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S E R I E S

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## Development of a modelling framework in support of an assessment of the economic and social impacts of climate change in the Caribbean

The ECLAC - CIAM model

Roberto Roson



UNITED NATIONS

ECLAC



Australian Government

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## Abstract

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The Caribbean region remains highly vulnerable to the impacts of climate change. In order to assess the social and economic consequences of climate change for the region, the Economic Commission for Latin America and the Caribbean (ECLAC) has developed a model for this purpose. The model is referred to as the Climate Impact Assessment Model (ECLAC-CIAM) and is a tool that can simultaneously assess multiple sectoral climate impacts specific to the Caribbean as a whole and for individual countries.

To achieve this goal, an Integrated Assessment Model (IAM) with a Computable General Equilibrium Core was developed comprising of three modules to be executed sequentially. The first of these modules defines the type and magnitude of economic shocks on the basis of a climate change scenario, the second module is a global Computable General Equilibrium model with a special regional and industrial classification and the third module processes the output of the CGE model to get more disaggregated results.

The model has the potential to produce several economic estimates but the current default results include percentage change in real national income for individual Caribbean states which provides a simple measure of welfare impacts. With some modifications, the model can also be used to consider the effects of single sectoral shocks such as (Land, Labour, Capital and Tourism) on the percentage change in real national income. Ultimately, the model is envisioned as an evolving tool for assessing the impact of climate change in the Caribbean and as a guide to policy responses with respect to adaptation strategies.



# I. Introduction

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## A. Motivation

There is an urgent need to assess the social and economic consequences of the climate change, especially in those areas which are expected to be most vulnerable, including the Caribbean. Unfortunately, the most vulnerable regions are also those where developing countries are located and a rigorous analysis is made difficult by lack of data and expertise.

On the other hand, climate change is a very complex phenomenon, on both the physical and social sides. Because of its intrinsic complexity, the United Nations Environmental Program (UNEP) established the Intergovernmental Panel for Climate Change (IPCC), gathering several scientists from different disciplines, including physics, climatology, oceanography, economics, agronomy, and others. Large scale computer models are run to simulate future climate conditions under a range of different scenarios and assumptions. In the same vein, socio-economic models are used to simulate the climate change impacts and costs/benefits of mitigation and adaptation policies. Physical and social models are often integrated into complicated Integrated Assessment Models (IAM).

Clearly, the purpose, approach and perspective of social modeling are quite different from that of physical modeling. Social and economic “laws” are not deterministic but based on observed behavior of socio-economic aggregates. Mathematical models, based on principles of rational behavior, are used to anticipate the response to shocks like the climate change, or to assess the likely effects of trade liberalization, or those of a fiscal reform. These mathematical models can be as complex as those used in physics, especially when there is a need to account for the interdependence between markets, which is essential in the case of a global phenomenon, like the climate change.

This research work is motivated by the necessity of developing a modeling platform for the assessment of climate change impacts in the Caribbean. A number of different studies have already been realized in this field, but they are hardly comparable because they use different methodologies, assumptions and have a sectoral perspective. On the other hand, a concerned policy maker, who wants to understand the possible consequences of climate change and what can be done about it, should be



interested in gauging the overall effects of the combined impact on, for example, tourism, agriculture and coastal infrastructure. At the moment, a tool for the simultaneous assessment of multiple climate impacts in the Caribbean simply does not exist.

More generally, there is a lack of quantitative economic models that focus on the Caribbean, and the Caribbean scientific community needs to develop its own modeling capacity. The use of quantitative models (simulation models, optimization models, econometric and forecasting models) is not widespread in the Caribbean, not even in institutions like national central banks (with only a few notable exceptions, e.g. Jamaica). Not surprisingly, data bases necessary to support and to implement applied models are lacking or inadequate.

This research is aimed at developing a fully functional modeling platform for the assessment of climate change impacts in the Caribbean, by adapting, coupling and extending a number of existing models. It could then be conceived as a sort of pilot, demonstration project, which shows the potential of quantitative economic modeling and stimulates further research and interest in the topic, by both scientists and stakeholders.

