# A Modeling Framework to Assess the Economic Impact of Climate Change in the Caribbean

Roberto Roson*

ABSTRACT

ECLAC-CIAM (Climate Impact Assessment Model) is a modeling platform, which has been realized to assess the economic consequences of climate change in the Caribbean. The model can be freely accessed, downloaded and possibly modified. The available version is a full-fledged model, which can be readily used to conduct simulation exercises. This paper provides a general description of the model as well as an illustrative simulation exercise. Our results from this exercise highlight that the Caribbean is a highly vulnerable region, in which climate change is expected to generate sizable and negative economic consequences.

KEYWORDS
Climate change, Computable General Equilibrium, Integrated Assessment, Caribbean.

JEL CODES
C68, Q51, Q54, Q56, R13.

## 1. Introduction

Climate change is a very complex phenomenon. Large scale computer models are run to simulate future climate conditions under different scenarios and assumptions. Socio-economic models are used to assess the climate change impacts and the costs/benefits of mitigation and adaptation policies. Physical and social models are often integrated into complicated Integrated Assessment Models (IAM).

A consistent finding among the many, diverse impact analyses is that negative consequences of climate change will be primarily felt in the developing countries of America, Africa and Asia. This poses a problem of equity in international negotiations, like those of the United Nations Framework Convention for Climate, as developing countries are historically responsible for only a negligible share of global greenhouse gases emissions. In this perspective, quantitative models can greatly help in the identification of burdens and benefits of global climate policies.

Unfortunately, the most vulnerable regions are also those where a rigorous assessment analysis is made difficult by lack of data and expertise. In the Caribbean, for example, a tool for the assessment of social impacts of climate change has not been available for a long time. More generally, there is a lack of quantitative socio-economic models focusing on the Caribbean region. The use of simulation, optimization, econometric and forecasting models is not widespread in the area, not even in institutions like the national central banks (with only a few notable exceptions, e.g., in Jamaica). Not surprisingly, data bases necessary to support and implement applied models are lacking or inadequate. Policy makers are usually unaware of the existence of quantitative economic models and decision support systems.

* Dept. of Economics, Ca'Foscari University, Cannaregio S.Giobbe 873, 30121 Venice, Italy. IEFE, Bocconi University, Milan, Italy. E-mail: roson@unive.it .

This issue has been recently tackled by the subregional Caribbean division of ECLAC, with financial support by the Australian agency AusAid. ECLAC commissioned a study "*to develop either a prototype model or to modify an existing framework that will address in a modeling framework climate change impacts in the Caribbean*". This paper provides a general description of the model realized to this purpose (named Climate Impact Assessment Model, ECLAC-CIAM), as well as an illustrative simulation exercise.

The ECLAC-CIAM model has been designed and developed on the basis of some fundamental concepts. First, a systemic approach has been followed. A systemic approach in modeling climate impacts is essential because climate change is a global phenomenon and the world economy is globalized. Economic effects of climate change in the Caribbean may be driven by physical impacts occurring, say, in the United States much more than direct physical impacts in the Caribbean. Unfortunately, most existing sectoral studies fail in capturing these systemic relationships.

Second, we required the model to be able to consider multiple impact effects simultaneously. This is necessary because climate change generates economic consequences in several, different sectors and in different ways. In addition to sea level rise, we could mention the effects on agricultural productivity (due to changing precipitation, increased evapotranspiration, carbon fertilization), on tourism demand (changing income, prices and tourism attractiveness), on energy demand (increased demand for cooling, decreased demand for heating), on human health and labor productivity (variations in mortality, morbidity), etc. From a policy perspective, the simultaneous assessment of multiple impacts is necessary because: (1) there is often a need to evaluate the overall effect of climate change in a certain country or region, (2) knowing the contribution of each sectoral effect to the total may help in determining priorities for adaptation policies, (3) different impacts may have counteracting effects.

Third, the model has been designed with a modular structure, easily accessible and understandable by other researchers. In order to keep up with the progress in the field of climate science, new elements can be easily inserted in the future, possibly by Caribbean researchers. Indeed, we hope to generate a "multiplier effect", with the ECLAC-CIAM model acting as a seed for further research and model development.

In this respect, a major difficulty is given by the fact that simulating with complex mathematical models may require specific, expensive software. Scientists from developing countries may not afford to buy the necessary software. We tried to circumvent this obstacle by basing the ECLAC-CIAM model only on auxiliary programs that can be downloaded and used free of charge. The program codes, all data and parameters, documentation, links to auxiliary software can be found and freely downloaded at: http://venus.unive.it/roson/ciam.html.

This paper is organized as follows. The next section provides a concise state of the art review of available numerical models for the assessment of socio-economic impacts of climate change. Section 3 describes the structure and the operational functioning of the ECLAC-CIAM model. Section 4 illustrates a simulation exercise, which analyzes the economic impacts of climate change at the year 2050. A final section concludes.

## 2. State of the Art

### *2.1 Applied economic models for climate change assessment*

Several applied, numerical models have been developed to assess the economic impact of climate change and related policies. These models differ in scope, methodology, level of aggregation, treatment of technology and uncertainty, integration with climate models.

