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THE IMPACT OF CLIMATE CHANGE ON THE MACROECONOMY IN THE CARIBBEAN

Economic Commission for Latin America and the Caribbean
Subregional Headquarters for the Caribbean

LIMITED
LC/CAR/L.264
7 June 2010
ORIGINAL: ENGLISH

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Acknowledgement

The Economic Commission for Latin America and the Caribbean (ECLAC) Subregional Headquarters for the Caribbean wishes to acknowledge the assistance of Dr. Patrick Watson, Consultant, in the preparation of this document.

Table of Contents

Executive Summary

In this study, an attempt is made to assess the economic impact of climate change on nine countries in the Caribbean basin: Aruba, Barbados, Dominican Republic, Guyana, Jamaica, Montserrat, Netherlands Antilles, Saint Lucia and Trinidad and Tobago.

A methodological approach proposed by Dell *et al.* (2008) is used in preference to the traditional Integrated Assessment Models. The evolution of climate variables and of the macroeconomy of each of the nine countries over the period 1970 to 2006 is analyzed and preliminary evidence of a relationship between the macroeconomy and climate change is examined.

The preliminary investigation uses correlation, Granger causality and simple regression methods. The preliminary evidence suggests that there is some relationship but that the direction of causation between the macroeconomy and the climate variables is indeterminate. The main analysis involves the use of a panel data (random effects) model which fits the historical data (1971-2007) very well.

Projections of economic growth from 2008 to 2099 are done on the basis of four climate scenarios: the International Panel on Climate Change A2, B2, a hybrid A2B2 (the mid-point of A2 and B2), and a 'baseline' or 'Business as Usual' scenario, which assumes that the growth rate in the period 2008-2099 is the same as the average growth rate over the period 1971-2007. The best average growth rate is under the B2 scenario, followed by the hybrid A2B2 and A2 scenarios, in that order. Although negative growth rates eventually dominate, they are largely positive for a long time.

The projections all display long-run secular decline in growth rates notwithstanding short-run upward trends, including some very sharp ones, moving eventually from declining positive rates to negative ones.

The costs associated with the various scenarios are all quite high, rising to as high as a present value (2007 base year) of US$14 billion in 2099 (constant 1990 prices) for the B2 scenario and US$21 billion for the BAU scenario. These costs were calculated on the basis of very conservative estimates of the cost of environmental degradation. Mitigation and adaptation costs are likely to be quite high though a small fraction of projected total investment costs.

INTRODUCTION

Is the global climate changing? Evidence of it is increasingly visible, and the trends appear undeniable. Rising temperatures are melting polar ice and together with thermal expansion of water may be contributing to sea level rise, changing precipitation patterns, more frequent intense weather events, storm surges and flooding, coastal erosion, increased sedimentation of coastal waters, and pollution from flooded or destroyed infrastructure and storm runoff (IPCC 2007a,b, IISD 2007, FAO 2007, UNEP 2008). It is widely believed that all countries will be affected, especially small island developing States and developing economies like those touched by the Caribbean Sea (UNEP 2007, 2006, UNFCC 2005, UNFCCC 2007, Bueno *et al*. 2008, Mimura *et al.* 2007, Easterling *et al.* 2009).

In this study, an attempt is made to assess the economic impact of climate change on nine countries in the Caribbean basin: Aruba, Barbados, Dominican Republic, Guyana, Jamaica, Montserrat, Netherlands Antilles, Saint Lucia and Trinidad and Tobago. How this is to be done is not obvious. As Dell *et al.* (2008) put it:

> "Climate change may – or may not – be a central issue for the world economy. Yet assessing the economic impact of climate change faces a fundamental challenge of complexity: the set of mechanisms through which climate may influence economic outcomes, positively or negatively, is extremely large and difficult to investigate comprehensively. Even if the effect of climate on each relevant mechanism were known, one would still be faced with the challenge of how various mechanisms interact to shape macroeconomic outcomes." Dell *et al.* (2008).

The methodological approach proposed by Dell *et al*. (2008) is used in preference to the traditional Integrated Assessment Models which "looks at the collection of mechanisms that make up the economy, determine their effects individually and then add them up". In their paper, as in this one, "instead of disaggregating the economy into its component mechanisms, the response to temperature and precipitation of the single economic variable: economic growth is examined". The advantage of this approach is that it "estimates the effect of short-run climate fluctuations using relatively few assumptions. It examines aggregated outcomes directly, rather than relying on *a priori* assumptions about what mechanisms to include and how they might operate, interact, and aggregate". Also, as part of this project, studies of specific sectors are undertaken (tourism, agriculture, energy and water) and, in using the aggregated approach, duplication of effort is avoided.

Section I of the paper analyzes the evolution of climate variables and of the macroeconomy of each of the nine countries over the period 1970 to 2006 and preliminary evidence of a relationship between the macroeconomy and climate change is examined. This is done on a country-by-country basis principally because the macroeconomy of the various countries is quite different even though they may experience a similar change in climate. In section II, the basic econometric model to be used is introduced: it is fundamentally a panel data, random effects model linking per capita economic growth to two climate change variables: temperature and precipitation[1]. In section III, projections of per capita GDP growth are made from 2008 to 2099 using the International Panel on Climate Change (IPCC) A2 and B2 scenarios[2] for temperature and precipitation, as well as two other scenarios: one is a hybrid of A2 and B2 and the other, which is called the 'Business as Usual' (BAU) scenario, and is formed by applying the average growth rate for the period 1971-2006. In section IV, the costs of the various scenarios are calculated and analyzed and, in section V, possible mitigation and adaptation measures are proposed and discussed. The paper then concludes.

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[1] Other specifications were attempted, all within the spirit of Dell et al (2008). In the first place, individual regressions were fitted using ordinary least squares (OLS). In this model, lagged values of the climate variables and both current and lagged values of the precipitation variable performed poorly. The model performed equally poorly when quadratic values of the precipitation variables were used. A Vector Autoregression (VAR) model was also used and its results are reported in a previous version of this paper. The model used here is retained because it uses the data of all the countries and so compensates for the short data sets required for the OLS and VAR analyses. It also improves on the results obtained from the VAR and is more intuitive.

[2] Some elaboration of these two scenarios is given in section 4 of this study.

I. CLIMATE CHANGE AND THE MACROECONOMY

A. MOVEMENT OF CLIMATE VARIABLES

In this study, the impact on the macroeconomy of changes in two climate variables, precipitation and temperature, are analyzed. The historical climate data are taken from the *Terrestrial Air Temperature and Precipitation: 1900-2006 Gridded Monthly Time Series, Version 1.01* (Matsuura and Willmott 2007). This data set provides worldwide (terrestrial) monthly mean temperature and precipitation data at 0.5 x 0.5 degree resolution (approximately 56km x 56km at the equator). Values are interpolated for each grid node from an average of 20 different weather stations, with corrections for elevation. Data were not always available for all of the countries in our study and approximations using observations that were close in latitude-longitude coordinates were utilised. Tables 1 and 2 show a selection of descriptive statistics for the monthly precipitation and temperature data

Table 1
Precipitation Data January 1966-December 2006: Descriptive Statistics

Statistic	*Aruba*	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad and Tobago*
Mean	39.607	243.998	160.043	257.360	129.092	114.415	76.084	200.663	153.455
Median	27.200	225.900	149.500	232.150	106.700	108.650	65.550	195.950	133.600
Maximum	288.200	867.000	670.000	686.400	666.300	429.900	289.700	900.800	1799.000
Minimum	0.000	32.600	15.500	35.300	0.000	6.000	20.900	15.700	0.000
Std. Dev.	42.252	122.603	89.976	131.719	82.560	69.771	42.622	105.146	151.049

