Small Island States first raised the issue of loss and damage due to climate change in 1991, advocating for a financial mechanism to compensate SIDS for the disproportionate impact they face. However, this proposal was rejected by developed countries at the first Conference of the Parties (COP 1) of the United Nations Framework Convention on Climate Change in Berlin, Germany [12].

Over the years, the topic of loss and damage was raised at subsequent COPs, including COP 7 in Marrakech in 2001 and COP 13 in Bali in 2007. Progress was made during COP 16 in Cancun, Mexico, where parties decided to examine the issue for 2 years under the Cancun Adaptation Framework. The review was completed at COP 18 in Doha, Qatar, leading to the formal recognition of loss and damage, and the establishment of the Warsaw International Mechanism on Loss and Damage (WIM) at COP 19 in Warsaw, Poland in 2013.

Under the Paris Agreement, agreed upon in 2015, Article 8 outlined the WIM as the primary vehicle to address loss and damage from climate change. However, the agreement did not include specific provisions for financing loss and damage incurred by SIDS [13].

From 2016 to 2019, the WIM Executive Committee explored the possibility of using insurance as a mechanism to address loss and damage, but no definitive decision was reached.

Finally, at COP 27 in Egypt in 2022, Parties agreed to fund loss and damage through a new climate fund. However, the exact details of this fund and its disbursement to governments to address loss and damage impacts remain to be negotiated in future COPs.

There is a need for a financial mechanism to tackle loss and damage from climate change, especially for SIDS. Thus, funds need to be mobilized at a large scale where they can be disbursed to governments to tackle loss and damage impacts. The next subsection reviews the literature on the application of insurance to address adverse weather events.

2.1. Literature review on weather insurance

Insurance can be used to mitigate the financial risks associated with adverse weather conditions. This type of insurance is referred to as weather insurance. Weather insurance works by pooling the risks of many individuals and enterprises, and then using this pooled risk to set the price of the insurance premium. This way, the cost of the insurance premium is spread out over a large number of people, which makes it more affordable for everyone. Furthermore, weather insurance transfers the risk from risk-averse policyholders to insurers that are willing to bear the risks [14].

Kraehnert et al. [14] note that weather insurance can be grouped into three categories, namely indemnity-based, parametric-based insurance, and insurance-linked securities (ILS).

Under indemnity insurance, the policyholder is provided with coverage for the damages or losses that they have incurred as a consequence of an event. There are two permutations: named peril and multiple perils. Under the name peril option, the policyholder may file a claim only after the occurrence of one named-peril event. The peril is specified in the contractual agreement between the policyholder and the insurer [15].

When the policyholder files a claim, they are usually required to show proof of losses, to verify their losses. The insurer would require an on-site adjuster to verify the losses of the policyholder. After the losses have been verified, the insurer may make a payout up to a specified limit to the policyholder, to cover the policyholder's losses [14].

In contrast to indemnity insurance which allows for claims to cover damages, parametric insurance allows for coverage after the occurrence of perilous events. The peril event act as a trigger to immediately mobilize payment to the policyholder regardless of the level of damage they incurred. Differently stated, the claim is written off against the event rather than the damage.

In weather insurance, sometimes an index is used as the trigger for the payout. The index is based on data collected from a natural event, such as rainfall and wind speed. When the index reaches a threshold level, it triggers a payout. Parametric insurance is appropriate, especially in instances where an extreme event may affect many stakeholders and it is too difficult to assess the loss of the policyholders. It is also useful as it addresses the asymmetric information of the potential losses each policyholder may experience. Furthermore, it is also appropriate when time is critical to mobilize financial resources for relief and recovery immediately after an extreme event [14].

ILS arise to address the problem of the difficulty of pooling risks at the national level. This challenge is addressed by widening the pool to an international scale. Presently, there are two types of ILS providing insurance against adverse weather events. They are catastrophe bonds (cat bonds) and weather derivatives. In a catastrophe bond, the policyholder issues the cat bond. Investors in this cat bond receive a coupon (interest rate payment) but are obligated to cover losses if named peril occurs. Catastrophe bonds are mainly used for reinsurance.