A first distinction can be drawn between simulation (positive) and optimization (normative) models. Simulation models are used to conduct "what if" experiments, by considering variations in climate or policy (or both). Almost all models with a Computable General Equilibrium (CGE) core, including the ECLAC-CIAM model presented here, are simulation models. Other models in this class are DART (Springer, 1998), ENVISAGE (Roson and van der Mensbrugghe, 2012), EPPA (Paltsev et al., 2005), GEMINI-E3 (Bernard and Vielle, 2008), GREEN (Burniaux et al, 1992; Lee et al., 1994), GTAP-E (Burniaux and Troung, 2002), GTEM (Pant, 2007), ICES (Eboli, Parrado and Roson, 2010). Optimization models consider instead a target, in terms of a function to be maximized or minimized. All models based on intertemporal utility maximization "à la Ramsey" fall in this class. Perhaps the most popular group of models of this kind is the DICE/RICE family, developed by William Nordhaus (Nordhaus, 1994, Nordhaus and Yang, 1996). Other models are EDGE (Jensen and Thelle, 2001), ENTICE (Popp, 2003), FUND (Anthoff and Tol, 2008), MERGE (Manne, Mendelsohn and Richels, 1995), PAGE (Hope et al., 1993), WIAGEM (Kemfert, 2001), WITCH (Bosetti et al., 2006).

Simulation models are usually large scale models, with regional and industrial detail. From a mathematical point of view, they are large non-linear systems of equations, to be solved with general mathematical packages or specialized software (e.g., GEMPACK, PATH/GAMS). Optimization models, on the other hand, are typically very aggregated models, solved by means of non linear programming algorithms (e.g., MINOS/GAMS, CONOPT/GAMS). The RICE/DICE models, for example, simply consider one aggregate good, that can be used for either consumption or investment. Climate change impacts are also modeled in a rather crude way, through a single damage function, reducing the level of potential income as a function of the increase in temperature.

The various approaches differ in terms of integration with climate models. Some models are "soft-linked" with climate models. This means that a climate model (e.g., a Global Circulation Model) is first used to generate a climate scenario, which is taken as given within the economic model. Results from the latter could then be used to feed the climate scenario, in an iterative process. Other models are "hard-linked", meaning that they possess a climate module fully integrated into the system. Most of the optimization models have this feature, but also some large scale simulation models, like EPPA and ENVISAGE. The advantage of having mutually consistent economic and climate blocks inside the same model should be balanced against the loss of complexity in the climate component, which is usually a reduced-form GCM, including only a limited number of equations.

When models consider the distant future, changes in available technology should be taken into account. On the other hand, investment in green technologies could be fostered by economic incentives, possibly part of a climate policy package. A few models (e.g., WITCH, ENTICE) explicitly address the issue of "endogenous technical change". Unfortunately, estimation of model parameters is very difficult, somewhat arbitrary and subjective. Other models consider the existence of "backstop technologies". These are technologies which are available today but are currently too costly to be viable under the present economic conditions. Nonetheless, they may put an upper bound on the cost of more traditional technologies, like those based on fossil fuels, which may become much more expensive in the future.

A special problem is associated with models of intertemporal optimization, like DICE, RICE and PAGE. These models require the use of discount factors, which cannot be easily estimated from current interest rates when the optimization horizon is far into the future and investment returns are affected by several uncertainties. Especially after the publication of the Stern Review (Stern, 2007) a strong debate has emerged, stressing that results from these models are very sensitive to assumptions about discount factors. Furthermore, there is not a single, correct scientific methodology that should be followed in the estimation process, because assumptions on discount factors are affected by (sometimes hidden) subjective value judgment.

*2.2 Advantages and limitations of CGE models for climate change impact assessment*

ECLAC-CIAM is a CGE model, based on the GTAP formulation, extended to include a set of sectoral damage functions. As such, it shares all pros and cons of other general equilibrium models in the field, which are related to the key characteristics briefly summarized above.

On the positive side, the high level of disaggregation allows one to understand the complex structural interdependencies of globalized economic systems. Furthermore, this makes it possible a precise definition of climate change impacts at a fine industrial and geographical detail. Since CGE models are general purpose tools, not originally designed for climate change analysis, it is easy to assess how non-climate policies may affect the climate, and vice versa. The rich output of the simulation exercises can be further processed (as it is, indeed, in ECLAC-CIAM). For example, from the origin/destination matrices of trade flows the exchange of "virtual carbon" can be estimated (Atkinsons et al., 2010), which is very useful information in the context of international climate negotiations.

On the negative side, CGE models are highly data demanding, originally conceived for short run policy analysis. Their use on a much longer time horizon may be problematic if significant changes in technology or consumer preferences will significantly alter the economic structure from its current state. Even for this reason, they should not be regarded as forecasting tools, nor to construct future economic scenarios.

### *2.2 Climate change assessment in the Caribbean*

Basically all recent studies on climate change effects in the Caribbean have been realized with support and under the auspices of ECLAC, often in association with other international bodies. The most recent publication is "The Economics of Climate Change in the Caribbean - Summary Report 2011" (ECLAC, 2011). Further research findings have been presented in international workshops, but not published yet.

The Summary Report 2011 presents results of climate change scenarios for the Caribbean, obtained with the use of a Regional Circulation Model, driven by two GCM models (ECHAM4 and HadCM3). The model predicts an increase in average temperature at the year 2050, with respect to the 1960-1990 baseline, of 1.78°C (SRES Scenario A2) and 1.84°C (B2) for the whole region. The picture for precipitation is mixed, with increases in some countries and decreases in other countries. It was also found that some increase in tropical cyclone intensity will likely occur if the climate continues to warm.