Source: Data compiled by author

Table 2
Temperature Data 1966-December 2006: Descriptive Statistics

Statistic	*Aruba*	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad and Tobago*
Mean	26.769	26.502	24.943	27.541	22.462	26.625	26.493	26.477	24.895
Median	27.000	26.500	25.100	27.400	22.500	26.700	26.600	26.500	25.000
Maximum	28.600	36.500	28.400	30.500	26.600	28.800	29.200	28.400	26.800
Minimum	24.700	24.700	21.600	25.700	19.700	23.900	23.000	24.700	22.900
Std. Dev.	1.043	0.883	1.480	0.832	1.257	0.846	1.215	0.692	0.777

Source: Data compiled by author

Time series plots of the data are shown in Figures 1 and 2 below:

Figure 1
Precipitation January 1966-December 2006

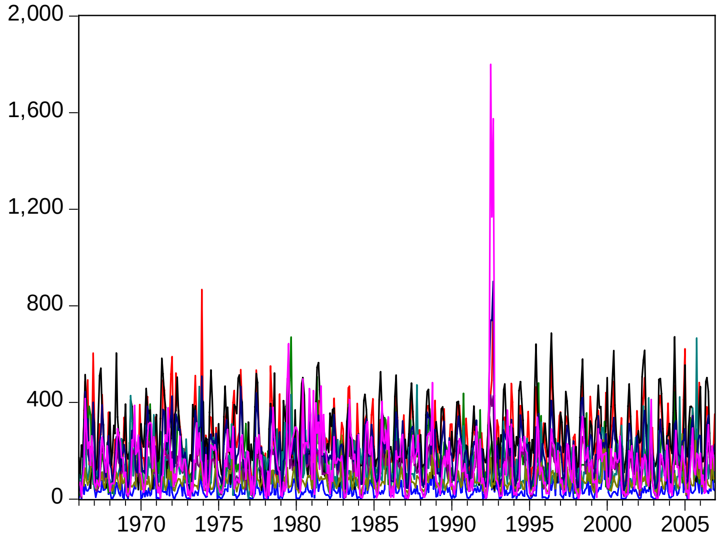
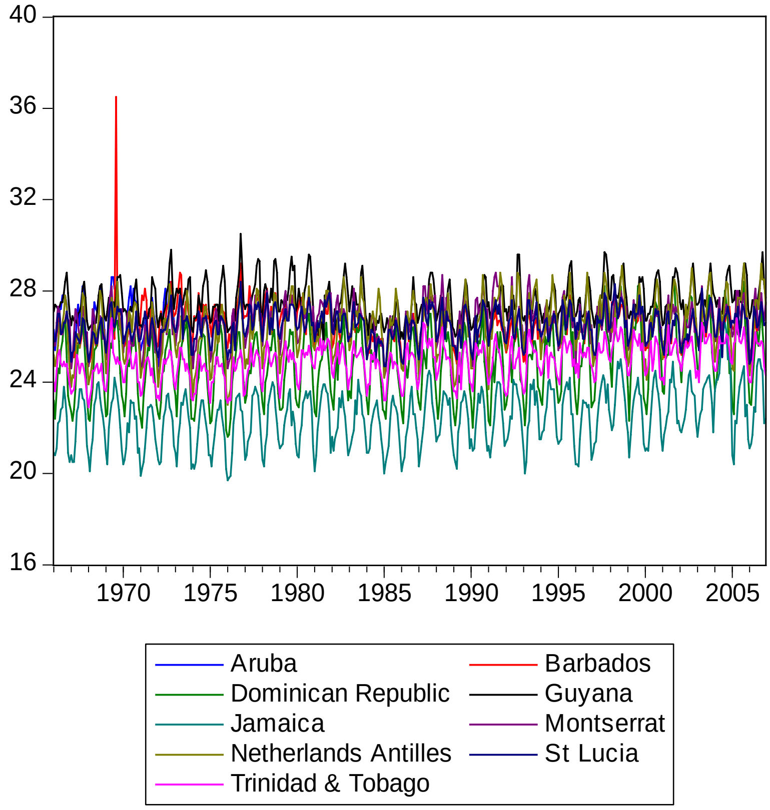


Figure 2
Temperature January 1966-December 2006



There seems to be no marked variation or trend in the precipitation data (apart from the unusual peak in precipitation in Trinidad and Tobago in 1980-1981). Further analysis using Augmented Dickey-Fuller (ADF) unit root shows that the series are all stationary and the application of Box-Ljung white noise[3] tests shows that the series are all white noise. The results of the unit root tests are shown in Table 3 below:

Table 3
Precipitation 1966-2006: P-values associated with ADF tests
(Intercepts and Trends included in test)

Aruba	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad & Tobago*
0.000	0.0001	0.0001	0.001	0.0007	0.0004	0.000	0.0001	0.0002

Source: Data compiled by author

There is some evidence of a mild upward trend in the temperature data. Unit root tests and white noise tests confirm that, though stationary, none of the temperature series is white noise (they may all be fitted as an ARMA(p,q) type model). The results of the unit root tests are shown in table 4 below:

Table 4
Temperature 1966-2006: P-values associated with ADF tests
(Intercepts and Trends included in test)

Aruba	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad & Tobago*
0.0322	0.0131	0.0285	0.0087	0.0002	0.0086	0.0120	0.0033	0.0009

Source: Data compiled by author

B. TRENDS IN THE MACROECONOMY

The GDP data used in this study are in United States dollars, 1990 prices, the source of which is the United Nations Statistics Division. United States prices are used to facilitate comparison across countries. Table 5 below shows some summary statistics for annual GDP growth per capita over the period 1971-2006:

Table 5
Annual GDP growth per capita (1990 US$) 1971-2006: Summary Statistics

	Aruba	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad and Tobago*
Mean	0.051	0.015	0.029	0.009	0.001	0.016	0.022	0.031	0.025
Median	0.070	0.020	0.028	0.011	0.001	0.029	0.014	0.027	0.029
Maximum	0.183	0.121	0.094	0.086	0.089	0.132	0.302	0.154	0.122
Minimum	-0.052	-0.081	-0.071	-0.140	-0.079	-0.237	-0.067	-0.074	-0.127
Std. Dev.	0.053	0.038	0.037	0.049	0.037	0.077	0.057	0.045	0.055

Source: Data compiled by author

[3] A white noise series is one that is purely random with a fixed mean and constant variance. Such a series has no special tendency to be above its mean value more often than it is below it, and vice versa.

Figure 3 below shows time plots of the series:

Figure 3
GDP growth per capita (1990 US$) 1971-2006: Time Plots

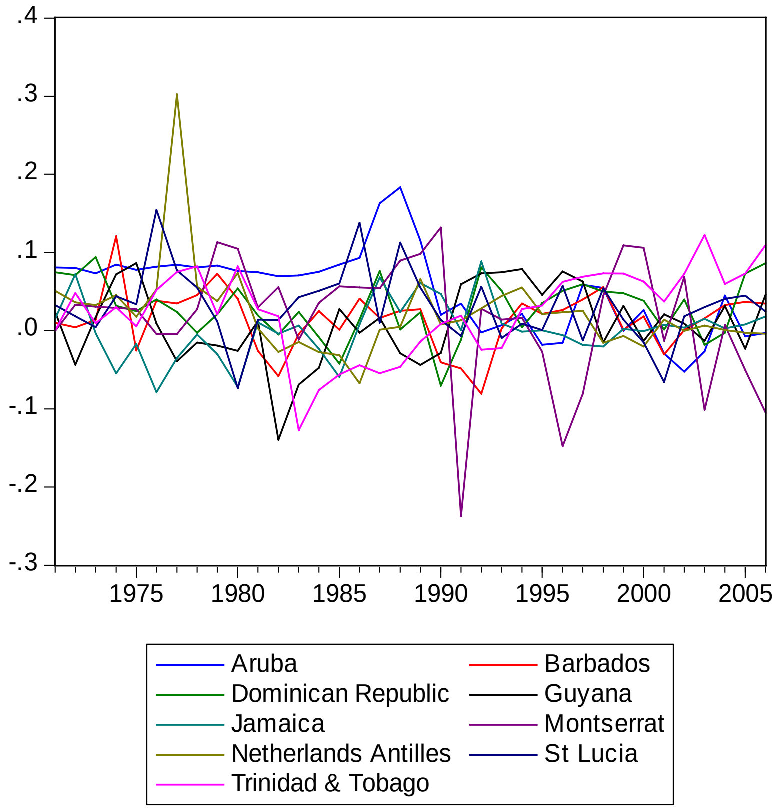


Table 6 below displays the p-values associated with the ADF tests of the growth variables:

