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RELATIVE VULNERABILITY OF SELECTED CARIBBEAN STATES TO CHANGES IN FOOD SECURITY DUE TO TROPICAL STORMS AND HURRICANES

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Abstract

In this paper, the determination of the relative vulnerability of selected Caribbean states to changes in their food security status because of the incidence of tropical storms and hurricanes required the aggregation of a composite indicator of the stability of food security and a risk indicator. Linear aggregation was utilized to derive the composite indicator of the stability of food security and this approach and Pareto ranking were used to aggregate this composite indicator and the risk indicator (Annual Frequency of Hurricanes and Storms) to assess relative vulnerability.

The most vulnerable states were the small island developing states (SIDS): St Kitts and Nevis, St Lucia, Dominica, Grenada and Antigua and Barbuda, supporting the position that SIDS are in a most precarious position. The least vulnerable states were Belize, Trinidad and Tobago and Jamaica. Pareto rankings and linear aggregation produced similar relative vulnerability orderings. However, Pareto rankings had the advantage of imposing fewer restrictions, such as the continuity and linearity of aggregation functions and they were able to show graphically that several countries may have the same relative vulnerability status because of the impact of different vulnerability factors, a situation that is lost in the numerical values of linear aggregation.

Keywords: *Food Security; Caribbean; Hurricanes; Food Security Indicators; Pareto rankings.*

1. Introduction

Caribbean states comprising the regional grouping CARICOM (the Caribbean Economic Community) differ greatly in size, from the relatively large continental states of Guyana, Suriname and Belize to the small island developing states (SIDS) which is a general characterization of the other island member states.[1] Thus the member states vary greatly in terms of the amount of land that is available for domestic food production and therefore the

[1] The member states of CARICOM are Antigua and Barbuda Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Lucia Saint Kitts and Nevis, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

capability for and the actual levels of food production. Many of the island states of CARICOM are thus net importers of food, while on the other hand, the continental state of Guyana is a major producer and exporter of rice and sugar.

The island states of CARICOM as well as its sole Central American state, Belize are often affected by Atlantic tropical storms and hurricanes. Indeed only recently the CARICOM Secretary General has been arguing the case for a reconsideration of the criteria for concessional financing for the SIDS of CARICOM because of their environmental and economic vulnerability (CARICOM Secretariat). Caviedes (1991) notes that hurricanes can cause severe human, environmental and developmental effects including human deaths; damages to buildings, infrastructure, surface hydrology, perennial and short term crops and hunting grounds; as well as bringing unusual biological contact between Africa and the Caribbean. Commenting on the vulnerability of the smaller SIDS of CARICOM comprising the Organization of Eastern Caribbean States (OECS), the International Development Association (IDA) of the World Bank states that: "The OECS countries will continue to face challenges posed by climate change and vulnerability to natural disasters, due to their geographic location, topography, and size" (IDA, 2014).

The objective of this paper is to determine the relative vulnerability of selected CARICOM states to changes in their food security status owing to the risk of tropical storms and hurricanes and this determination raises the problems of aggregation of indicators of the stability of food security into a composite indicator or index as well as the aggregation of such a composite indicator and an indicator of the incidence of tropical storms and hurricanes. The paper therefore first sets out analytical and theoretical frameworks for the measurement of the vulnerability of states to changes in their food security status. Then the paper reviews the recent literature on the procedures and methods of aggregation of food security indicators including the advantages that Pareto rankings can bring to this process. Aggregation methods are then applied to data on the stability of food security and the incidence of tropical storms and hurricanes for selected CARICOM states to arrive at their relative vulnerabilities to changes in their food security status owing to tropical storms and hurricanes. The paper concludes by briefly discussing measures that may be put in place to increase the resilience of these CARICOM states to changes in their food security status.