The Report includes a number of sectoral impact studies, namely those for agriculture, coastal and marine environment, human health, tourism, transportation, water resources, energy. These studies are hardly comparable, but nonetheless have the merit of focusing on the Caribbean, highlighting difficulties and challenges in the estimation of physical impacts of climate change for the region.

## 3. Model Structure

### *3.1 Overview*

The ECLAC-CIAM model includes three modules, operating sequentially, as shown in Figure 1.

*Insert Figure 1*

The first module is used to translate values of climate variables into changes of economic parameters for the global macroeconomic component. The CGE module is then used to conduct a comparative static simulation, contrasting the state of the world economy before and after the variation of climate-related parameters. The following regions are considered in the CGE: North America, Central America, Belize, Caribbean, Guyana and Suriname, South America, Europe, Africa, Asia, Oceania. To get more geographical detail for the Caribbean region, results of the CGE module are post-processed, to get approximated values for some macroeconomic variables (in particular, changes in real national income) in single States of the Caribbean aggregate. In the following, the functioning of each module is more specifically described.

### *3.2 The Sectoral Damage Functions*

The first module in the ECLAC-CIAM model is used to generate exogenous shocks to a number of economic parameters and variables of the core Computable General Equilibrium model, on the basis of a given climate scenario. This is obtained through the application of sectoral “damage functions”.

A damage function is a relationship between some variable describing the climate state (in this case this is the absolute variation of global surface temperature from its value at the year 2000, in Celsius degrees) and some parameters of the economic model (usually expressed as percentage change with respect to the baseline level). The type of sectoral impact determines which parameters are considered. For example, estimated variations in agricultural productivity translate into percentage changes for the multi-factor productivity parameter of the “Agriculture” industry in the CGE model. Effects on human health are interpreted as changes in labor endowment or productivity, and so forth.

In Figure 2, for example, three damage functions for the agricultural sector are plotted, corresponding to five regions in the CGE model: Central America, Belize, Caribbean, Suriname and Guyana, South America.

The horizontal axis measures the variation in temperature (°C) with respect to the year 2000. The vertical axis measures the estimated percentage change in total agricultural productivity in the three countries. Please notice that the estimates refer to the whole agriculture sector, not to a specific crop, and they do not consider changes in water supply or extreme events. The relationship between temperature and productivity in agriculture is a non-linear one: moderate increases in temperature (and in carbon dioxide concentration) are beneficial, higher temperature levels reduce agricultural productivity.

*Insert Figure 2*

Other damage functions in the ECLAC-CIAM model are simple linear relationships, often because there is not enough information to estimate the several parameters of non-linear functions. For example, Figure 3 plots the five damage functions for the sea level rise effect. In this case, the vertical axis measures the percentage loss in the endowment of capital and land stocks in each country. It is clear that the small island States in the Caribbean are highly vulnerable to sea level rise.

*Insert Figure 3*

The ECLAC-CIAM model considers seven sectoral impacts, and each impact is associated with a specific damage function. In addition to agriculture and sea level rise, the following impacts are taken into account:

- Water Availability - this is a second source of variation for agricultural productivity, which is assumed to depend on estimated changes in runoff. According to current parameter values, an increase of 1°C in temperature would reduce agricultural productivity in the Caribbean, because of lower water availability, of -0.21%;
- Tourism - changes in temperature are associated with changes in net receipts from foreign tourists, corresponding to foreign income transfers in the CGE model. A 1°C increase in temperature would reduce tourism receipts by 8.6 billion US$ in Central America, 10 million US$ in Belize, 5.5 billion US$ in the Caribbean, 204 million US$ in Suriname and Guyana, but it would increase tourism receipts by 26.8 billion US$ in South America;
- Energy Demand - this refers to changes in energy consumption by households, considering both

cooling and heating needs. In the CGE model, any variation in energy consumption is accommodated through changes in all other expenses, so that the budget constraint for each household in each country holds. A 1°C increase in temperature would increase energy consumption by 0.21% in Belize and 0.24% in the Caribbean. It would reduce energy consumption by -0.23% in Central America, -0.25% in Suriname and Guyana, -0.02% in South America;

- Human Health - additional cases (mortality, morbidity) of cold-related, heat-related and vector-borne diseases are translated into changes of labor productivity in each region. A 1°C increase in temperature would reduce labor productivity by -0.58% in Central America, -0.57% in Belize, -0.13% in the Caribbean, by -0.11% in Suriname, Guyana and rest of South America;
- On the job Productivity - this refers to labor productivity in open air activities, which may be directly dependent on temperature and humidity. A 1°C increase in temperature would reduce (average) labor productivity by -0.43% in all five regions, except South America (-0.38%).

All figures are indicative and should be taken with caution. Parameters of the damage functions can be changed at any time, whenever more reliable information becomes available. At present, parameter values are estimated on the basis of a wide range of sectoral studies, and correspond to values used in the ENVISAGE Integrated Assessment Model (Roson and van der Mensbrugghe, 2012), developed at the World Bank.