## **B. Key concepts**

The development of the modeling framework has been driven by some “key concepts”, that are essential, desired characteristics of the model structure and methodology. These are discussed in the following sections.

### **1. Systemic approach**

Physical impacts of climate change are usually associated with specific geographical locations and economic sectors. Consider for example, that agricultural land would be lost in a certain Caribbean island due to climate-induced sea level rise. The economic consequences of this loss would go far beyond the island and its agricultural industry. Land would become a scarce factor, making production of land-based industries less competitive. Imports could substitute domestic production, but the need to keep a balance on foreign trade would imply a devaluation of the national currency, a recovery of competitiveness in other industries, changes in prices, wages, profits, trade flows, and industrial production volumes. In the end, the effects of sea level rise would be felt in non-agricultural sectors as well as by trade partners overseas.

A systemic approach to 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 by direct physical impacts in the Caribbean. Existing sectoral studies fail to capture the systemic feedbacks.

### **2. Multiple impact assessment**

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 and (3) different impacts may have counteracting effects.

A simulation platform should then be able to consider several effects simultaneously, as well as single out the contribution of each sectoral impact. A side benefit of this approach is the possibility of comparing the different sectoral impact analyses on a homogenous basis.

### **3. Modularity**

The science of climate change is making continuous progress. New models, new evidence, new theories are proposed. The IPCC summarizes the most updated available knowledge in “Assessment Reports” every 5-6 years (a new AR is expected in 2013). In order to keep up with the progress in the field, a modeling framework should be structured in such a way that new elements can be easily inserted in the future, to avoid rapid obsolescence.

Even if the model is very complex, it should not look like a “black box”, or a machine that can be adjusted only by its inventor. Updatable parameters and equations should be kept separate and easily accessible by other model- users. The model should be fully documented and “user-friendly”. This is an important principle we have tried to implement in the ECLAC-CIAM model.

### **4. Open access**

The principle of open access is related to the previous one. The model framework should be made accessible and understandable, so that results can be readily replicated and tested. The model itself could be expanded in the future, for example by some Caribbean researchers. The objective is to have a type of “multiplier effect”, with the ECLAC-CIAM model acting as the basis for further research and model development.

In this respect, a major difficulty is the fact that simulating with complex mathematical models may require specific, expensive software. Scientists from developing countries may not be able to afford 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 two most important auxiliary components are the RunGTAP program and the LibreOffice/OpenOffice suite.

## **C. Objectives**

The objectives of this study are 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. The preferred approach is to build an Integrated Assessment Model (IAM) with a Computable General Equilibrium Core.

In practice, these objectives have been pursued through the development of three modules that need to be executed sequentially during a simulation exercise. The first module defines the type and magnitude of economic shocks on the basis of a climate scenario. The second module is a global Computable General Equilibrium model (CGE) with a special regional and industrial classification, singling out the Caribbean region. The third module processes the output of the CGE model to get more disaggregated results.

The program codes, all data and parameters, links to auxiliary software can be found and freely downloaded at: <http://venus.unive.it/rosen/ciam.html>.

## **D. State of the art**

### **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, as well as 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 CGE core, including the ECLAC-CIAM model presented here, are simulation models. Other models in this class are DART (Springer, 1998; Klapper

et al., 2003), ENVISAGE (van der Mensbrugghe, 2009; 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 inter-temporal utility maximization “à la Ramsey” fall into this class. Perhaps the most popular group of models of this kind is the DICE/RICE family, developed by William Nordhaus (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, 1999, 2004; Richels and Blanford, 2008), 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 much 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, which can be used for either consumption or investment. Climate change impacts are also modeled in a rather crude way, through a 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”, which means that they possess a climate module fully integrated into the system. Most optimization models have this feature, as well as some large scale simulation models, like EPPA and ENVISAGE. The advantage of having mutually consistent economic and climate blocks within 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 stretch into 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 can be 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 inter-temporal 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. 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 the United Nations Economic Commission for Latin America and the Caribbean, often in association with other international bodies. The most recent publication is “The Economics of Climate Change in the Caribbean - Summary Report 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 and energy. As noted above, these studies are hardly comparable, but nonetheless have the merit of focusing on the Caribbean and highlighting difficulties and challenges in the estimation of physical impacts of climate change for the region.