Linnerooth-Bayer et al. [15] note that weather insurance can operate at macro, meso, and micro levels. In macro-insurance, the policyholder is typically a government. Meso-insurance refers to weather insurance that is targeted at special interest groups [15, 16]. Micro-insurance refers to weather insurance that is administered to individuals.

Various types of insurance are suitable for different situations. Bucheli et al. [17] observed that indemnity insurance is commonly used at the micro and meso level for European farmers, offering coverage for specific named perils or multiple perils. However, indemnity insurance encounters challenges related to asymmetric information, as farmers possess better knowledge of their losses and risks than insurers. Adjusters are employed to verify losses, but they may face capacity limits when multiple farmer policyholders are affected by adverse weather events, leading to basis risk where payouts may not fully cover the total loss cost.

Shirsath et al. [18] note that moral hazard and adverse selection hinder the effectiveness of weather insurance with indemnity payments for small farmers in developing countries[1]. Despite its common use, this type of insurance does not adequately address the challenges faced by these farmers. This argument is supported by various studies, including Iturrioz [19] and Cai et al. [20].

Vroege et al. [21] note that some indemnity insurance schemes utilize satellite imagery to verify losses. However, this is at an aggregated level. Accurate estimation at the field level for individual farmers necessitates satellite observations below 1 m resolution, obtained from commercial satellites, which increases insurers' costs. Despite this approach, moral hazard remains a concern, as farmers might avoid risk reduction measures to receive insurance payouts.

Parametric insurance emerges as the appropriate weather insurance for farmers.

Singh [22] records the endeavors made in India during the early 20th century to establish an agricultural insurance program based on a rainfall index. The focus is on the work of Indian economist Chakravarti, who created a rainfall and crop output formula in 1915 that linked the impact of excessive rainfall to crop output. Regrettably, Chakravarti's scheme was never implemented.

Halcrow [23] proposed a novel concept for the US federal crop insurance program, introducing the area-yield approach with full or partial coverage options based on mean area-yield falling below a specified threshold. He also suggested weather-index crop insurance, compensating when the index exceeded a predefined "limit of tolerance," laying the foundation for yield-based and index-based parametric insurance. Practical implementation of index-based insurance gained traction in the 1990s, exemplified by Skees et al. [24] developing an area-yield crop insurance contract using the county average crop yield as the index triggering insurance payouts.

At the macro level, insurance can also be provided to governments. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) emerges as a notable case study of a macro-level weather insurance. It provides coverage to multiple governments in the Caribbean and Central America against specific named perils, namely earthquakes, tropical cyclones, and excess rainfall. By 2019, CCRIF made over 36 payouts to 13 member governments on their named perils, totaling US$130.5 million [25].

Other examples of macro-level weather insurance include the African Risk Capacity (ARC)[2], Mexican Catastrophic Risk Insurance Facility (FONDEN)[3], and Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI)[4].

The aforementioned insurance programs offer governments financial protection against the economic impact of extreme weather events and natural disasters. They provide a mechanism for governments to transfer a portion of the financial risk associated with weather-related events to insurance providers. Furthermore, they tend to be parametric type insurance which triggers a specified payout to government policyholders after the occurrence of named perils.

Presently, there is a gap in the literature as no study has recommended a macro-level weather insurance to address loss and damage in the Caribbean SIDS. While the CCRIF does provide some coverage, it is only sufficient for relief and recovery efforts, and not the total cost of loss and damage. This study seeks to fill this gap by proposing a weather insurance framework to address loss and damage from climate change. Secondly, given the unavailability of data on the actual total cost of loss and damage of Caribbean SIDS in the aftermath of extreme weather events, this study proposes a framework to structure the insurance. The framework will consider the named peril and a proxy for the loss and damage.

Given that the concept of insurance has been explained, the next section reviews the disaster insurance options in the Caribbean. Examples will be provided for each type of insurance, namely macro-insurance, meso-insurance, and micro-insurance.