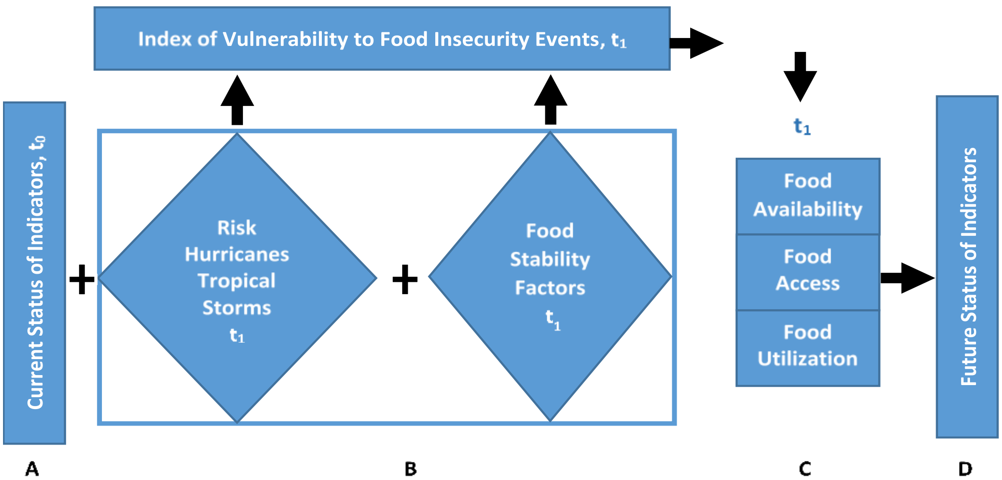


Figure 1. A Framework for Analysis of Vulnerability of States to Changes in Food Security

2. Analytical Framework

A framework illustrating how food security and risk factors can lead to changes in the food security status of a state is given in Figure 1 which is modelled after Lovendal and Knowles (2005).

From the outset it is important to note that this model is illustrating vulnerability to a *change* in the food security status of a state. Thus a state that is food secure can have the same index of vulnerability as a state that is food insecure in the sense that the factors can cause the same proportional change in their food security status. In Figure 1, Section A indicates the current food security status for a state (favorable or unfavorable). This current status (at time t_0) may be measured by a set of indicators of the pillars or dimensions of food security as for example the set of indicators provided by FAOSTAT data domain on Food Security.(FAO, 2015a, 2015b) These pillars are Availability, Access, Stability and Utilization.

Section B determines the vulnerability of the state to changes in food security and this vulnerability arises from a combination of external risk factors and factors inherent to the stability of food security itself. Lovendal and Knowles (2005) discuss a wide range of external risk factors which include political, social, economic, health, environmental and natural hazards. This study as indicated in Figure 1 will deal specifically with the risk of hurricanes and tropical storms as the major risk factor affecting most of the CARICOM member states. There are also factors internal to food security itself, which affect the stability of the food security status of a state. For example these factors are provided in the FAOSTAT suite of indicators for the Stability pillar including cereal import dependency (%), the percentage of irrigated arable land and domestic food price volatility. Aggregation methods are required to derive a composite indicator of the Stability dimension from these indicators. The model illustrates that the aggregation of a composite index for Stability and the indicator for the risk factor produces an index of vulnerability to changes in food security for the particular state, which gives a measure of the extent of change in the food security status of the state, that can be caused (in this case) a tropical storm or hurricane. The higher this index the more vulnerable a state is expected to be.

The food security vulnerability index for a state has an expected impact on the other pillars of food security (Availability Access and Utilization) as seen in Section C of Figure 1 to determine the state of food security for the state in a future period (say, t_1) as also illustrated in Section D of Figure 1. This study as described earlier was limited to the determination of the relative vulnerability indices for selected CARICOM member states and thus concentrates on Section B of the model in Figure 1.

3. Theoretical Model

Pangaribowo, Gerber, and Torero (2013) have put forward a theoretical dynamic model of food security F_t (which they term 'food and nutrition security'). A modified, more rigorous version of this model may be represented as:

$$F_t = F\,(N_t, N_{t-1}, \ldots, N_0,\ D_t, D_{t-1}, \ldots, D_0,\ A_t, A_{t-1}, \ldots, A_0, B_H,\ \mu_t, \mu_{t-1}, \ldots, \mu_0,\ \sigma_t,\ \sigma_{t-1}, \ldots, \sigma_0) \quad (1)$$

where food security F_t is a function of factors at the present time t and that have changed over time, $(time = t,\ t\text{-}1,\ t\text{-}2,\ 0)$ which include:

N_t a vector of factors in the health and agricultural environment;

D_t a vector of demographic characteristics such as age;

A_t *a* vector of human capital and household characteristics;

μ_t a vector of internal stability factors which Pangaribowo, Gerber, and Torero (2013) refer to as risks stemming from limited information, such as lack of access to profitable markets, and volatility in commodity prices.