For example, impacts on agriculture are dependent on the amount of fertilization induced by an augmented concentration of carbon dioxide in the atmosphere. The existence and magnitude of this effect is very controversial. It was also found that most Caribbean crops are much more sensitive to precipitation than temperature. Unfortunately, when results from different climate models are compared it can be easily noticed that precipitation scenarios are much less robust than those of temperature. In other words, two climate models do not usually produce very different estimates for variations in temperature, but they may generate quite divergent predictions about precipitation.

All these difficulties and uncertainties are not specific to the Caribbean. The correct scientific approach in the assessment of climate change should explicitly recognize that the various estimates of physical impacts are associated with different degrees of confidence.



## II. Methodology

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### A. The climate change damage functions

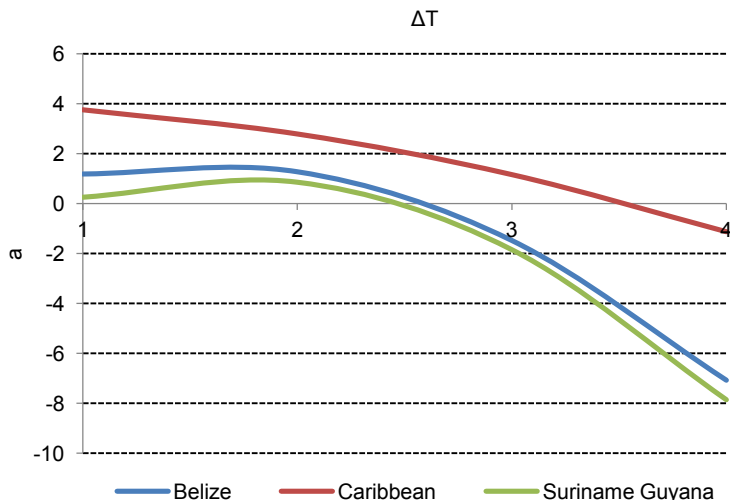
The first module in the ECLAC-CIAM model is used to generate exogenous shocks to a number of economic parameters and variables of the core Computable General Equilibrium model, on the basis of a given climate scenario. This is obtained through the application of sectoral “damage functions”.

A damage function is a relationship between some variable describing the climate scenario (in this model this is the absolute variation of global surface temperature from its value at the year 2000, in Celsius degrees) and some parameters in 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 multifactor productivity parameter of the “Agriculture” industry of the CGE model. Effects on human health are interpreted as changes in labor endowment or productivity, and so forth.

To illustrate the concept, consider FIGURE 1 here below. In this figure, three damage functions for the agricultural sector are plotted, corresponding to three regions in the CGE model: Belize, Caribbean, and Suriname & Guyana (Sur-Guy).

The horizontal axis measures the variation in temperature ( $^{\circ}\text{C}$ ) 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 carbon dioxide concentration) are beneficial, higher temperature levels reduce agricultural productivity.

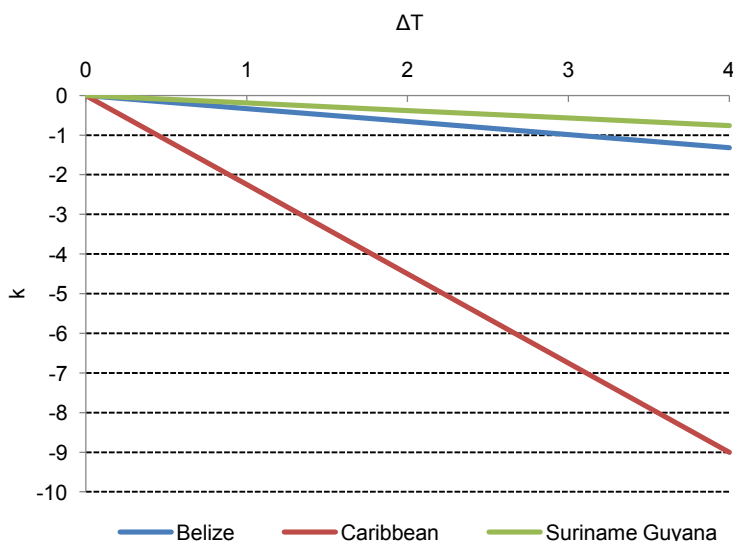
**FIGURE 1  
THREE DAMAGE FUNCTIONS (AGRICULTURE)**



Source: Consultant generated.