Most of the sectoral studies used to this purpose do not make explicit reference to the Caribbean or other tropical regions. For example, parameters in the damage functions for agricultural productivity (Figure 2), are obtained through weighted averaging of some crop response functions. Three crops have been considered: wheat, rice and maize. Although these are the three most diffused crops in the world, they are certainly not representative of tropical agriculture. It is hoped that better data and more reliable parameter estimates will be made available in future versions of the ECLAC-CIAM model.

### *3.3 The Core CGE Model*

The core of the ECLAC-CIAM model is a standard GTAP Computable General Equilibrium (CGE) model. This is a large macroeconomic model, including thousands of equations, grouped in 213 categories. A complete, formal description of the model is beyond the scope of this paper, but it can be easily found in Hertel and Tsigas (2007). The CGE model, which is not specifically designed for climate change analysis, provides a representation of the world economy and its interdependencies among regions, industries and markets.

Most parameters in the CGE model are calibrated. This means that their values are set in such a way that the model replicates, in the baseline, observed statistical data, like consumption levels and trade patterns. Simulation exercises are performed by varying exogenous variables (e.g., tax rates, productivity factors, factor endowments) and by computing a counterfactual general equilibrium for the world economy, in which all markets, for both products and primary factors, clear. Therefore, a CGE model is primarily designed to study structural adjustment processes triggered by changes in some parameters, rather than to forecast future economic scenarios.

Production in each regional industry takes place by employing intermediate and primary factors. Intermediate factors are produced by other industries, domestic or foreign. The role of each factor in the production process is determined when the model is calibrated, that is when parameter values are set in accordance with observed industrial cost structures. Demand for production factors may change in simulation exercises, because of variations in production levels and relative prices. Expensive factors are (partially) substituted with less expensive ones, on the basis of the assumed industrial production functions and "elasticity of substitution" parameters (determining how sensitive factor patterns may be to relative prices).

Because regional industries are large heterogeneous aggregates, goods produced in the same industry but in different regions are treated as distinct goods. Intermediate and final demand for any product is split inside a nesting structure: first, relative prices determine how much is imported and how much is domestically demanded; second, imports are allocated among different foreign sources, again on the basis of relative prices and elasticities of substitution (which may vary by region and sector). Prices of imported goods include international transport and trade margins, tariffs and non-tariff trade barriers.

In equilibrium, production volumes in each regional industry must match total demand, including: intermediate demand from other domestic and foreign industries, domestic and foreign household consumption, public expenditure, domestic and foreign demand for investment (physical). Equilibrium conditions are achieved by setting prices of products and primary factors.

Endowment stocks of primary resources are normally given, although it is possible to change in the model the partition between endogenous and exogenous variables. Primary factors are internationally immobile, fully or partially mobile among industries of the domestic economy. In equilibrium, factor endowments must match the demand generated by the various domestic industries.

National income is the value of all primary resources, domestically owned. This includes wages, capital returns, land and resource rents, tax revenue. National income is allocated among private household consumption, public expenditure and savings. Consumption patterns are determined on the basis of utility function maximization under budget constraint. Therefore, final consumption demand is sensitive to relative prices.

Regional savings are hypothetically pooled by a virtual international bank, which then distributes them to regional investments, on the basis of expected future returns (linked to current returns). Therefore, regional savings and investments do not necessarily match. National accounting identities imply that any excess saving mirrors a foreign trade surplus, and vice versa. However, equilibrium conditions require the balance of payments, possibly including foreign transfers and remittances, to be zero. This condition is satisfied by adjusting the international exchange rates.

When the model is calibrated, parameter values are set so that the model endogenously computes production, consumption, investment levels fully consistent with national accounts statistics. Counterfactual equilibria are obtained by changing calibration values for exogenous parameters and variables.

This is exactly what happens when a simulation exercise with ECLAC-CIAM is run. Climate change damage functions are first used to estimate how variations in climate conditions (changes in average surface temperature) affect a number of exogenous variables in the CGE model, like labor productivity, total agricultural productivity, land and capital endowments, etc. All changes in exogenous variables are simultaneously inserted inside the CGE model, which is then used to compute consistent levels for variables like relative prices, income and utility levels, investments, international trade patterns, production volumes, tax revenues, and others. This rich array of results provides a global picture of the economic consequences of the climate change.

### *3.4 Downscaling*

Despite the fact that the output of a CGE simulation may be quite sizable, it may not provide results at the desired level of detail in some circumstances. For example, it would be interesting to know the effects of climate change for individual States within the Caribbean aggregate region. This is not directly possible, because calibration of the CGE model requires very detailed national accounting data, which are not available for individual States in the Caribbean.

Nonetheless, some results may be indirectly obtained through the application of microsimulation techniques. In ECLAC-CIAM, microsimulation techniques are used to get indirect estimates of changes in real income (GDP) for individual Caribbean States. The States considered in the analysis are:

- Antigua and Barbuda
- Barbados
- Bermuda
- Caribbean small states
- Cuba
- Dominica
- Dominican Republic
- Grenada
- Jamaica
- St. Kitts and Nevis
- St. Lucia
- St. Vincent and the Grenadines
- Trinidad and Tobago

This is made possible by the fact that the Gross Domestic Product is just the sum of value added realized by all industries in a country. The CGE model provides, in addition to estimates of the GDP (real and nominal) for all regions in the set, estimates of variation of industrial value added, for all regions including the Caribbean. On the other hand, from the World Bank Development Indicators data base it is possible to get the sectoral composition of the national income for all countries above and for the six industries of the CGE model. A reasonable approximation of the variation in national income can therefore be obtained as a weighted average of changes in industrial value added, where the weights are given by the sectoral shares in national GDP. This operation is performed by the output module of the ECLAC-CIAM model.