σ_t a vector of external risk factors which include according to Pangaribowo, Gerber, and Torero *(2013),* 'environmental' risks, that all farmers encounter such as drought, floods, insect attacks, and others.

B_H a vector of other demographic characteristics which are time invariant.

It may be assumed that combinations of factors: N_t , D_t and A_t are included in the food security dimensions: Availability, Access and Utilization, whereas the μ_t vector constitutes the Stability dimension.

Now we may define another function which may be termed a vulnerability function as:

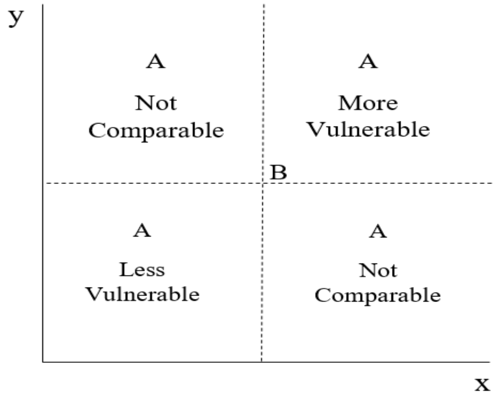
$$V_t = V(\mu_{\mathrm{t}}, \sigma_{\mathrm{t}}) \qquad (2)$$

where for example V_t can be measured by a vulnerability index as suggested in Section B of Figure 1. Equal vulnerability (or iso-vulnerability) fronts can also be defined from (2) as:

$$\mu_{\mathrm{t}} = \omega(\sigma_{\mathrm{t}} | V_i) \qquad (3)$$

These will be combinations of stability and risk vectors that yield the same fixed value of the Vulnerability index V_i

Iso-vulnerability fronts can be obtained in at least two ways. The first is to specify a functional form for Equation (2) as for example an assumption of linear aggregation and to derive mathematically the form of (3). A second approach is the method of Pareto ranking (Rygel, O'Sullivan and Yarnal, 2006). This latter approach can be illustrated as follows: For simplicity, we shall assume that composite indicators have been obtained for the vectors μ_t and σ_t as x and y, so that x measures 'stability' and y measures 'risk'. Pareto ranking is based on the Pareto principle, popular in Micro-Economic theory. In this approach, each case (or country) (i) is considered to have scores on the indicators x and y. It can be further assumed that a higher score for any indicator indicates greater vulnerability. When two cases (or countries) A and B are considered, case A is more vulnerable than case B, if and only if, the scores for A are at least equal to the scores for B for both indicators and if there exists at least one indicator for which A scores higher than B. This ranking can be illustrated in Figure 2.



Source: Modified from Rygel, O'Sullivan and Yarnal (2006)

Figure 2. Pareto Ranking Illustrating the Relative Vulnerability of A to Point B.

Where there are *n* cases $(n > 2)$ for consideration, Pareto optimal fronts can be created based on the concept of non-domination - where a "non-dominated case is one that has no other cases in the data set that are clearly more vulnerable, by virtue of their scoring at least as high or higher on all indicators" (Rygel, O'Sullivan and Yarnal, 2006). The highest scoring or most vulnerable case is selected for an indicator and all the non-dominated cases for this most vulnerable case consist of a non-dominated set of cases. They will consist of all cases that have equal or higher values for the second indicator. The first non-dominated set of cases is selected, and then these cases are removed from the data set and similarly, a second non- dominated set is selected and the process is repeated, until every case in the data set is selected. The set of non-dominated cases at each repetition is called a Pareto-optimal front, this Pareto optimal front is a special case of a revealed iso-vulnerability front. When these non-dominated cases are plotted they reveal the iso-vulnerability fronts as a series of curves, which are not necessarily continuous, in a manner similar to the revealed preference theory of Microeconomics (Singh; Varian, 2006). The advantage of the Pareto optimal front is that there is not the requirement of the assumption of continuity of the vulnerability function (2) and hence there is no need to undertake linear or geometric aggregation, for example, to determine the vulnerability index. Concern has been raised about the need for the almost arbitrary choice of such continuous function aggregation methods, as the rankings that are obtained vary widely according to the aggregation method used. (Santeramo, 2015b). Rygel et al (2006) suggest that if there are *k* Pareto-optimal fronts in the data set, they can first be ranked with rank scores from 1 to *k* with *k* being the rank score for the most vulnerable set. These rank scores can then be rescaled from 0 to 1 to increase interpretability as a vulnerability index.