3. Disaster Insurance in the Caribbean

Several insurance options are available in the Caribbean region. With regard to disaster insurance, the known options are CCRIF (a macro-insurance), Windward Island Crop Insurance Ltd (WINCROP) (a meso-insurance), and Microinsurance Catastrophe Risk Organization (MiCRO) (a micro-insurance).

3.1. Caribbean Catastrophe Risk Insurance Facility

The CCRIF was formed in 2007[5]. It was the first multi-country insurance to pool risk in the world. It was developed in response to the frequent hurricanes that were battering the Caribbean islands on an annual basis.

The CCRIF's objective is to mitigate the financial impact of natural disasters in the Caribbean and Central America by mobilizing funds when a policy is triggered. The CCRIF is a parametric-based insurance that triggers payouts to the respective member governments after the occurrence of any of the following perils, tropical cyclones, earthquakes, and excess rainfall [29]. There are also policies for the fisheries sector and the electric utility sector.

At the beginning of the policy year, each participatory country agrees to the total payout which can be made to them by the CCRIF. They also agree upon the premium the country must pay to access coverage. From the CCRIF's inception to 2020, the organization made a total of 48 payments to 14 countries at US$190 million [30].

3.2. Windward Island Crop Insurance Ltd.

In 1987, the Windward Island Crop Insurance Ltd. was established in Dominica to provide insurance to banana farmers against wind damage. The program was expanded to St. Vincent and the Grenadines in 1996, then to Grenada in 2000 [31].

WINCROP was established as an insurance company that is owned by the banana marketing boards in its member countries[6]. Its purpose is to provide coverage for banana farmers at low

[1] Moral hazard is the tendency for insured policyholders to adopt riskier behavior because they are insured from loss. Adverse selection is where the risker stakeholders seek insurance coverage and the less risky stakeholders choose to be uninsured.

[2] ARC is a macro-level weather insurance company established by the African Union to help African governments mitigate their risks from extreme weather events. ARC provides its member states with capacity building services, early warning technology, contingency planning, and risk pooling and transfer facilities [26].

[3] FONDEN was operationalized as a macro-level weather insurance company in 1999. Its objective is to provide the Government of Mexico coverage against various natural disasters, including hurricanes, earthquakes, volcanic eruptions, and severe weather events [27].

[4] PARAFI objective is to provide the Pacific Island Countries (PICs) with weather insurance coverage, disaster risk modeling, and assessment. It provides coverage against tropical cyclones, earthquakes, and tsunamis [28].

[5] In 2014, the CCRIF was restructured into a segregated portfolio company (SPC). Subsequently, the CCRIF was renamed "CCRIF SPC" [29].

[6] The member countries for WINCROP are Dominica, Grenada, St Lucia, and St Vincent and the Grenadines. The respective banana boards are the Dominica Banana Marketing Corporation (DBMC), the St Lucia Banana Corporation (SLBC), the St. Vincent Banana Growers' Association (SVBGA), and the Grenada Banana Corporation Society (GBCS).

premiums. This is achieved by the pooling of the risk of the farmers and the purchase of reinsurance [32].

The insurance scheme provides coverage for 20% of the estimated loss of banana deliveries. All farmers are required to pay a premium equivalent to about 5% of sales receipts, which is automatically deducted by the banana marketing and export board in each respective country [32].

Unfortunately, WINCROP experiences several challenges. This first challenge is financial viability. WINCROP banana crop insurance falls within the provisions of Annex II of the World Trade Organization agreement on agriculture [33]. Therefore, it must be administered without any government subsidy, so that the state would not give its banana farmers an unfair advantage over other countries.

The second challenge relates to the assessment of losses. WINCROP relies upon On-Call Assessors to carry out assessments of losses before paying claims. In the aftermath of hurricanes, WINCROP often finds itself challenged in mobilizing sufficient assessors to assess the losses. This results in delays in the payouts to the farmers.

The third challenge is the tendency for the organization to face a high bill for claims after a hurricane. This is expected for their disaster insurance since almost all the banana farmers would be affected by the hurricane.

This leads to the fourth challenge where WINCROP finds difficulty in acquiring reinsurance.