*3.5 Data Requirements*

Implementation of the ECLAC-CIAM model requires data to implement the CGE model, as well as information to estimate parameters for the damage functions and to conduct the post-processing analysis. Parameters for damage functions have been obtained from a number of different studies, considering various climate change impacts. The downscaling procedure is based on data about the value added composition of the national GDP for the Caribbean states.

Much of the parameters of the core CGE models are calibrated, with the exception of elasticities of substitution, which are taken from the literature, or from conventional reference values. Calibration of a CGE model entails choosing parameter values such that the model endogenously computes trade flows, consumption and production volumes fully consistent with available input-output or social accounting matrices. The calibration process may be long and cumbersome (as well as conditioned by data availability), but global, standardized data resources are now available, making things much easier. ECLAC-CIAM has been calibrated using the GTAP 8 Data Base.

Since 1992, the Global Trade Analysis Project (GTAP) consortium, headed by the Purdue University in the U.S., collects national accounts to build and to maintain a global SAM data base. The GTAP 8 Data Base is the eighth major public release of the GTAP Data Base since the Project began. A GTAP Data Base is created on the basis of domestic data bases or input-output (I-O) tables, which are combined with international datasets on macroeconomic aggregates, bilateral trade, energy, agricultural input-output, and protection for the new reference years. Interim releases of the data base are constructed as significant updated datasets become available. Improvements are also made in data sourcing, scope, and construction procedures. In GTAP 8 data comes from a variety of sources (including World Bank, National Statistical Agencies, ITC/CEPII, COMTRADE, IEA, OECD, and many others) and are reconciled inside a consistent framework. The whole process of construction is quite complex and it is fully documented at www.gtap.org.

## 4. An Illustrative Simulation Exercise

To illustrate how the ECLAC-CIAM model works and what kind of results it can produce, we present in this section an example of simulation exercise[1]. Let us consider the IPCC SRES Scenario A2 at the year 2050, which entails an increase in average temperature of 1.2°C w.r.t. the year 2000. The damage functions express this scenario in terms of changes in economic variables, namely:

• an increase for land productivity in Central America of +3.38%, +1.03% in Belize, +0.68% in the Caribbean, +0.41% in Suriname and Guyana, +4.64% in South America;

• a decrease for capital stock in Central America of -0.25%, -0.40% in Belize, -2.69% in the Caribbean, -0.22% in Suriname and Guyana, -0.08% in South America;

• a decrease for labor productivity in Central America of -1.10%, -1.20% in Belize, -0.67% in the Caribbean, -0.64% in Suriname and Guyana, -0.58% in South America;

• a decrease in the demand for services (tourism) in Central America of -1.38%, -1.43% in Belize, -3.34% in the Caribbean, -7.52% in Suriname and Guyana, an increase in South America of +2.22%;

• a decrease for energy production in Belize, Suriname and Guyana of -0.05%, -0.06% in the Caribbean and Central America, -0.04% in South America.

These (as well as the corresponding values for all other regions) constitute exogenous shocks for the general equilibrium model. After the CGE model has been run, estimates for several economic variables are available. For example, Table 1 reports the estimated variations in production volumes in Agriculture, Energy, Light Manufacturing, Heavy Manufacturing, Market Services, Non Market Services sectors in the five American regions (however, results are available for all regions and industries in the model).

*Insert Table 1*

Notice that the exogenous variation in land productivity does not correspond to the estimated variation in agricultural production volume. A similar reasoning applies to energy production and market services. This is because the model accounts for changes in relative competitiveness and in the terms of trade. In the Caribbean, for example, the drop in the demand for market services (a consequence of the reduced attractiveness of Caribbean touristic destinations) brings about lower production volumes in agriculture (a supplier of the tourism industry). It also implies a real devaluation of the national currency, reducing production costs and improving the international competitiveness in the energy and manufacturing sectors.

Table 2 presents the percentage changes in household consumption levels, by industry. Lower consumption levels indicate reduced well-being. Furthermore, consumption patterns change because of variations in relative prices.

*Insert Table 2*

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[1] This exercise can be easily replicated by the interested readers.

Simulation results show that reduction in consumption levels, imposed by climate change effects, may be quite sizable, especially in the Caribbean. The ECLAC-CIAM model can also provide a more detailed welfare analysis, for instance by computing the "equivalent variation" (EV) for each region, which is a money-metric index of welfare impacts. The EV is the change in income that would have produced the same variation in utility levels, at constant prices. It turns out that climate change at the year 2050 would generate economic consequences that are equivalent to a loss of about 7.5 billions US$ (per year) in Central America. EV losses for the other regions are: 17 millions US$ in Belize, 6.7 billions US$ in the Caribbean, 84 millions US$ in Suriname and Guyana, 4.2 billions US$ in South America.

Clearly, the magnitude of the loss depends on the size of the regional economy. To better appreciate the effect on welfare, Table 3 displays the EV variation relative to national income, which amounts to the percentage change in real GDP. In addition to results for the five aggregate regions, we present the estimated variation for individual countries within the Caribbean, obtained through the output module of ECLAC-CIAM, as well as other estimates, whose meaning is explained in the following.