Table 6
GDP growth per capita 1971-2006: P-values associated with ADF tests
(Intercepts and Trends included in test)

Aruba	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad & Tobago*
0.2906	0.0095	0.0155	0.0467	0.0134	0.0013	0.0072	0.0029	0.3946

Source: Data compiled by author

The GDP per capita of Aruba and Trinidad and Tobago displays unit roots (their plots are slightly trending, the one downward, the other upward) while the others do not (they are all stationary though some are not white noise). It is interesting to note that Aruba has the fourth largest carbon footprint in the world and Trinidad and Tobago the sixth. This shall be raised again later on but already it is tempting to ask whether this large footprint is a cause or a consequence of the trending growth.

C. RELATIONSHIP BETWEEN GDP AND CLIMATE VARIABLES: PRELIMINARY EVIDENCE

What then is the relationship between the macroeconomy and the climate variables? In this section we provide some preliminary evidence and leave consideration of the major evidence to the following section. Table 7 below shows the simple correlation coefficients between GDP per capita growth and current and lagged values of the climate variables:

Table 7
Simple correlation coefficients between GDP per capita growth and current and lagged values of the climate variables

Country	*Temp*	*Prec*	*Temp$_{-1}$*	*Prec$_{-1}$*	*Temp$_{-2}$*	*Prec$_{-2}$*
Aruba	-0.4653	-0.1901	-0.3748	-0.1097	-0.2806	-0.0889
Barbados	0.3459	-0.2470	0.3085	0.1551	0.0991	0.1233
Dominican Republic	0.1209	-0.1216	0.0362	0.1678	-0.0060	-0.0889
Guyana	-0.0438	0.1915	0.1038	-0.0820	-0.0827	-0.1289
Jamaica	0.1603	-0.0302	0.0874	-0.1018	0.1354	0.2172
Montserrat	-0.1291	0.2410	-0.0329	0.0959	-0.0040	0.1653
Netherlands Antilles	-0.2066	-0.3732	-0.3778	-0.2253	-0.4383	0.1153
St Lucia	-0.2642	0.1971	-0.2097	-0.2019	-0.4731	-0.0676
Trinidad and Tobago	0.3903	-0.1736	0.3357	-0.1922	0.1403	-0.2259

Source: Data compiled by author

Growth is reasonably strongly and negatively correlated with temperature (current and lagged values) in the case of Aruba and, to a lesser extent, the Netherlands Antilles, but in all the other cases it is either positively related (quite strongly in the case of Barbados and Trinidad and Tobago) or weakly negatively related. There is further ambiguity in the relationship between growth and precipitation: sometimes it is positive, sometimes negative and, except for the case of Aruba, the sign differs according to the lag. The largest value of the simple correlation coefficient for temperature is -0.4653 (the case of Aruba, current value) and the largest precipitation coefficient is -0.4731 (Saint Lucia, lag 2).

Correlations, of course, do not imply causation. To complement the simple correlation analysis, A Vector Autoregression analysis involving (block) causality tests was carried out and in only two cases was it found that climate variables Granger-caused growth: temperature ‘caused’ growth in the Netherlands Antilles (at 10% significance level) and precipitation ‘caused’ growth in Saint Lucia (again 10%). On the other hand, growth Granger-caused temperature in three cases (Aruba, Montserrat and Trinidad and Tobago), all at 5%. This is an observation that is clearly worth following up.

Further to this, some simple regressions of the form shown in equation (1) below are performed:

$$g_t = \square + \sum_{i=0}^{p} \alpha_i T_{t-i} + \sum_{i=0}^{p} \beta_i P_{t-i} + u_t \qquad (1)$$

Here, g is the growth rate per capita of a given country and T is the temperature and P the precipitation variables, which may be lagged up to time period p. Below in table 8 are the results of simple linear regressions, going up to lag 2:

Table 8
OLS fit of Equation (1)

	Aruba	*Barbados*	*Dominican Republic*	*Guyana*	*Jamaica*	*Montserrat*	*Netherlands Antilles*	*St Lucia*	*Trinidad and Tobago*
□	1.670**	-0.826**	-0.117	0.185	-0.420	0.836	1.469	3.005**	-1.062***
□$_0$	-0.052*	0.022	0.014	0.005	0.010	-0.017	-0.007	-0.040	0.036*
□$_0$	-0.001	0.000	0.000	0.000	0.000	0.001	-0.002	0.000	0.000
□$_1$	-0.001	0.022	0.007	0.021	-0.009	-0.016	-0.021	-0.003	0.028
□$_1$	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000
□$_2$	-0.003	-0.012	-0.015	-0.032	0.017	-0.009	-0.019	-0.066	-0.018***
□$_2$	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000

(*** $p<0.01$, ** $p<0.05$, * $p<0.1$).
Source: Data compiled by author

These fits are not at all good as the coefficients are generally not significant. In the spirit of ‘general to specific’ modelling, variables are progressively removed from each equation. Only three of the equations had one and only one significant variable (the others had none) and these are reported here.

Table 8
OLS fit of Modified Equation (1)

	Aruba	*Barbados*	*Trinidad and Tobago*
□	1.445***	-0.801**	-1.261**
□$_0$	-0.051***	0.0307**	0.0515**

(*** $p<0.01$, ** $p<0.05$).
Source: Data compiled by author

In the three retained cases, only the current valued temperature variable is significant, with positive signs for Barbados and Trinidad and Tobago and a negative one for Aruba. No precipitation variable, at any lag, is ever significant.

The preliminary analysis[4] indicates that there is no overwhelming evidence in favour of a strong relationship between growth and climate change. There is also the strong possibility that, to the extent that the relationship may be valid, growth may respond positively or negatively to the climate change variables. It may also be possible that growth is affecting the climate and not necessarily the other way around.

[4] Equation 1 was also modified to include quadratic values of the temperature and precipitation variables and the results obtained were just as poor as when the lagged values were used.

II. MODEL

Although there are many econometric studies dealing with the impact of climate change, precious few deal with the problem of the macroeconomy. They restrict themselves instead to sectors of the economy, especially the agricultural sector (like Deschenes and Greenstone 2007). A recent and worthy exception to this rule is the work of Dell *et al*. (2008) who, using a framework established by Bond *et al*. (2007), show that the following equation:

$$g_{it} = \square_i + \square_{rt} + \sum_{j=0}^{L} \rho_j T_{it-j} + \square_{it} \qquad (1)$$

may be derived from an aggregate production function of the type:

$$Y_{it} = e^{\beta T_{it}} A_{it} L_{it}$$

where Y is aggregate output, g is the growth rate of per capita output, L measures population, A measures labour productivity, and T measures climate. Two climate change variables are used: temperature and precipitation.