3.3. Microinsurance Catastrophe Risk Organization

The Microinsurance Catastrophe Risk Organization was developed in 2011 to provide disaster reinsurance for Haiti after experiencing a devastating earthquake in 2010 [34].

MiCRO's objective is to facilitate insurance options for low-income populations that are vulnerable to natural disasters. To extend more coverage, MiCRO's goal is to act as a reinsurance company, by aggregating the risk for international reinsurance companies, while retaining some of the risk itself [34].

In 2016, MiCRO expanded to Guatemala and provided an index-based bundled earthquake, drought, and excess rainfall insurance that covers the disruption to business.

As a parametric index insurance product, MiCRO's payouts depend on the observed levels of a predefined index. The index in turn is computed based on data on rainfall and droughts, and ground vibration. The approach was adopted as it provides transparency and allows the insurance product to minimize the administrative costs associated with loss adjustment. However, the reliability and validity of the index depend upon a strong correlation between observed index levels and losses experienced [35].

Indeed, there are disaster insurance options available in the Caribbean. Therefore, the concept of applying loss and damage insurance for Caribbean SIDS is not farfetched. The next section will propose the mechanics of a voluntary loss and damage insurance for Caribbean SIDS.

4. Proposed Voluntary Loss and Damage Insurance

Caribbean SIDS affected by the damage and loss from climate change requires a framework to mobilize the appropriate finance. In this regard, a macro disaster insurance framework could be used. A macro-insurance is recommended since it can be used to mobilize a payout for the affected governments rather than for individuals.

The purpose of the insurance would be to pool risks and mobilize finance for SIDS that are disproportionately affected by climate change. There are SIDS in three different regions, namely the Caribbean, the Pacific, and the Atlantic, the Indian Ocean, and the South China Sea (AIS). The proposed voluntary loss and damage insurance could be structured for premiums and payouts for the different regions of SIDS. In other words, the finances affecting the payout for the SIDS in the Caribbean should be separated from the SIDS in the Pacific and the AIS.

Both Annex I and non-Annex I countries could be asked to join the proposed voluntary loss and damage insurance. All participatory countries can pay premiums. However, one option would be for only the SIDS to be eligible for the receipt of payouts after extreme weather events. This idea could be introduced at the Conference of the Parties to gauge the international community's comments and appetite.

The second option would be for all participatory countries to be required to pay a premium, and for all participatory countries to be eligible for a payout after the occurrence of an extreme weather event. In this second option, the proposed loss and damage insurance would be an international loss and damage insurance rather than a loss and damage insurance for SIDS.

The proposed insurance should be parametric as it may be too difficult to assess the loss with on-site adjusters promptly and efficiently.

The proposed loss and damage insurance should use named perils as its trigger. For example, excess rainfall or excess wind speed can be used as a trigger. In fact, a parametric index based on the perils should be used to trigger the payout. There should be policy options for each peril.

The subsequently issue would be how to structure the insurance including pricing the payout and the premiums. Those issues are considered in the next subsections.

4.1. Data for pricing the payout for the proposed insurance

A weather insurance must have a variable to represent the extreme weather event and a variable to represent losses [36]. Following the principles of Halcrow [23] and Skees et al. [24], this study proposes an insurance based on excess rainfall and real GDP[7].

A country should be considered as an example of the proposed loss and damage insurance. Dominica is selected as it experienced multiple hurricanes within the past 2 decades.

Precipitation is seasonal. See Tables 1a and 1b [37]. There is a higher chance of tropical storms or hurricanes occurring between August and October. Although time series data on precipitation exist, any analysis must consider this seasonality.

Therefore, the data used as a demonstration of the proposed insurance include:

1) Dominica precipitation data from 2000 to 2019. While data on precipitation exist up to 2020, the year 2020 was the year COVID-19 was declared a pandemic. To exclude the COVID-19 impact, data from the year 2020 are removed. These precipitation data are available at the World Bank [37].
2) An estimate of the loss and damage. To a layman, the loss and damage can easily be seen in a hurricane year as the difference

[7] This study follows the direction that a mean area yield or a similar proxy can be used as the indicator of the loss for the parametric weather insurance.