4. Empirical Approach to Relative Vulnerability Assessment

4.1. Indicators for Stability of Food Security

The measurement of relative vulnerability in this paper involved aggregation to create a composite indicator of the stability of food security and the aggregation of this composite indicator with an indicator of the incidence of tropical storms and hurricanes as indicated in Figure 1 and as discussed above. Pangaribowo, Gerber, and Torero (2013) have provided a recent and very detailed account of the development of the concept and definition of food security. They traced the development from the 1970's perspective on food supply or the pillar of availability to Sen's work on entitlements which added the access pillar, to the focus on nutrition which added the utilization pillar (Pangaribowo, Gerber, and Torero, 2013). By the 1996 World Food Summit. the multidimensionality of food security was established with the widely accepted four pillars of availability, accessibility, utilization and stability and the definition that "food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (Pangaribowo, Gerber, and Torero, 2013). To measure each of these dimensions requires a range of indicators. Carletto, Zezza, and Banerjee (2013) have commented on the lack of consensus on measuring these dimensions resulting in an inefficient multiplicity of survey instruments collecting information on the dimensions of food and nutrition security, with tremendous variation in the content, quality, and quantity of the information collected. They called for an improvement in the state of food security measurement worldwide and the development of a small set of indicators for measuring food security. The recent availability of the FAO suite of food security indicators in the new Food Security data domain may have provided a significant contribution towards the goal expressed by Carletto, Zezza, and Banerjee (2013).

Aurino (2014) provides a detailed discussion and rationalization for indicators for three pillars of food security: availability, accessibility and utilization that are used in this new FAOSTAT Food Security data domain (FAO, 2015). Pangaribowo, Gerber, and Torero (2013) provide a thorough discussion of the indicators for stability, in the first instance they state that 'Stability' refers to the stability of the three other dimensions: availability, access, and utilization as reflected in Figure 1. The main indicators therefore that represent stability with respect to availability and access include: the composition of food available to the population, as indicated by the dependence on imports of food and cereals; the variability of food production; and the variability of access to food as represented by the volatility of food prices.

4.2. Derivation of Composite Indicator for the Stability of Food Security

Santeramo (2015a) has presented the steps that are required to aggregate a number of indicators into a single composite indicator for a complex phenomenon like the stability of food security. These steps are:

a. The definition of the phenomenon under investigation.

b. Formulation of the different dimensions of the phenomenon. Such dimensions he states should "convey the different (and possibly unrelated) information" and should be (statistically) independent of each other.

c. Determination of the relative weights across different dimensions.

d. Selection of variables for the different dimensions. Santeramo (2015a) states that obtaining variables of good quality is crucial for constructing composite indictors. Ideally, he states such "variables should be SMART: specific, measurable, accessible, relevant, and timely.

e. Selection of data. He states that this data usually consist of "a set of heterogeneous indicators: quantitative (hard) data, qualitative (soft) data collected from surveys or policy reviews, and proxies aimed at conveying more information on the phenomenon when specific variables are unavailable".

f. The imputation of missing data. This is required he states since, most modern statistical techniques assume (or require) complete data, and deficiencies in the manner in which existing statistical packages deal with missing data.

g. Normalization of indicators by for example the computation of z-scores.

h. Weighting of the normalized indicators and other measures of dimensions.

i. Aggregation of indicators and dimensions to form the composite indicator via an aggregation method such as the popular linear and geometric aggregation.

Santeramo (2015b) has shown that the choice of the methods to compute composite indexes has a significant impact on the relative position of countries in inter-country comparisons of food security. His analysis suggests that the choice of the normalization and weighting methods are the least relevant whereas different alternatives for data imputation would lead to different results and the choice of the aggregation formula is the most crucial decision as "diverse formulas provide very different composite indexes" or indicators. He therefore recommends that care has to be exercised in the derivation of composite indicators.