In this paper, we take our cue from the work of Dell *et al*. (2008) and estimate an equation of the form of equation (1). The period covered by the data is 1971-2007 and the model is fitted using a panel data (random effects) model. The results were unsatisfactory for models with lags greater than 0. However, inclusion of squared values of the temperature (but not the precipitation) variable, improved the results obtained. These results are shown in table 9 below:

Table 9
Results showing Per capita economic growth as a function of Temperature and Precipitation

Temp	0.173700***
	(0.062411)
$Temp^2$	-0.003392***
	(0.001238)
Prec	-8.50×10^{-6}**
	(3.83×10^{-6})
Constant	-2.177154***
	(0.783053)

(Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$).
Source: Data compiled by author

The overall $\square^2$ test of model adequacy yields a p-value of 0.006, indicating an exceedingly good model fit. The temperature variable is positively signed and highly significant while its squared is negatively signed and also highly significant. This means that growth may respond positively or negatively to temperature increases as temperature increases. The precipitation variable is negatively signed and significant at the 5% level so that the growth rate will slow as precipitation increases. Depending on the strengths of the negative and positive pulls of the temperature effect, the growth rate may respond either positively or negatively to temperature but will always respond negatively to changes in the precipitation variable.

III. PROJECTIONS TO 2099

The model retained is predicated on data from 1971 to 2007. In order to project growth for the rest of the century, scenarios for changes in precipitation and temperature for the rest of the century must be taken into account. Experts have established data for these variables based on criteria that have become well known, such as the IPCC A2, B2 and other scenarios, both of which play an important role in this study. The A2 scenario describes a very heterogeneous world where the underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios. The B2 scenario is a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development and, while the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

In this study, we consider four scenarios: the A2, B2, a hybrid A2B2[5] (the mid-point of A2 and B2), and a 'baseline' or BAU scenario. The latter assumes that the growth rate in the period 2008-2099 is the same as the average growth rate over the period 1971-2007. The choice of this growth rate is quite arbitrary though not illogical. Other possible choices are the growth rate in 2007 or the average rate or some shorter period, all just as arbitrary. The growth path that results from each scenario is then determined.

Forecasts for both climate variables (2008-2099) under A2 and B2 were obtained from the Institute of Meteorology in Cuba, whose predictions were obtained from the European Centre Hamburg Model, an atmospheric general circulation model developed at the Max Planck Institute for Meteorology. Data were not always available for all of the countries in our study and approximations were made using observations that were close in latitude-longitude coordinates.

Annex 1 shows some descriptive statistics of the projected growth rates (of per capita income in 1990 United States dollars) over the period 2008-2099 for the nine countries under consideration for the A2, B2 and A2B2 scenarios as well as the actual growth rates for the period 1971-2007 (to be used as the BAU rate of growth). Table 10a below shows only the mean values under the various scenarios:

Table 10a
Average growth rates in per capita income (constant 1990 US$): 2008-2099

	A2	*B2*	*A2B2 Hybrid*	*Growth 1971-2007*
Aruba	0.001844	0.008156	0.005042	0.050423
Barbados	-0.010676	-0.005068	-0.007838	0.015154
Dominican Republic	0.008960	0.013260	0.011138	0.030200
Guyana	-0.009309	-0.001219	-0.005140	0.009745
Jamaica	-0.004528	0.000540	-0.001991	0.001285
Montserrat	-0.009512	-0.003969	-0.006704	0.021585
Netherlands Antilles	-0.016996	-0.010468	-0.013700	0.021585
St Lucia	0.001482	0.007197	0.004380	0.030605
Trinidad and Tobago	-0.007970	-0.000963	-0.004403	0.025333

Source: Data compiled by author

[5] This was done on the advice of personnel from the Institute of Meteorology (INSMET) in Cuba, which the INSMET suggested should be called a 'business as usual' scenario. This term is reserved for quite another scenario in this paper.

In all cases, the best average growth rate is under the B2 scenario[6], followed by the hybrid A2B2 and A2 scenarios, in that order. The lowest volatility in growth rates (as measured by the standard deviation) are also under the B2 scenario, followed by the A2B2 and A2 scenarios, in that order. It is interesting to note that in all cases, the average of the actual growth rates 1971-2007 exceeds that of the projected rates. It is also of interest that the average projected growth rates are often negative notwithstanding the fact that positive growth rates in fact dominate right up to the 2070s although they decline slowly over time and, after a while, negative rates become more prominent[7]. Table 10b below shows the average growth rates for A2, B2 and A2B2over the period 2050-2099:

Table 10b
Average growth rates in per capita income
(constant 1990 US$) for A2, B2 and A2B2: 2050-2099

	A2	***B2***	***A2B2***
Aruba	-0.01759	-0.00472	-0.01109
Barbados	-0.0293	-0.01735	-0.02328
Dominican Republic	-0.00613	0.002957	-0.00152
Guyana	-0.03291	-0.01665	-0.02458
Jamaica	-0.02216	-0.01193	-0.01701
Montserrat	-0.02673	-0.01559	-0.02107
Netherlands Antilles	-0.03718	-0.02382	-0.03044
St Lucia	-0.01741	-0.00532	-0.0113
Trinidad and Tobago	-0.03	-0.01532	-0.02254

Source: Data compiled by author

Negative growth rates are clearly dominating in this subperiod although the best rates continue to be produced under the B2 scenario, followed by the A2B2 and A2 scenarios, in that order. The negative rates become even more pronounced in later periods (after 2075). What does this all mean?

One possible explanation is that high and sustained economic growth may be a cause of, and not a consequence of, environmental degradation. It also means that high and sustained economic growth is possible even as the environment degrades through the effect of such high growth rates on phenomena like carbon emissions[8]. The last decade has in fact been characterised by high growth rates, especially in emerging economies with relatively large carbon footprints (Brazil, India, China and others) and that trend came to an end not because of climate change or other environmental phenomena but because the financial system failed. If and when a recovery comes, and growth takes off again, it is hardly likely to be related to environmental phenomena and, indeed, there is no reason why such growth cannot continue for some time to come, notwithstanding the frontal attack on the environment.

Another reason for what may appear to be a perverse result may be the fact that the GDP data used to fit the model from which the forecasts are derived do not take into account costs associated with damage to the environment and the projected values consequently do not reflect such costs. Perhaps if the data did take into account the costs associated with environmental damage, then growth may not be recorded as being so high and may even be negative. There is a strong prima facie case, however, that such environmental degradation does eventually strike back and cause sustained declines in economic growth, which is what the domination of negative growth rates may be suggesting, albeit way into the future of the projection period.

[6] The BAU scenario is not considered here as its growth rate is imposed and known in advance.
[7] The plots of these rates are shown in Appendix 2.
[8] Recall that causality tests found evidence that climate variables may Granger-cause growth.

Plots of the various projected growth rates, as well as the actual growth over the period 1971-2007, are shown in Annex II. The projections all display long-run secular decline in growth rates notwithstanding short-run upward trends, including some very sharp ones, moving eventually from declining positive rates to negative ones.

IV. COSTING CLIMATE CHANGE

Costs are calculated for growth under four scenarios: A2, B2, A2B2 and the BAU baseline scenario. The costs taken into account must be associated with the environmental degradation resulting from a given scenario. Such degradation may result directly from carbon dioxide emissions, land degradation, pollution of the waterways and related phenomena. Caribbean islands are also vulnerable to climate change-induced sea-level rise and what are termed 'extreme events' Mimura *et al.* 2007). The latter are occurrences such as hurricanes, earthquakes and the like which have been known to wipe out entire economies in the Caribbean (like Hurricane Ivan in the case of Grenada). The frequency and intensity of such events is predicted to increase as a consequence of climate change (Easterling *et al.* 2009).