Table 1a
Precipitation of Dominica (mm)

Dominica	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Long-run average
Jan	88.59	84.27	48.28	39.08	47.67	115.63	86.75	60.06	53.50	72.62	46.71	**58.34**
Feb	50.09	158.95	36.24	44.73	48.08	58.40	31.20	31.41	59.54	38.80	9.37	**39.25**
Mar	29.50	39.96	53.93	21.27	63.52	22.89	41.05	35.95	48.91	27.61	24.78	**39.56**
Apr	35.89	34.22	97.50	34.30	42.91	37.80	31.90	21.69	54.75	57.92	49.23	**53.62**
May	44.60	27.24	61.27	39.02	159.20	75.97	43.52	30.99	48.16	96.56	94.61	**70.61**
Jun	45.68	125.55	52.52	67.87	73.60	291.62	116.81	81.25	70.60	80.56	114.12	**78.11**
Jul	90.59	169.55	73.37	**109.81**	152.51	175.54	126.14	108.15	121.06	114.01	172.37	**108.35**
Aug	112.81	17.53	75.36	**119.68**	90.39	141.39	131.84	**233.24**	132.79	82.13	153.55	**125.61**
Sep	128.18	62.58	120.82	77.74	124.84	107.15	127.79	95.57	223.24	101.46	173.43	**136.05**
Oct	81.03	36.39	152.30	**167.20**	188.30	191.44	196.18	**189.86**	203.44	80.16	261.38	**144.44**
Nov	128.59	24.69	69.84	**220.35**	271.10	214.59	76.63	49.90	82.61	106.67	119.55	**133.36**
Dec	59.65	61.57	44.10	54.14	76.27	49.61	84.22	60.95	66.59	46.54	77.63	**77.09**

Table 1b
Precipitation of Dominica (mm)

Dominica	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	202.20	37.33	47.34	54.94	50.22	32.35	41.54	79.27	40.41	60.80
Feb	116.32	38.22	34.87	46.01	59.37	34.45	38.34	58.24	24.06	46.21
Mar	44.05	52.39	22.66	20.72	48.32	70.95	60.00	30.18	28.80	49.63
Apr	86.53	83.12	120.95	39.94	46.69	46.42	69.14	55.41	36.22	24.29
May	179.15	153.36	135.00	61.49	17.64	71.97	**86.74**	63.49	96.39	21.44
Jun	220.96	30.47	86.75	39.83	36.47	61.71	**86.58**	59.10	85.26	61.49
Jul	101.36	109.11	109.67	63.67	47.99	131.65	**89.13**	69.67	131.49	125.85
Aug	99.43	203.52	154.51	122.01	**136.63**	80.56	**139.66**	95.17	151.39	107.62
Sep	268.44	70.32	135.18	124.03	63.94	193.01	**268.84**	99.60	98.77	104.80
Oct	78.41	278.89	155.30	111.87	94.49	124.67	109.88	108.96	101.59	230.36
Nov	43.38	57.78	54.98	176.86	**154.06**	234.28	60.42	195.55	97.49	161.52
Dec	204.51	55.73	114.43	63.85	61.93	102.61	85.89	53.63	91.37	51.51

between the real GDP last year and the actual GDP in the present year. However, the loss and damage are not easily identifiable in a non-hurricane year. Recognizing that loss and damage are an ongoing problem that lasts more than 1 year, the loss and damage are estimated as the difference between the long-run average for GDP and the actual GDP. This long-run average is estimated as the 5-year moving average of the real GDP. The real GDP data used to compute this loss and damage estimate are obtained from the World Bank over the 2000–2019 period [38].

GDP data are typically reported annually. However, the seasonal precipitation data are at the monthly frequency. To match the higher frequency, the GDP data are transformed into monthly data using linear interpolation.

The last column of Table 1a shows the long-run average value for the precipitation. The other values in bold in Table 1a show when the precipitation is higher than the long-run average in a year a tropical storm or hurricane hit Dominica.