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 2 plots the three 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 much more vulnerable to sea level rise.

**FIGURE 2  
THREE DAMAGE FUNCTIONS (SEA LEVEL RISE)**



Source: Consultant generated.

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:

## 1. 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 -0.21per cent;

## 2. 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 10 million US\$ in Belize, 5.5 billion US\$ in the Caribbean, 204 million US\$ in Suriname and Guyana;

## 3. Energy demand

This refers to changes in energy consumption by household, 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 0.21per cent in Belize and 0.24per cent in the Caribbean. It would reduce energy consumption by -0.25per cent in Suriname and Guyana;

## 4. 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 -0.57per cent in Belize, -0.13per cent in the Caribbean and by -0.11per cent in Suriname and Guyana;

## 5. On the job productivity

This refers to labor productivity in open air works, which may be directly dependent on temperature and humidity. A 1°C increase in temperature would reduce (average) labor productivity by -0.43per cent in all three countries.

All figures above 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 coincide with values used in the ENVISAGE Integrated Assessment Model, developed at the World Bank.

Most of the sectoral studies used to this purpose do not make explicit reference to the Caribbean, as the Caribbean is normally included in a large region in global models like ENVISAGE. For example, parameters in the damage functions for agricultural productivity (FIGURE 1) 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 the Caribbean agriculture.<sup>1</sup>

It is hoped that studies focusing specifically on the Caribbean will provide better data and more reliable parameter estimates in future versions of the ECLAC-CIAM model. In this sense, there is a role for complementarity between partial and general equilibrium models.

## B. The core general equilibrium model

The core of the ECLAC-CIAM model is a standard Computable General Equilibrium (CGE) model. This is a large macroeconomic model, including thousands of equations, grouped in 213 categories. A

<sup>1</sup> Nonetheless, our estimates do consider the relative diffusion of the three reference crops in the Caribbean.



complete, formal description of the model is beyond the scope of this work, but it can be easily found in Hertel and Tsigas (2007). The CGE model provides a description of the world economy and interdependencies among regions, industries and markets. Such model is not specifically designed for climate change analysis, but can be used for a variety of different purposes.

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 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.

ECLAC-CIAM is based on the standard GTAP model and a specific regional/industrial aggregation. The following regions are considered in ECLAC-CIAM:

- North America
- Central America
- Belize
- Caribbean
- Guyana and Suriname
- South America
- Europe
- Africa
- Asia
- Oceania

In each of the ten regions, the following industries are taken into account:

- Agriculture
- Energy
- Light manufacturing
- Heavy manufacturing
- Market services
- Non-market services

and the following primary factors:

- Unskilled labour
- Skilled labour
- Capital
- Land
- Natural resources

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, and 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 labour 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.

### **C. Post-processing analysis**

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.<sup>2</sup>

Nonetheless, some indirect results may be obtained through the application of microsimulation techniques. The basic idea of these techniques is that of linking some macroeconomic variables to microeconomic ones. Microsimulation has been extensively used, for example, to estimate variations in the household income of rural villages in some African countries, by combining macro-estimated changes in wages, rents, etc., with information about the sources of income for the households.

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
- Saint Kitts and Nevis
- Saint Lucia
- Saint 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 inside the Caribbean aggregate. On the other hand, from the World Bank Development Indicators data base it is possible to get the sectoral composition (considering the six industries in the CGE model) of the national income for all countries above. A reasonable approximation for the variation of 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 computation can be done after running the CGE model, by copying some output variables in a specially designed spreadsheet, which is the third module in the ECLAC-CIAM model. Of course, other ex-post elaborations are possible. Later in this document, for example, the calculation of an index of income inequality will be illustrated.