Nagy *et al.* (2006) establish that the Caribbean region's cumulative losses of climate-related disasters for 1970–1999 represent 43% of the region's GDP. This cost per GDP ratio is likely to increase over the period 2008-2099 and, conservatively, may rise up to 60%. In this study, costs shall be measured in any one year, and for a given scenario, (A2, B2, A2B2 and BAU) as the present value (base year 2007) of a given cost per GDP ratio. Table 11 below shows, for each scenario, the corresponding total cost to 2025, 2050, 2075 and 2099 based on a ratio of 45% and a discount rate of 0.5%.

Table 11
Present value of costs of climate change at the end of 2025, 2050, 2075 and 2099 under scenarios A2, B2, A2B2 and BAU (1990 US$ million) Cost per GDP ratio: 45%, discount rate: 0.5%

Country	*Year*	*A2*	*B2*	*A2B2*	*BAU*
Aruba	2025	17,387.54	17,254.51	17,323.00	19,351.63
Aruba	2050	61,699.46	59,569.95	60,648.27	90,575.97
Aruba	2075	123,824.37	117,524.78	120,617.98	305,647.26
Aruba	2099	166,426.87	171,744.44	168,520.31	913,094.96
Barbados	2025	21,585.47	21,299.55	21,444.88	20,382.32
Barbados	2050	59,049.21	56,659.18	57,856.95	55,565.68
Barbados	2075	95,361.97	89,966.91	92,615.66	100,801.66
Barbados	2099	114,535.39	113,046.98	113,582.91	156,344.68
Dominican Rep.	2025	295,578.59	293,637.85	294,512.57	253,115.76
Dominican Rep.	2050	1,154,210.46	1,121,602.42	1,137,171.10	856,444.69
Dominican Rep.	2075	2,594,438.25	2,432,811.44	2,509,344.92	1,977,020.50
Dominican Rep.	2099	3,862,754.85	3,922,061.38	3,881,010.70	3,947,996.39
Guyana	2025	7,264.68	7,314.10	7,290.45	6,190.43
Guyana	2050	20,556.89	20,137.45	20,359.51	15,707.23
Guyana	2075	34,085.11	32,346.99	33,222.68	26,413.35
Guyana	2099		41,011.06		

		40,625.19		40,739.21	37,947.94
Jamaica	2025	61,335.27	61,075.23	61,176.11	43,625.90
Jamaica	2050	210,884.38	205,411.96	207,945.54	99,589.69
Jamaica	2075	399,869.39	376,761.33	387,468.00	150,604.73
Jamaica	2099	513,186.15	513,179.46	511,222.73	195,329.98
Montserrat	2025	203.74	204.46	204.04	238.93
Montserrat	2050	524.51	518.75	521.33	712.33
Montserrat	2075	802.13	775.24	787.79	1,425.09
Montserrat	2099	926.53	924.89	923.80	2,446.34
Netherlands Ant.	2025	22,768.23	22,641.75	22,702.00	22,817.00
Netherlands Ant.	2050	62,230.38	60,281.34	61,236.26	68,024.85
Netherlands Ant.	2075	97,855.28	93,261.85	95,459.90	136,090.03
Netherlands Ant.	2099	113,479.57	112,768.05	112,833.10	233,615.09
St Lucia	2025	7,641.19	7,575.98	7,609.24	6,802.89
St Lucia	2050	28,926.54	27,757.31	28,341.84	23,159.91
St Lucia	2075	61,562.54	57,315.35	59,377.45	53,840.15
St Lucia	2099	85,863.72	87,159.37	86,223.03	108,323.50
Trinidad & Tobago	2025	143,452.45	142,658.40	143,024.24	134,404.25
Trinidad & Tobago	2050	442,836.32	424,733.97	433,549.98	422,996.47
Trinidad & Tobago	2075	778,638.20	722,506.23	749,190.54	899,160.35
Trinidad & Tobago	2099	952,513.50	941,658.55	943,488.23	1,645,258.17

Source: Data compiled by author

Table 12
Present value of total costs of climate change at the end of 2025, 2050, 2075 and 2099 under scenarios A2, B2, A2B2 and BAU (1990 US$ million)Cost per GDP Ratio:45%, Discount Rate: 0.5%

Year	***A2***	***B2***	***A2B2***	***BAU***
2025	577,217	573,662	575,287	506,929
2050	2,040,918	1,976,672	2,007,631	1,632,777
2075	4,186,437	3,923,270	4,048,085	3,651,003
2099	5,850,312	5,903,554	5,858,544	7,240,357

Source: Data compiled by author

Right up to the 2070s, the highest costs derive from pursuing the most environmentally hostile A2 scenario since it enjoys the largest growth rates in the earlier periods (and the resulting production levels have higher present values). The A2B2, B2 and BAU scenarios come in second, third, and fourth, respectively. Eventually, as the A2 scenario begins to result in the largest negative growth, its costs fall off and by 2099 this scenario is actually associated with the lowest cost.

The costs shown do not take into account all costs associated with the degradation of the environment that may result from pursuit of the competing strategies. Various competing estimates of some of these costs are available in multiple strands of the literature, including the cost of future extreme events. It is possible to estimate some of them directly, in particular the cost resulting from carbon dioxide emissions. The World Factbook[9] provides information on the 'carbon footprints' of the nine countries over the period 1980-2005. Table 13 below summarises[10]:

Table 13
Per capita carbon dioxide emissions from the consumption and flaring of fossil fuels, 1980-2005 (metric tons carbon equivalent)

	1980	*1990*	*2000*	*2005*
Aruba		2.49	2.89	2.85
Barbados	1.1	1.35	1.7	1.41
DR	0.27	0.34	0.57	0.53
Guyana	0.57	0.24	0.6	0.56
Jamaica	0.98	0.87	1.12	1.15
Montserrat	0.43	0.96	2.28	2.02
Netherlands Antilles	17.68	14.07	14.98	13.69
St Lucia	0.25	0.33	0.58	0.61
Trinidad and Tobago	2.49	4.13	6.68	9.68

Source: Data compiled by author

Using this and the GDP per capita data, a model of the form shown below was fitted using a panel data fixed effects model:

$C = a + bY$

where C is the per capita CO_2 emissions in table 3 and Y is per capita GDP (United States dollars, 1990 prices). An excellent fit was obtained (table 14 below) and this was then used to forecast carbon emissions for the period 2006-2099:

Table 14
Results showing Per Capita Carbon Dioxide Emission as a function of Per Capita GDP

Y	1.332***
	(0.2745)
Constant	-10.615***
	(2.25)

(Standard errors in parentheses; *** p<0.01).
P-value($\square^2$) = 0.000

[9] http://www.photius.com/rankings/carbon_footprint_of_countries_per_capita_1980_2005.html
[10] The Netherlands Antilles has the 4th largest carbon footprint in the world and Trinidad and Tobago the 6th.

The emissions[11] are costed at the going rate per metric ton and these costs (at present values) are added to the existing costs. Table 15 below shows, for each scenario, the corresponding cost, adjusted for CO_2 emissions, to 2025, 2050, 2075 and 2099 based on cost-to-GDP ratio of 45%, a discount rate of 0.5%.and a cost of US $30.00 per metric ton of CO_2 emission.

[11] The emissions are measured in carbon equivalent and must be converted into CO_2 equivalent by multiplying the carbon quantity by 44/12.