4.2. How to price the payout for the proposed insurance

The payout for the proposed voluntary loss and damage insurance should be linked to the expected loss and damage incurred.

A government may be concerned that excessive rainfall may cause damage to several communities in its country. The government may respond to the problem by procuring the services of a disaster insurer. The insurance facility can be structured as follows. There are multiple criteria for the trigger.

1) The first is when a hurricane makes landfall in the country. This introduces some randomness allowing the insurer to accumulate funds when hurricanes do not occur.
2) The second is when the rainfall exceeds the long-run average monthly rainfall (as seen in the last column of Table 1a). This ensures that a payout is triggered when a hurricane occurs, there is excess rainfall, and a need for funds to cover the costs of loss and damage.
3) The third criterion is the forecasted GDP for the year must be less than the long-run average. This ensures that the payout corresponds with the loss and damage incurred.

The government policyholder may only be eligible for 1 payout per named peril per annum. So if a claim is successful for a year, the government may not be eligible to file additional claims for that named peril for the rest of the year.

The size of the payout can be the difference between the long-run GDP and the actual GDP. This can be a sum that was agreed upon in advance between the insurer and the policyholder government.

If Dominica had a weather insurance policy as described, the first trigger criteria would occur in the years 2003, 2007, 2015, and 2017. See the hurricanes in Table 2. Additionally, in those years, the actual precipitation is higher than the long-run average from May to November. Therefore, the second criterion was filled. The third criterion would only be filled in 2015 and 2017.

Table 2
Hurricanes affecting Dominica

	Dominica GDP	5-year average	Loss and damage	Hurricane
1998	$416,019,763	$391,807,372	$24,212,391	
1999	$417,492,802	$401,443,955	$16,048,847	
2000	$427,263,049	$410,795,932	$16,467,117	
2001	$426,990,264	$417,731,034	$9,259,230	
2002	$414,914,984	$420,536,172	−$5,621,188	
2003	$441,275,102	$425,587,240	$15,687,862	Hurricane Fabian
2004	$454,737,039	$433,036,088	$21,700,951	
2005	$457,719,487	$439,127,375	$18,592,112	
2006	$479,046,723	$449,538,667	$29,508,056	
2007	$509,480,430	$468,451,756	$41,028,673	Hurricane Dean
2008	$545,760,826	$489,348,901	$56,411,925	
2009	$539,377,659	$506,277,025	$33,100,634	
2010	$543,005,698	$523,334,267	$19,671,431	
2011	$541,791,805	$535,883,284	$5,908,522	
2012	$536,054,229	$541,198,044	−$5,143,815	
2013	$530,694,005	$538,184,679	−$7,490,674	
2014	$555,922,065	$541,493,561	$14,428,505	
2015	$540,737,037	$541,039,828	**−$302,791**	Tropical Storm Erika
2016	$555,681,105	$543,817,688	$11,863,417	
2017	$518,900,603	$540,386,963	**−$21,486,360**	Hurricane Maria
2018	$537,309,040	$541,709,970	−$4,400,930	
2019	$566,874,381	$543,900,433	$22,973,948	
2020	$472,745,391	$530,302,104	−$57,556,713	
2021	$504,333,887	$520,032,660	−$15,698,773	

However, based on the aforementioned methodology, the payout for 2015 would be only US$302,791, but for 2017 it would be US $21,486,360.

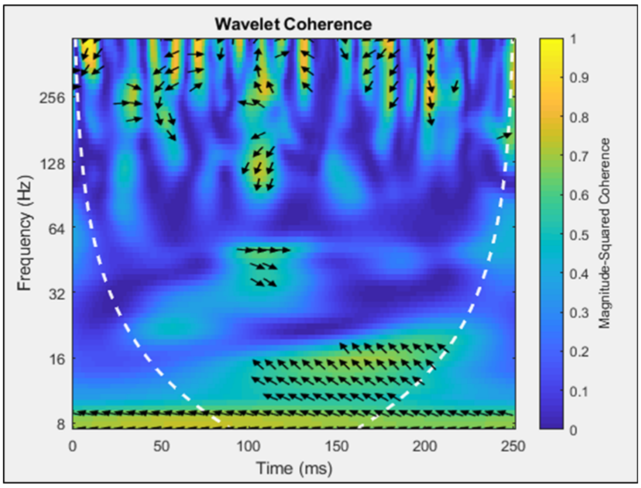
The methodology is relatively fair for an insurer as it allows the insurer to accumulate funds in years when all the criteria are not met. This allows the insurer to have the necessary funds for the payout in the years when all the trigger criteria are met.