4.3. Derivation of Vulnerability Index for Selected CARICOM States

Rygel, O'Sullivan and Yarnal (2006) suggest that vulnerability assessment is still in its infancy, even though the potential usefulness of the vulnerability indices has been well documented. In this study, the procedure to determine the vulnerability of selected CARICOM states to changes in food security status (because of the incidence of tropical storms and hurricanes and the stability of food security) proceeded as follows. Stage 1 consisted of a determination of an indicator for the external risk factor. Data was obtained on the 'number of hurricanes and tropical storms' affecting CARICOM states for the period 1840 to 2013 (Hurricane City, Nevis Disaster Management Department and Unisys). This data showed that the two member states on the South American Continent (Guyana and Suriname) did not suffer from the effects of tropical storms and hurricanes over the period. Hence they were not selected for the study. The island state of Montserrat has been so badly affected by an erupting volcano that its population has been drastically reduced and its statistical data collection has been disrupted. Hence this state has also not been selected for the study. The data for the selected other CARICOM states for the 'number of hurricanes and tropical storms' are presented in Column (6) of Table 1. The risk of hurricanes and tropical storms was then determined as a (historical) relative frequency, calculated for each country as the total number of hurricanes occurring in that country divided by the total number of data years (174). Thus the relative annual frequency of hurricanes and tropical storms over the period 1840 to 2013, which measures the likelihood that a state would be struck by a hurricane or tropical storm was the indicator used to measure risk in this study.

Stage II derived the composite indicator for the 'Stability of food security' for the selected countries using the procedure of Santeramo (2015 a) outlined above. Steps (a) through (d) were achieved by the utilization of the 'Stability' suite of food security indicators from FAOSTAT for the selected countries (FAO, 2015a). Data was unavailable for some indicators for some countries. Given the caution that is recommended by Santeramo (2015b) for data imputation (step f.), only those indicators for which all the data were available for all the countries were utilized in the study and these were:

- Value of food imports over total merchandise exports (%) (3-year average) for the period 1990-1992 to 2009-2011.
- Cereal import dependency ratio (%) (3-year average) for the period 1990-1992 to 2009-2011, and
- Per capita food production variability (International $ per person constant 2004-06) (FAO, 2015) for the period 1992 to 2011.

Normalization of the data for each selected indicator for the selected countries was achieved by the computation of z-scores. The z-score for each year for each indicator was calculated using the mean and sample standard deviation for the all observations for the indicator and using the EXCEL function STANDARDIZE. Then the mean z-score for each indicator for each country was calculated. The final steps (h. and i.) were accomplished by linear aggregation of the mean values of the normalized indicators for each country, using equal weights for the three indicators. This equal weighted sum of the means (or Mean of means) yielded the composite indicator for 'Stability' of food security as in Figure 1. Equal weighting was utilized to avoid subjective bias in the selection of weight, since there was no *a-priori* information to suggest an alternative objective set of weights.

Stage III derived the vulnerability index of Section B of Figure 1. Rygel, O'Sullivan and Yarnal (2006) suggest several approaches to this derivation. The first is the creation of a weighted sum of composite and other indicators as just utilized for the derivation of the 'Stability' composite indicator. They however suggested that in the case of vulnerability assessment this method can lead to misleading results as a low score on one indicator may obscure a high score on another indicator, whereas the high score may indicate a component that is of particular importance to vulnerability. They therefore recommended the method of Pareto ranking discussed above. In this study, both methods (linear aggregation and Pareto ranking) were used, to determine the impact of the aggregation method on the relative vulnerability of the selected CARICOM states.

Table 1. Derivation of 'Stability of Food Security' and Risk Indicators

(1)	(2)	(3)	(4)	(5) Weighted Sum of z-scores	(6)	(7)
	Mean z-scores					
Country	Cereal Import Dependency Ratio	Food Production Variability	Foods Imports/ Total Exports	Composite Indicator 'Stability' (Equal weights)	Number of Tropical Storms and Hurricanes 1840-2013[a]	Annual Frequency/ Risk of Hurricanes and Storms
Antigua & Barbuda	0.50	-0.59	0.13	0.01	22	0.13
Bahamas	0.47	-0.69	-0.62	-0.28	59	0.34
Barbados	0.46	-0.47	-0.33	-0.11	10	0.06
Belize	-2.73	1.12	-0.87	-0.83	23	0.13
Dominica	0.50	0.46	-0.19	0.26	16	0.09
Grenada	0.50	-0.27	1.42	0.55	6	0.03
Haiti	-1.53	-0.97	1.75	-0.25	31	0.18
Jamaica	0.47	-0.64	-0.75	-0.31	25	0.14
St. Kitts & Nevis	0.50	1.44	-0.15	0.59	17	0.10
St. Lucia	0.50	0.93	0.35	0.59	14	0.08
St. Vincent & the Grenadines	0.06	0.40	0.40	0.29	8	0.05
Trinidad & Tobago	0.32	-0.71	-1.14	-0.51	2	0.01