Table 15
Present value of costs of climate change (adjusted for CO_2 Emissions) at the end of 2025, 2050, 2075 and 2099 under scenarios A2, B2, A2B2 and BAU (1990 US$ million)
Cost per GDP ratio: 45%, discount rate: 0.5%, US $30.00 (2007 prices) per metric ton of CO_2 emission

Country	*Year*	*A2*	*B2*	*A2B2*	*BAU*
Aruba	2025	17,666	17,531	17,600	19,665
Aruba	2050	62,854	60,673	61,777	92,467
Aruba	2075	126,375	119,897	123,078	314,212
Aruba	2099	169,890	175,287	172,007	947,700
Barbados	2025	183,780	189,037	185,825	965,034
Barbados	2050	207,914	211,812	209,279	987,681
Barbados	2075	231,333	233,280	231,690	1,016,843
Barbados	2099	243,685	248,132	245,189	1,052,682
Dominican Rep.	2025	363,694	367,366	364,771	1,155,631
Dominican Rep.	2050	715,339	706,490	709,892	1,402,255
Dominican Rep.	2075	1,309,340	1,246,778	1,275,561	1,862,126
Dominican Rep.	2099	1,835,237	1,862,514	1,843,437	2,674,902
Guyana	2025	1,840,447	1,869,629	1,849,503	2,686,589
Guyana	2050	1,844,003	1,873,061	1,853,000	2,689,125
Guyana	2075	1,847,661	1,876,359	1,856,476	2,691,990
Guyana	2099	1,849,451	1,878,698	1,858,519	2,695,078
Jamaica	2025	1,859,461	1,888,683	1,868,510	2,702,279
Jamaica	2050	1,884,337	1,912,703	1,892,929	2,711,596
Jamaica	2075	1,916,183	1,941,557	1,923,170	2,720,058
Jamaica	2099	1,935,538	1,964,607	1,944,187	2,727,456
Montserrat	2025	1,935,802	1,965,019	1,944,515	2,727,579
Montserrat	2050	1,935,835	1,965,051	1,944,548	2,727,628
Montserrat	2075	1,935,863	1,965,077	1,944,575	2,727,701
Montserrat	2099	1,935,876	1,965,093	1,944,589	2,727,807
Netherlands Ant.	2025	1,937,370	1,966,579	1,946,079	2,729,306
Netherlands Ant.	2050	1,940,126	1,969,212	1,948,772	2,732,436
Netherlands Ant.	2075	1,942,677	1,971,570	1,951,222	2,737,195
Netherlands Ant.	2099	1,943,839	1,972,974	1,952,491	2,744,074
St Lucia	2025	1,944,177	1,973,330	1,952,837	2,744,917
St Lucia	2050	1,945,042	1,974,150	1,953,680	2,745,582
St Lucia	2075	1,946,374	1,975,356	1,954,946	2,746,830
St Lucia	2099	1,947,373	1,976,577	1,956,047	2,749,050
Trinidad & Tobago	2025	1,951,056	1,980,243	1,959,720	2,752,525
Trinidad & Tobago	2050	1,959,144	1,987,880	1,967,578	2,760,274
Trinidad &Tobago	2075	1,968,481	1,996,165	1,976,358	2,773,188
Trinidad &Tobago	2099	1,973,610	2,002,367	1,981,963	2,793,597

Source: Data compiled by author

In Table 16 below presents a summary of the aggregated costs for 2025, 2050, 2075 and 2099 for all nine countries.

Table 16
Present value of total costs of climate (adjusted for CO_2 emissions) change at the end of 2025, 2050, 2075 and 2099 under scenarios A2, B2, A2B2 and BAU (1990 US$ million)
Cost per GDP ratio: 45%, discount rate: 0.5%, US $30.00 (2007 prices) per metric ton of CO_2 emission

Year	***A2***	***B2***	***A2B2***	***BAU***
2025	12,033,452	12,217,416	12,089,360	18,483,526
2050	12,494,592	12,661,030	12,541,455	18,849,044
2075	13,224,287	13,326,039	13,237,075	19,590,143
2099	13,834,500	14,046,248	13,898,429	21,112,346

Source: Data compiled by author

With the addition of this one extra cost alone, a marked difference in the costs is observed. For instance, total A2 cost in 2025 moves from $577,217 million to $12,033,452 million. Other costs may be determined and added accordingly.

The figures shown in tables 15 and 16 are based on conservative assumptions about costs of climate degradation. They should be taken almost as the minimum effects resulting from climate change.

V. MITIGATION AND ADAPTATION

The IPCC defines mitigation as an "anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" and adaptation as the "adjustment in natural or human systems to a new or changing environment." Mitigation in this optique involves any action tending to ease the burdens to human life and property imposed by a changing climate. Adaptation in the context of climate change refers to adjustment in natural or human systems in response to the effects (positive or negative) of climate change. An International Development Research Centre (2008) study states that "at its core adaptation is about the capacity of social actors to shift livelihood strategies under stress and to develop supporting systems that are resilient."

Many studies have been carried out on a global scale to determine the cost of appropriate mitigation and adaptation strategies. One such study is that of Haites (2008), who estimates that, though large, additional investment to finance mitigation and adaptation measures is relatively small, between 1.1% to 1.7% of projected global investment in 2030. In the absence of other information, this ratio should be the same in the Caribbean. According to Haites (2008), "the mitigation scenario entails less investment in fossil-fired, mainly coal, generation capacity and transmission and distribution. However, the mitigation scenario projects additional investment for carbon capture and storage (CCS) for coal- and gas-fired generation, renewables, nuclear and hydro. The result is almost the same annual investment for power supply under the reference and mitigation scenarios, but a substantial shift in the mix of power supply investment."

Haites believes that "most of the additional investment and financing needed for climate change mitigation and adaptation is expected to be financed by corporations, although this may require government policies and incentives", including playing "a significant role in funding research, development and demonstration."

Parry *et al.* (2009) reviewed several studies on adaptation costs for climate change, including for developing countries, and noted that "they have similar-sized estimates and have been influential in discussions on this issue." In their view, however, "the studies have a number of deficiencies which need to be transparent and addressed more systematically in the future" and that "a re-assessment of the UNFCCC estimates for 2030 suggests that they are likely to be substantial under-estimates."

VI. CONCLUSION

There is evidence of climate change in the Caribbean basin. There is also evidence that such climate change may be directly related to human activity. Projected growth under various scenarios will be quite costly in environmental terms and, eventually, such growth shall be reversed, probably on account of the negative impact on the environment. Steps have to be taken from now to mitigate these possibilities and to encourage the populations of the countries to adapt to a world that is less damaging to the environment. This will not be costless but, in the long run, it will be more beneficial.

Annex I

GROWTH IN PER CAPITA INCOME 1971-2007 AND PROJECTIONS 2008-2099
Summary Statistics

ARUBA

	A2	B2	A2B2 Hybrid	1971-2007
Mean	0.001844	0.008156	0.005042	0.050423
Median	0.009015	0.007446	0.008645	0.069643
Maximum	0.035974	0.036099	0.032696	0.183383
Minimum	-0.055962	-0.024950	-0.040201	-0.052260
Std. Dev.	0.026421	0.016214	0.020719	0.052030

BARBADOS

	A2	**B2**	**A2B2 Hybrid**	**1971-2007**
Mean	-0.010676	-0.005068	-0.007838	0.015154
Median	-0.004236	-0.006031	-0.004936	0.021469
Maximum	0.024060	0.023592	0.019377	0.120874
Minimum	-0.065552	-0.037566	-0.051378	-0.080852
Std. Dev.	0.025416	0.015750	0.019849	0.037594

DOMINICAN REPUBLIC

	A2	**B2**	**A2B2 Hybrid**	**1971-2007**
Mean	0.008960	0.013260	0.011138	0.030200
Median	0.014218	0.012365	0.013754	0.031811
Maximum	0.039491	0.038296	0.038884	0.094127
Minimum	-0.038494	-0.012072	-0.023961	-0.070638
Std. Dev.	0.020791	0.013186	0.016493	0.037022

GUYANA

	A2	**B2**	**A2B2 Hybrid**	**1971-2007**
Mean	-0.009309	-0.001219	-0.005140	0.009745
Median	0.002878	-0.002761	-0.000696	0.012302
Maximum	0.030357	0.029845	0.027918	0.086145
Minimum	-0.084804	-0.038558	-0.060890	-0.139593
Std. Dev.	0.032550	0.019374	0.025238	0.049201