*Insert Table 3*

The column "Overall" shows the estimated change in regional GDP. We can see that the impact on the Caribbean GDP is quite large: at the year 2050, because of climate change, national income would be about 3% lower than its hypothetical level in the absence of climate change. The corresponding results for Belize, Suriname and Guyana are also quite significant, whereas the impact on Central and South America is significantly smaller.

The columns "Upper" and "Lower" refer to a sensitivity analysis on the simulation results. In this example, we informed the model software that uncertainty exists about the correct value for some shocked parameters. More specifically, we assumed that changes in labour productivity and demand for market services can take any value in the range +/-50% of their baseline estimate. In other words, we replaced a single value for the variation in specific parameters with a (rectangular) probability distribution. The model can then infer the probability distribution of output variables, associated with the distribution of input shocks. This is obtained by running the simulation several times with alternative input values, using the Stroud's statistical quadrature technique (Stroud, 1957, DeVuyst and Preckel, 1997). Consequently, information is produced not only about central values for all output variables, but also about other statistical moments, like the standard deviation. In Table 3, the "Lower" column shows the estimated change in real GDP minus its estimated standard variation, whereas in the "Upper" column the standard variation is added. Therefore, the two values correspond to the bounds of a likelihood interval for the estimated change in regional GDP.

The remaining four columns on the right present results of some other simulation exercises, in which only one class of climate change effects is taken into account at a time. For example, in the "Labor" column estimates of variations in real GDP are obtained by varying only labor productivity parameters, while keeping all other parameters (e.g., land productivity) unchanged. In this way, it is possible to single out the contribution of a specific climate change effect to the overall result. We can see that variations in labor productivity is indeed the most important economic effect of climate change in Belize, Central and South America. Losses in the capital stock, associated with the sea level rise, is the most important impact in the Caribbean, whereas drop in tourism demand is the most important factor in Suriname and Guyana.

## 5. Conclusion

ECLAC-CIAM is a modeling platform, which has been realized to assess the economic consequences of climate change in the Caribbean. The model is aimed at filling a knowledge gap, by making it possible the realization of a quantitative assessment of the economic effects of climate change.

It is clear that the model can be improved in several different ways: better quality of economic data, more reliable estimates of physical direct effect of climate change, improved climate scenarios, finer industrial and regional disaggregation levels, etc.

Nonetheless, the current version of ECLAC-CIAM, which can be freely accessed, downloaded and possibly modified, is already a fully working, state of the art model. As such, it can be readily used to conduct simulation exercises like the one presented in this paper. From this simple illustrative simulation, a number of key findings can be obtained. Our results confirm that the Caribbean is a highly vulnerable region, in which climate change is expected to generate sizable and negative economic consequences. Sea level rise, bringing about losses in land and capital infrastructure stocks, and a decline in the tourism industry are the two most relevant factors. These results can inform mitigation and adaptation policies at both the regional and international level.

The model is very flexible and other simulation exercises could be easily conceived, for example by changing time horizon, climate scenario or sectoral impacts. All other exogenous parameters in the CGE model could be modified as well, which is especially helpful to explore the interactions between climate and other policies (e.g., fiscal reforms, trade liberalization, productivity growth).

It is also possible to "swap" endogenous and exogenous variables in the model. For example, in the standard closure the model computes equilibrium wages, to ensure full employment of the given labor stock. If, instead, (real) wages are specified ex-ante, labor demand may become endogenous. The difference between total labor supply and estimated demand is readily interpreted as involuntary unemployment.

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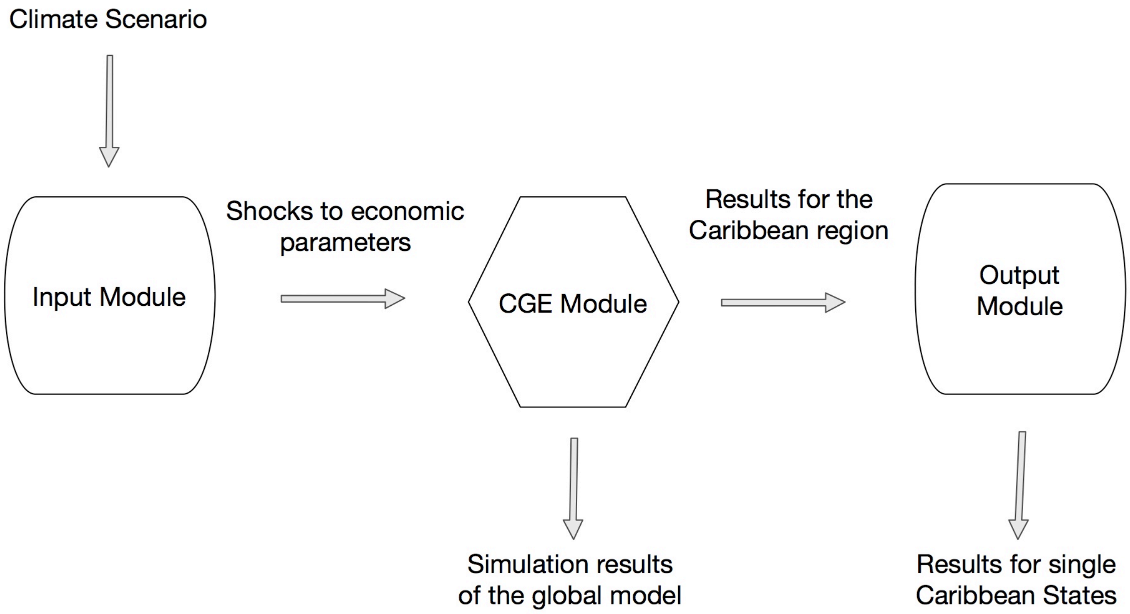