Source: Hurricane City, Nevis Disaster Management Department, Unisys

5. Results and Discussion

5.1. The Indicators

Table 1 presents the results of the derivation of the indicators used to obtain the vulnerability indices for the selected CARICOM countries. Columns (2) to (4) present the mean z-scores for the countries for the Stability of Food Security indicators. Here it is seen that Dominica Grenada St Kitts and Nevis and St Lucia are the most unstable countries with respect to Cereal import dependency. St Kitts and Nevis is the most unstable country with respect to Food production variability and Haiti is the most unstable country with respect to food imports as a proportion of total merchandise exports. Column (5) presents the results for the Composite indicator for Stability based on the linear summation of columns (2) to (4). Overall, St Kitts and Nevis and St Lucia were the most unstable countries with respect to food security with composite indicator scores 0.59. It may be noted that since the sum of independent standard normal variables produces a normally distributed random variable of mean zero, the mean of the composite indicator for the countries is itself expected to be equal to zero.

Column (7) of Table 1 shows that the country with the highest risk of getting struck annually by hurricanes is the Bahamas with a hurricane or tropical storm striking one of its islands every three years on average. The country with the lowest risk of getting struck by a hurricane or tropical storm is Trinidad and Tobago which has only been struck by a hurricane or tropical storm twice in the last 174 years.

5.2. Pareto Optimal Rankings

Pareto-optimal ranking was applied to the two factors in Column (5) and Column (7) of Table 1. This resulted in the derivation iso-vulnerability (Pareto-optimal) fronts as given in Figure 2. In this diagram vulnerability increases as we move to the right of the diagram.

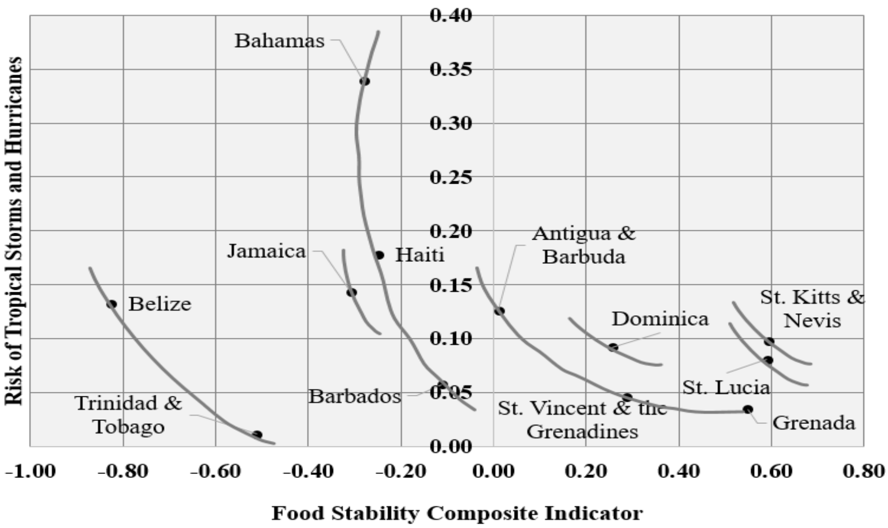


Figure 2. Graphs showing Iso-Vulnerability (Pareto-Optimal) Fronts Based on Indicators - 'Annual Frequency/ Risk of Hurricanes and Storms' and 'Stability Composite Indicator'

It is seen in Figure 2 that there are seven Pareto-optimal fronts. These fronts are described in Table 2, which shows that St Kitts and Nevis is the most vulnerable country with respect to changes in food security based on the risk of tropical storms and hurricanes and the stability of food security itself. The second tier vulnerable country was St. Lucia. The countries least vulnerable to changes to stability of food security and the risk of tropical storms and hurricanes were Belize and Trinidad and Tobago. Table 2 also presents a vulnerability index giving the relative vulnerability of the all the states the higher the value of the index, the more vulnerable the state.