JAMAICA

	A2	**B2**	**A2B2 Hybrid**	**1971-2007**
Mean	-0.004528	0.000540	-0.001991	0.001285
Median	0.003298	-0.000981	-0.000856	0.002044
Maximum	0.034091	0.033190	0.033631	0.088798
Minimum	-0.059508	-0.032773	-0.041135	-0.078804
Std. Dev.	0.024305	0.015734	0.019491	0.036214

MONTSERRAT

	A2	B2	A2B2 Hybrid	1971-2007
Mean	-0.009512	-0.003969	-0.006704	0.016437
Median	-0.002292	-0.005917	-0.004665	0.028071
Maximum	0.019707	0.021557	0.018411	0.132082
Minimum	-0.066761	-0.030403	-0.047598	-0.237471
Std. Dev.	0.023703	0.014746	0.018608	0.076250

NETHERLANDS ANTILLES

	A2	B2	A2B2 Hybrid	1971-2007
Mean	-0.016996	-0.010468	-0.013700	0.021585
Median	-0.009689	-0.011160	-0.009391	0.013214
Maximum	0.018545	0.019205	0.014765	0.302405
Minimum	-0.078908	-0.044751	-0.061507	-0.067338
Std. Dev.	0.027562	0.016839	0.021548	0.056447

ST LUCIA

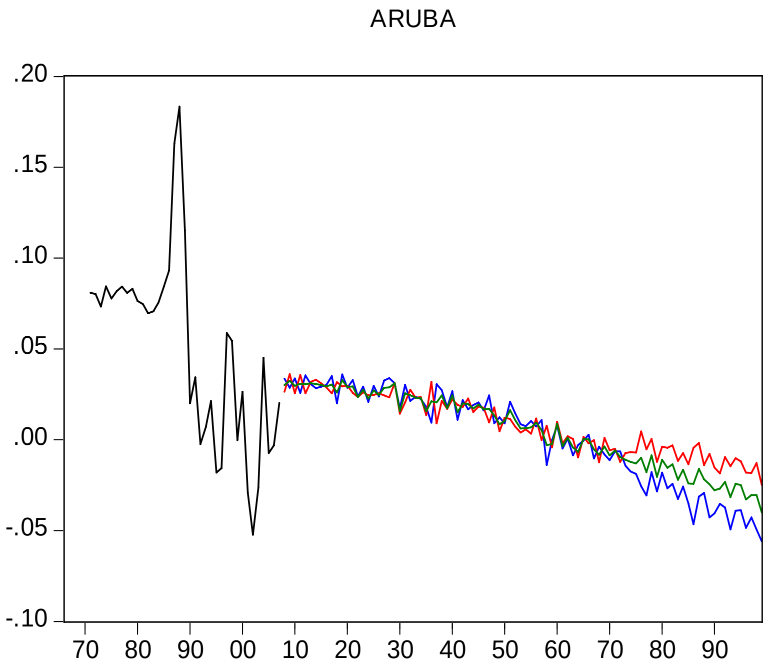
	A2	B2	A2B2 Hybrid	1971-2007
Mean	0.001482	0.007197	0.004380	0.030605
Median	0.008731	0.005685	0.007234	0.024426
Maximum	0.041375	0.040470	0.040915	0.154479
Minimum	-0.054548	-0.023342	-0.038629	-0.073566
Std. Dev.	0.025658	0.015774	0.020190	0.044821

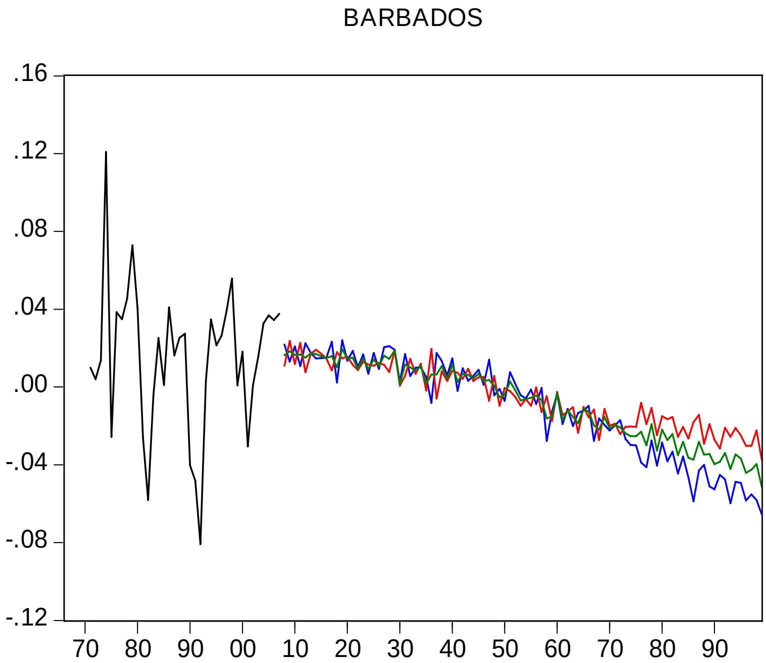
TRINIDAD AND TOBAGO

	A2	B2	A2B2 Hybrid	1971-2007
Mean	-0.007970	-0.000963	-0.004403	0.025333
Median	0.001864	-0.002630	-0.000613	0.030152
Maximum	0.036982	0.036022	0.036486	0.122278
Minimum	-0.075747	-0.038147	-0.056481	-0.127455
Std. Dev.	0.030169	0.018018	0.023480	0.054538
Observations	92	92	92	37