## D. Database

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

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<sup>2</sup> Calibration is a technique for the estimation of model parameters, which are chosen so as to make the model replicating observed data. In CGE models, it is imposed that the baseline equilibrium generates income flows consistent with some available social accounting or input-output matrix.

analysis. Data requirements for the latter two stages have already been discussed, so in this section I shall focus on the CGE core only.

Generally speaking, a CGE model is very data demanding. A national CGE model requires at least a complete input-output table, plus additional information on income flows (sometimes combined into a Social Accounting Matrix). Not all accounting agencies in the world produce input-output or SAM matrices. Other agencies produce tables, but not on a regular basis. In fact, the estimation of a regional input-output table is a long and cumbersome process. The core CGE model used in ECLAC-CIAM is a global, not a national one. It therefore needs a global Social Accounting Matrix, including input-output tables for all regions in the world and a complete description of international trade flows and investments.

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](http://www.gtap.org).

Input-output tables and other data are provided by members of the GTAP network. To build a consistent SAM data base, all the different tables must refer to a single year, so they must first be made temporally homogeneous. Data with multiple sources must be reconciled, for example export flows of a country should be made consistent with import flows of another country. All these operations are carried out through the use of special statistical techniques of maximum likelihood, aimed at reconstructing disaggregated data on the basis of partial information (e.g., on marginal totals) and some reference structure. The same techniques are used to reconstruct tables and data in countries where disaggregated information is not available, or in large “residual” regions (including the Caribbean).

As CGE models are based on official national accounts, they share all the pros and cons of this data source. Only market transactions are considered, self employment and home production are not accounted for, public services are valued at their cost. Grey or black economies can be accounted only to the extent that the national agencies do so. For example, the Italian accounting agency ISTAT produced in the past upward, revised estimates of the national product, in order to consider the effects of tax evasion and erosion.



### III. An illustrative simulation exercise

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A full-fledged assessment of the climate change impacts on the Caribbean is not the primary scope of this research, which is rather aimed at developing a modeling framework for subsequent analysis. Nonetheless, an illustrative simulation exercise is presented and discussed here, to demonstrate what the model can and cannot do, and how the whole system works.

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. 2000. The damage functions express this scenario in terms of changes in economic variables, namely:

- an increase for land productivity in Belize of +1.03per cent, +0.68per cent in the Caribbean, +0.41per cent in Suriname and Guyana;
- a decrease for capital stock in Belize of -0.40per cent, -2.69per cent in the Caribbean, -0.22per cent in Suriname and Guyana;
- a decrease for labour productivity in Belize of -1.20per cent, -0.67per cent in the Caribbean, -0.64per cent in Suriname and Guyana;
- a decrease in the demand for services (tourism) in Belize of -1.43per cent, -3.34per cent in the Caribbean, -7.52per cent in Suriname and Guyana;
- A decrease for energy production in Belize of -0.05per cent, -0.06per cent in the Caribbean, -0.05per cent in Suriname and Guyana.
- These are exogenous shocks for the general equilibrium model. After the CGE model has been run, estimates for several economic variables are available. We present here only results for the real national income, which provides a simple measure of welfare impacts.

The CGE model gives percentage changes in national income for the three regions Belize, Caribbean, Suriname & Guyana (as well as for all other regions in the world). Through the use of the microsimulation methodology described in the previous section, we disaggregate the Caribbean result down, at the individual State scale.

In addition, we performed a sensitivity analysis by informing the model software that uncertainty about the correct value of some sectoral shocks exists. This is done by replacing single values for shocks with probability distributions, within a certain range. For example, instead of assuming a decrease in the demand for services in the Caribbean of -3.34per cent, we could inform the software that the shock can take any value in the range [-1.67per cent, -5.01per cent] (this would be a rectangular distribution, with -3.34per cent as its central value). In this case, the RunGTAP software would perform several estimates and would use special mathematical methodologies to infer a likely probability distribution for all output variables, including the real national income.

Finally, after considering all shocks simultaneously, we ran the model by considering single sectoral shocks (Land, Labor, Capital and Tourism effects). This amounts to consider the case where the only impact of climate change is on land, or on labor, or on capital, or on tourism. The reason why these “decomposition” simulations are carried out is that, in this way, it is possible to single out the contribution of each effect to the total, thereby understanding what kind of effect would be most relevant in the various regions.