Table 2. Rankings of Selected CARICOM based on Pareto-Optimal Fronts Using Indicators - 'Annual Frequency/ Risk of Hurricanes and Storms' and 'Food Stability Composite Indicator'

Pareto-Optimal Front	Countries in Non-Dominated Set	Relative Vulnerability Index
Level 1	St. Kitts and Nevis	1.00
Level 2	St. Lucia	0.83
Level 3	Dominica	0.67
Level 4	Antigua and Barbuda, St. Vincent, Grenada	0.50
Level 5	Bahamas, Haiti, Barbados,	0.33
Level 6	Jamaica	0.17
Level 7	Belize, Trinidad and Tobago	0.0

5.3. Rankings Derived from Linear Aggregation

Table 3 gives the results for the linear aggregation with equal weights of the Stability Composite Indicator and the risk indicator to produce a second and alternative vulnerability index. The results in Table 3 produce approximately the same ordering of the CARICOM states with respect to vulnerability as the Pareto rankings provided in Table 2. The only exception being Dominica which is ranked as more vulnerable than Grenada on the Pareto rankings based on the iso-vulnerability fronts, but less vulnerable than Grenada with the linear aggregation in Table 3.

Table 3. Rankings of Selected CARICOM States Based on Linear Aggregation of 'Annual Frequency/ Risk of Hurricanes and Storms' Indicator - and 'Food Stability Composite Indicator'

Country in Ranked Order	Stability Composite Indicator	Risk Indicator	Vulnerability Index
St. Kitts & Nevis	0.594	0.098	0.691
St. Lucia	0.590	0.080	0.671
Grenada	0.548	0.034	0.582
Dominica	0.256	0.092	0.348
St. Vincent & the Grenadines	0.287	0.046	0.333
Antigua & Barbuda	0.011	0.126	0.138
Bahamas	-0.280	0.339	0.059
Barbados	-0.112	0.057	-0.054
Haiti	-0.249	0.178	-0.071
Jamaica	-0.308	0.144	-0.164
Trinidad & Tobago	-0.511	0.011	-0.500
Belize	-0.826	0.132	-0.694

6. Conclusion

The results obtained in this study showed that the most vulnerable states to changes in their food security status due to the combination of tropical storms and hurricanes and inherent instability in the country's food security are St Kitts and Nevis, St Lucia, Dominica, Grenada and Antigua and Barbuda. The least vulnerable states in this context are Belize, Trinidad and Tobago and Jamaica. Thus in general the smaller island states were determined to be the most vulnerable, supporting the position that the SIDS are in need special assistance, in terms of concessionary financing and otherwise, because of their more precarious situations. Again it must be noted that what this study measured was the vulnerability to changes in the food security status of a state. Thus a necessary follow up study to this one is to examine the food security statuses of these CARICOM states because countries which have a very food insecure status and a high level of vulnerability to that status because of tropical storms and hurricanes will be in a very precarious situation, if indeed a hurricane strikes.

The study also introduced Pareto ranking into the milieu of the methods which may be utilized to aggregate indicators of different dimensions of food security and to aggregate composite indicators of food security with indicators of other factors to assess relative vulnerability status. The results obtained in this study show that the Pareto rankings were quite similar to the rankings obtained by linear aggregation and had the advantage of imposing less restrictions on the aggregation process, such as the continuity of aggregation functions and linearity of such functions. Pareto ranking was also able to show graphically that several countries may have the same relative vulnerability, because of the impact of different vulnerability factors, a fact that is lost in the linear aggregation, which simply produces a numerical value for each country.

A number of *ex ante* measures can be suggested from this study to reduce the vulnerability of CARICOM states to changes in their food security status because of tropical storms or hurricanes. These measures should focus primarily on increasing and stabilizing the output from the domestic food production sector and reducing the dependence on imports, for the food supply of the population by expanding domestic food production by: promoting investment in the domestic agricultural sector, reducing excessive deforestation to conserve water resources, reducing soil erosion and the enforcement of land use planning to protect valuable agricultural lands. Other measures which may assist in boosting and stabilizing food production include changing cropping patterns and other mitigation technologies to adapt to climate change, and the implementation of weather-indexed crop insurance (World Bank, 2011).

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