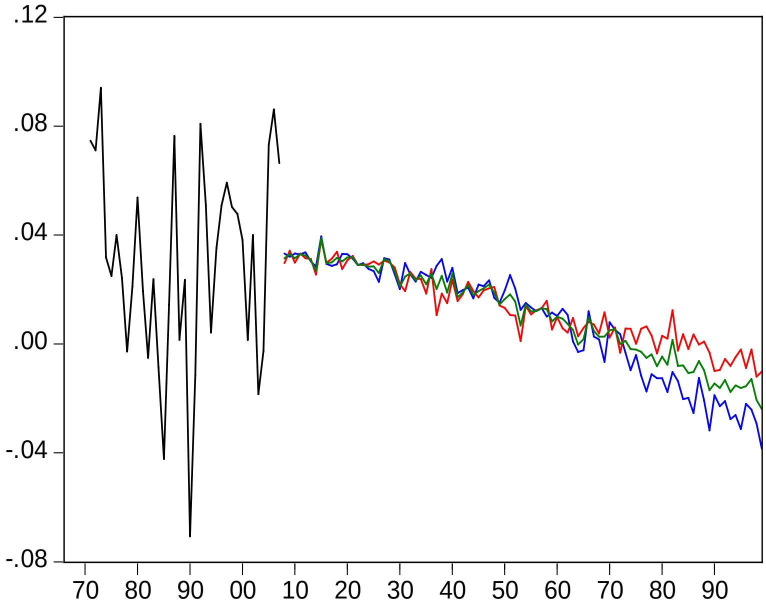
Annex II

GROWTH IN PER CAPITA INCOME 1971-2007 AND PROJECTIONS 2008-2099
Time Plots

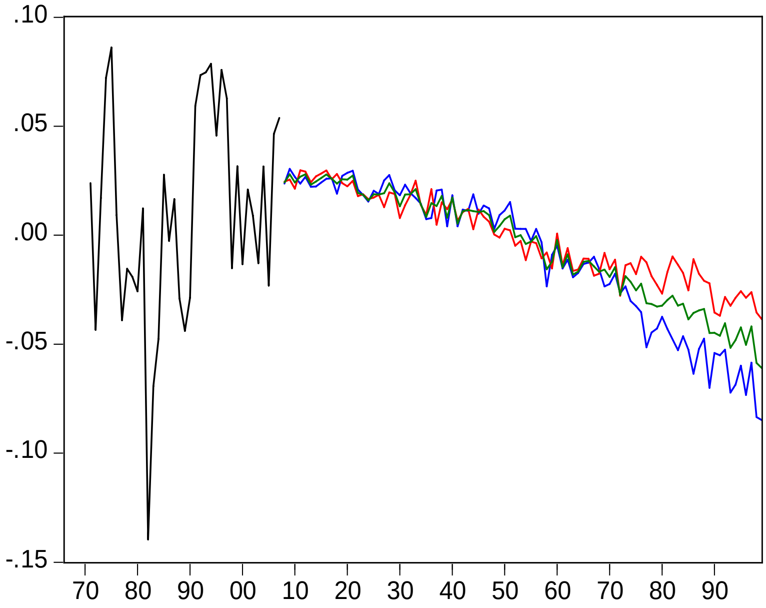




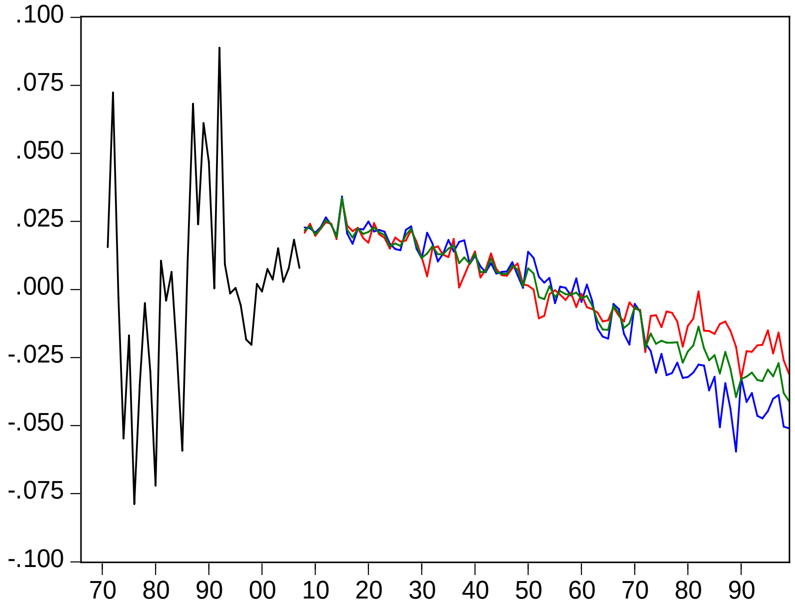
DOMINICAN REPUBLIC



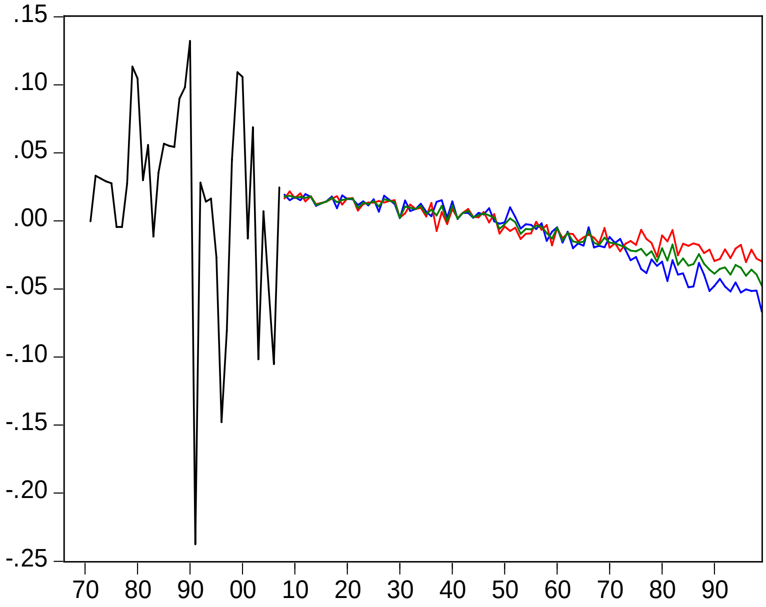
GUYANA

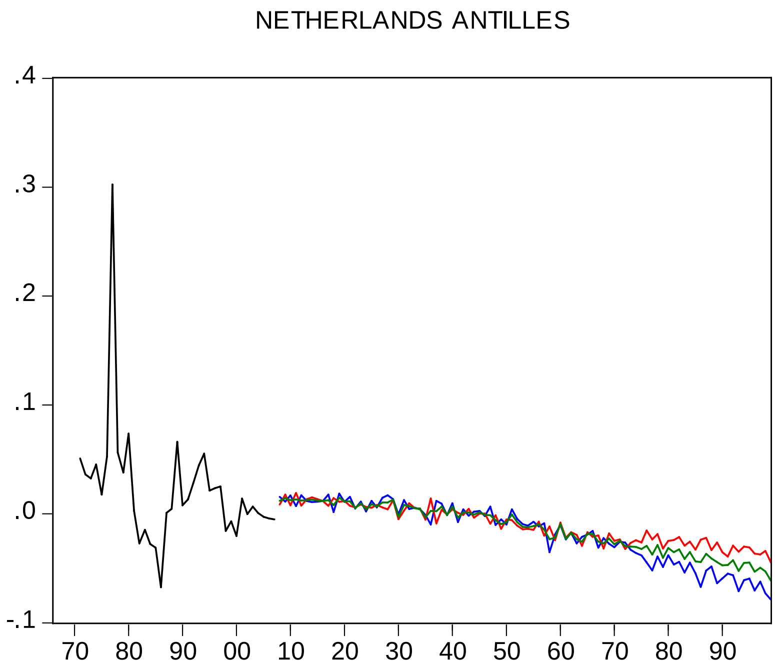


JAMAICA



MONTSERRAT

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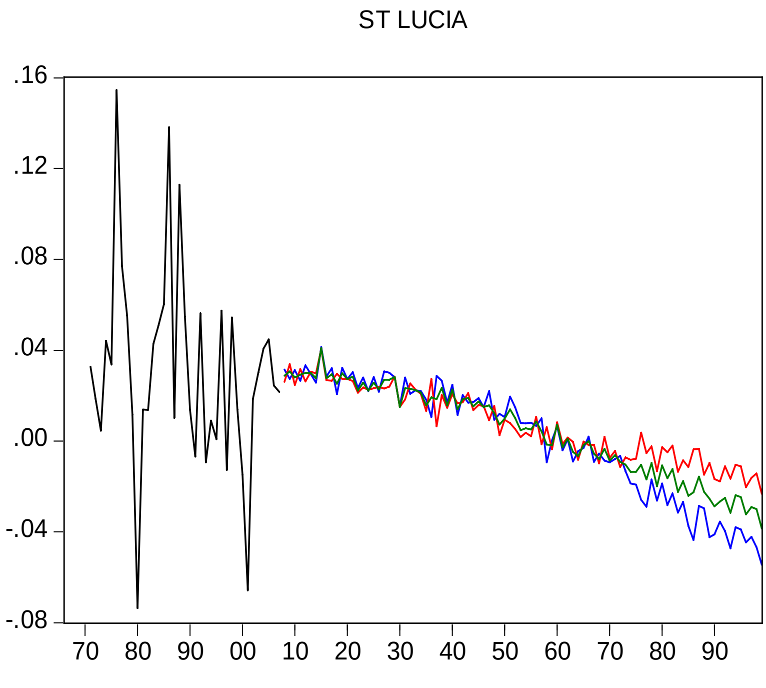
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