Note the abovementioned methodology causes variation in the payout. To mitigate against the variation in the payout, the insurer and the policyholders can agree to the first two trigger criteria and drop the third. The payout can be a fixed sum that is agreed upon by the policyholder and the insurer. For example, the policyholder and the insurer can agree that the size of the payout can be US $21,486,360 once the trigger criteria are met.

Note, the issue of basis risk arises as the trigger should have a strong dependence with the payout. Traditionally, insurers use correlation to measure the dependence between the parametric index and the payout. However, correlation's main limitation is that it is a measure of linear dependence, but rainfall is not linear. Correlation fails to capture non-linear dependencies, resulting in an inaccurate assessment of the true relationship.

Due to the limitation in correlation, and the need to account for the seasonality in precipitation, this study uses wavelet coherence to measure dependence. Wavelet coherence is a statistical measure used to analyze the relationship between two time series in the time–frequency domain. Wavelet coherence is appropriate as it allows researchers to study the dependence between two time series in the time and frequency domains.

Figure 1
Scalogram showing wavelet coherence of loss and damage and precipitation for Dominica



In Figure 1, the horizontal axis (x-axis) represents time (years), and the vertical axis (y-axis) represents the frequency domain (months). When interpreting wavelet coherence, weak correlation/ dependence is depicted by colder colors (blue) while warmer color (red) depicts a strong dependence between the two variables. A ridge shows a localized area of high coherence between the two time series at a specific frequency and time interval.

Arrows wavelet coherence plots represent the lead/lag phase relations. Arrows that are pointing right show in-phase behavior. This means the two time series are synchronized and show a positive relationship. Arrows that are pointing left show anti-phase behavior.

An arrow pointing to the top suggests that variable x leads to variable y. An arrow pointing to the bottom suggests that variable y leads to variable x[8].

The cone of influence represents the area near the edges wavelet coherence plot where the coherence values may be less reliable due to edge effects. The white contour line shows the wavelet power at the 5% significance level.

Figure 1 portrays the wavelet coherence between Dominica's precipitation and the estimated loss and damage. The 100–200 on the x-axis correspond to the time 2012–2018. The strongest dependent occurs in those years, which also corresponded with the hurricane years of 2015 and 2017. The strongest dependence is observed between scales 8–16, indicating that the strongest dependence between rainfall and loss and damage occurs in the latter months of the year. A ridge occurs in the aforementioned frequency and time interval. Outside of the latter half of the year (frequency 8–16) and the 2012–2018 period (100–200 time), the wavelet coherence is mainly cold (blue) suggesting a weak dependence between precipitation and loss and damage.

The variable ordered first is the loss and damage estimate, while the second variable is precipitation. Therefore, in the ridge, precipitation leads to loss and damage.

The aforementioned results justify the use of precipitation data for the trigger for the loss and damage payout. This addresses the

[8]This is where the wavelet coherence is specified with the following code: [wcoh,wcs] = wcoherence(x,y).
Therefore, an upward pointing arrows mean that the first variable leads the second variable. Downward pointing arrows mean the second variable leads the first.

basis risk. This wavelet coherence is better than correlation as its consideration of frequency accounts for the monthly fluctuation in precipitation annually.

4.3. How to price the premium for the proposed insurance

The premium can be based on the principle of solidarity. To do this, the insurer should compute the total cost of the payout for all policyholders in the loss and damage insurance. Then it can charge each policyholder a premium that is equal to the average cost of the insurance.