*Figure 1. The modular structure of ECLAC-CIAM*

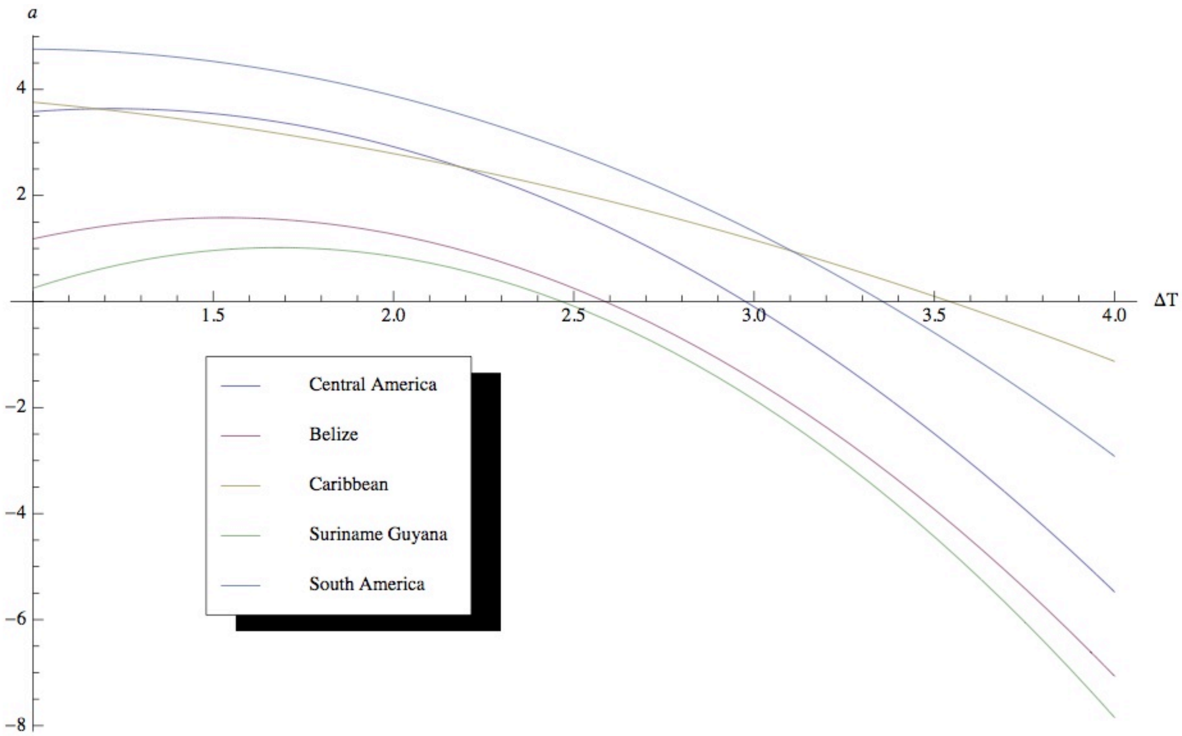


*Figure 2 - Five Damage Functions (Agriculture)*

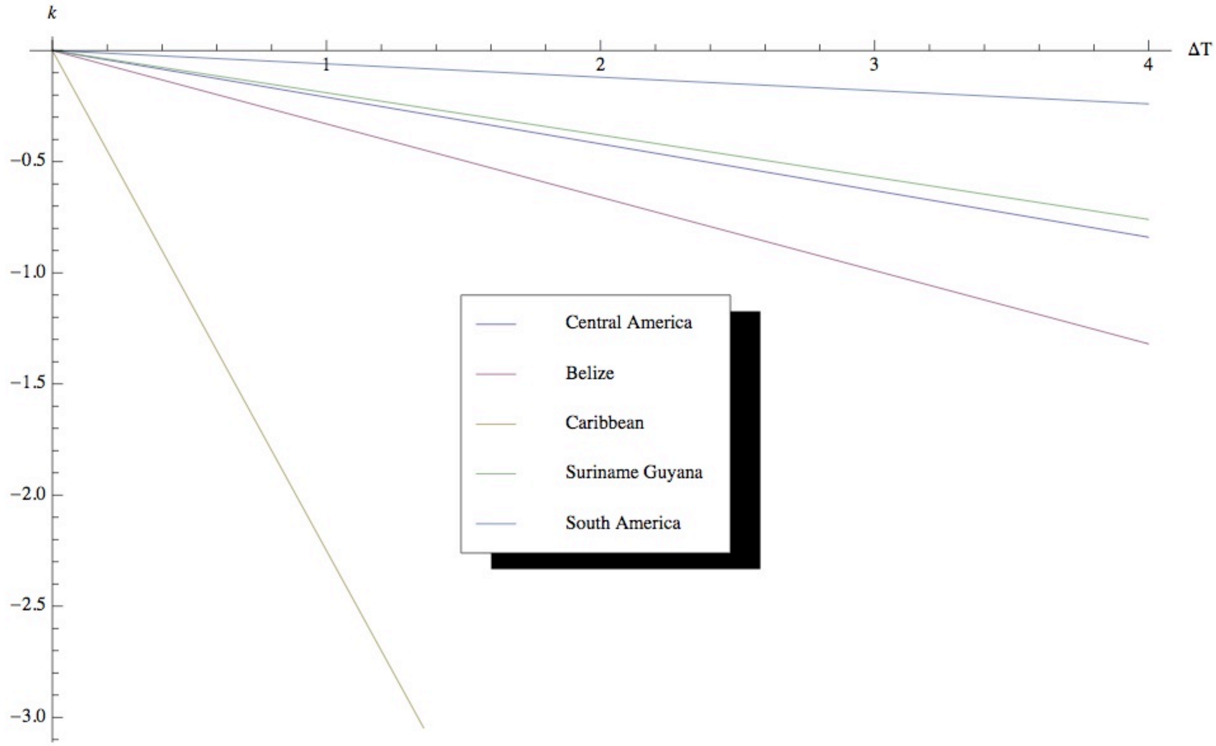


*Figure 3 - Five Damage Functions (Sea Level Rise)*

*Table 1 – Percentage variations in industrial production volumes*

| | C. America | Belize | Caribbean | Sur. Guyana | S. America |
|---|---|---|---|---|---|
| Agriculture | -0.13 | -1.83 | 0.39 | -0.6 | -1.84 |
| Energy | 1.21 | 0.09 | 4.1 | 0.79 | -2.75 |
| L.Manuf. | 0.61 | 0.26 | 2 | 3.29 | -1.24 |
| H. Manuf. | 1.72 | -0.27 | 3.71 | 6.57 | -2.51 |
| M. Services | -1.64 | -1.38 | -4.22 | -7.33 | 1.67 |
| N.M. Services | -0.95 | -1.1 | -1.82 | -0.99 | -0.69 |

*Table 2 – Percentage variations in household consumption volumes*

| | C. America | Belize | Caribbean | Sur. Guyana | S. America |
|---|---|---|---|---|---|
| Agriculture | 0.21 | -0.23 | -1.1 | -0.64 | 0.6 |
| Energy | -0.87 | -1.55 | -4.12 | -1.95 | 0.17 |
| L.Manuf. | -0.38 | -1.16 | -2.55 | -1.29 | 0.22 |
| H. Manuf. | -0.89 | -1.8 | -4.13 | -2.16 | -0.05 |
| M. Services | -0.72 | -1.71 | -3.37 | -1.91 | -0.26 |
| N.M. Services | -0.86 | -1.91 | -3.05 | -1.77 | -0.35 |

*Table 3 – Percentage variations in real national income*

| | Overall | Lower | Upper | Land | Labor | Capital | Tourism |
|---|---|---|---|---|---|---|---|