For example, assume that the total cost of the payout in any given year is US$$107,431,800. This figure is derived by assuming five countries would each require a payout of US $21,486,360. However, assume that the total number of policyholders in the insurance is 15. Then, the size of the premium for each policyholder is computed as follows:

$$\text{Premium} = 1/15 * \text{US\$\$}107,431,800 = \text{US\$}7,162,120 \quad (1)$$

Most likely, the insurer will incur some administrative costs to administer the insurance. To fully cover all costs, including the administrative costs, Equation (1) should be specified as follows:

$$\text{Premium} = [1/15 * \text{US\$\$}107,431,800 = \text{US\$}7,162,120.] + \text{fixed fee}$$

where the fixed fee is an additional fee to cover the administrative costs.

Notably, as the number of policyholders increases, the average premium decreases. This results in the cross-subsidization of the insurance. For this reason, this loss and damage insurance should include as many policyholders as possible.

4.4. Rebuilding better

Climate insurance to compensate SIDS for damage and loss from climate change aligns perfectly with the scope of the low-carbon economy. Payouts to governments provide crucial financial resources for rebuilding infrastructure more sustainably.

For instance, in the power sector, damaged power stations can be reconstructed with a focus on reducing GHG emissions. Opting for combined-cycle power stations instead of single-cycle stations improves energy efficiency and lowers carbon emissions, contributing to the overall transition to cleaner energy sources.

In the transport sector, the insurance compensation allows SIDS to replace destroyed diesel-fueled buses with hybrid electric vehicles (HEVs). Embracing HEVs significantly reduces carbon emissions in the transportation system.

Moreover, in the waste sector, weather insurance payouts can be utilized to transform open landfills into transfer stations and sanitary landfills while implementing Integrated Solid Waste Management practices. This move effectively minimizes methane emissions and promotes sustainable waste handling, further aligning with the principles of the low-carbon economy.

Therefore, through a weather insurance to compensate SIDS for loss and damage from climate change, the global community supports these nations in their endeavors to rebuild more sustainably and resiliently. The use of insurance payouts to adopt low-carbon solutions fosters a transition toward the low-carbon economy.

5. Conclusion

The Caribbean region is vulnerable to the physical risk of climate change. No high GHG-emitting industrialized country wants to accept the liability risk of climate change or any extreme weather event. There is a need to address these risks.

The liability risk can be addressed through weather insurance. Certainly, insurance is an attractive tool as it can mobilize damage and loss finance without attributing any legal liability to any country.

The proposed voluntary insurance would be a macro-insurance and it could pool risk from multiple countries. Both high-risk countries and low-risk countries can be included in the insurance. This framework which could be built on the principle of solidarity would effectively result in risk transfer and subsidization. In other words, the low-risk countries would be subsidizing the payouts for the high-risk countries.

The insurance should be parametric-based as it is easier to administer than indemnity insurance. The perils which could be considered for parametric insurance are excess rainfall and excess wind speed. However, the insurance should have separate policy options for both types of perils. This would prevent the risks from one extreme event and policy from affecting the financial viability of other extreme events and policies.

Recall, this study had the following research question.

1) How to structure the payout and the premium for the proposed parametric insurance for loss and damage for Caribbean SIDS?

The proposed voluntary loss and damage parametric insurance should use multiple criteria for the trigger. The first criterion should be when a hurricane makes landfall in the country. The second criterion can be when the rainfall exceeds the long-run average monthly rainfall.

To eliminate potential variation in the payout, the insurer and the policyholders can agree on a fixed sum for the payout.

To minimize basis risk, the loss and damage estimate and the rainfall data should have a strong dependence. This dependence can be captured through the use of wavelet coherence. Notably, no study has used wavelet coherence to model the dependence between a named peril and a loss estimate for any Caribbean country. Therefore, this study makes an empirical contribution to the literature.

Caribbean SIDS did not create the climate change problem and are presently bearing this negative externality. Something is urgently needed to mobilize loss and damage finance for Caribbean SIDS. In this regard, climate insurance and green bonds emerge as possible tools to address this climate change challenge.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Don Charles: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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