| Central America | -0.73 | -0.84 | -0.63 | 0.03 | -0.43 | -0.18 | -0.16 |
| Belize | -1.46 | -1.69 | -1.24 | -0.33 | -0.75 | -0.17 | -0.22 |
| Caribbean | -2.92 | -3.47 | -2.37 | 0.04 | -0.43 | -1.49 | -1.05 |
| *Antigua Barbuda* | -3.20 | -3.72 | -2.74 | -0.09 | -0.43 | -1.51 | -1.24 |
| *Barbados* | -3.11 | -3.64 | -2.61 | -0.06 | -0.43 | -1.50 | -1.18 |
| *Bermuda* | -3.76 | -4.17 | -3.51 | -0.11 | -0.46 | -1.54 | -1.55 |
| *Carib. small states* | -2.71 | -3.31 | -2.06 | -0.03 | -0.42 | -1.48 | -0.96 |
| *Cuba* | -3.22 | -3.71 | -2.77 | 0.03 | -0.44 | -1.51 | -1.21 |
| *Dominica* | -3.20 | -3.67 | -2.80 | 0.25 | -0.45 | -1.50 | -1.13 |
| *Dominican Republic* | -2.68 | -3.28 | -2.04 | 0.05 | -0.42 | -1.48 | -0.92 |
| *Grenada* | -3.15 | -3.66 | -2.67 | -0.02 | -0.43 | -1.51 | -1.19 |
| *Jamaica* | -2.97 | -3.52 | -2.43 | 0.01 | -0.43 | -1.49 | -1.09 |
| *St. Kitts and Nevis* | -3.17 | -3.69 | -2.68 | -0.10 | -0.43 | -1.51 | -1.23 |
| *St. Lucia* | -3.29 | -3.78 | -2.87 | -0.04 | -0.44 | -1.51 | -1.27 |
| *St. Vincent Grenad.* | -3.14 | -3.65 | -2.67 | 0.05 | -0.44 | -1.50 | -1.16 |
| *Trinidad and Tobago* | -1.61 | -2.45 | -0.52 | -0.17 | -0.37 | -1.42 | -0.42 |
| Suriname Guyana | -1.66 | -2.05 | -1.27 | -0.08 | -0.40 | -0.12 | -1.06 |
| South America | -0.19 | -0.30 | -0.08 | -0.01 | -0.36 | -0.04 | 0.22 |