The simulation results are summarized in TABLE 1. Lower and upper values refer to the central value +/- the standard deviation.

**TABLE 1**  
**ILLUSTRATIVE SIMULATION RESULTS (REAL NATIONAL INCOME)**

Country	All shocks	Lower	Upper	Land	Labour	Capital	Tourism
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
Suriname	-1.66	-2.05	-1.27	-0.08	-0.40	-0.12	-1.06
Guyana							
Sub-Caribbean estimations							
Antigua and 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
Caribbean 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
Saint Kitts and Nevis	-3.17	-3.69	-2.68	-0.10	-0.43	-1.51	-1.23
Saint Lucia	-3.29	-3.78	-2.87	-0.04	-0.44	-1.51	-1.27
Saint Vincent and the Grenadines	-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

Source: Author's calculations.

It can be noticed that:

- The loss of real income is substantial in all three regions, with a value for the Caribbean close to -3per cent. The corresponding estimate for North America would be -0.09per cent, -0.05per cent for Europe;

- inside the Caribbean aggregate the variation goes from a minimum of -1.61per cent for Trinidad and Tobago to a maximum of -3.76per cent for Bermuda;
- the main driver of income loss in Belize is the reduction in labor productivity;
- the main drivers of income loss in the Caribbean are shocks on capital stock (sea level rise) and on tourism;
- The main driver of income loss in Suriname and Guyana is the effect on tourism.

Our results confirm that the Caribbean area is very vulnerable to climate change impacts. More generally, climate change impacts are expected to worsen the distribution of wealth and income in the world, with rich countries becoming relatively richer and poor countries becoming poorer.

This finding stimulated a further elaboration on the model output. We calculated an index of income inequality for all Caribbean countries before and after the simulation exercise. The chosen index is the Gini coefficient, ranging between zero and one. A unitary value for the Gini coefficient would imply that all countries considered (in the Caribbean group) have the same level of GDP per capita. Higher values of the index would indicate more income equality, and vice versa.

The initial level of the Gini coefficient for all Caribbean countries considered in our simulation was 22.55per cent. After applying the variation in national income reported in TABLE 1, the same coefficient rises to 22.69per cent. This means that climate change would have adverse distributional effects not only between the Caribbean and the rest of the world, but it would also worsen the distribution of income among the Caribbean States.





## IV. Possible future development

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The ECLAC-CIAM model could be improved in many different ways.

First, parameters should be improved and updated, especially those of climate change functions. We noticed that the values currently in use in the model were derived from previous, global IAM models. New impacts could be taken into consideration and better parameter estimates could be obtained by studies explicitly addressing the issue of climate impacts in the Caribbean. In this respect, one should notice that the parameters in ECLAC-CIAM are applied to large economic aggregates and refer to a period of one year. Therefore, it is likely that parameters cannot be simply borrowed from available sectoral studies, but need to be adjusted to the specific geographical and temporal scale of the model.

Second, the SAM database used to calibrate the CGE model, which refer to 2007, could be updated. The CGE model itself could be used to this purpose, by careful swapping endogenous and exogenous variables. For example, suppose that more recent data on macroeconomic variables would be made available for all countries in the ECLAC-CIAM disaggregation. In this case, one should make variables like GDP or sectoral value added exogenously set at their new level, while letting the model to endogenously compute a consistent new value for a set of productivity parameters. Results from this simulation run would then make the new model baseline.

Third, econometric studies could provide better estimates for the elasticity of substitution parameters. Generally speaking, CGE models are quite sensitive to the values of these parameters, yet their values are often just “guess-estimated”.

Fourth, the use of microsimulation methodologies could be extended to other variables, like consumption and investment levels. More information on macroeconomic variables for single Caribbean States would also generally improve the quality of the output disaggregation process.



## **V. Using the model as a policy assessment tool**

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### **A. Adaptation policies**

The ECLAC-CIAM model could be used to assess some proposed adaptation policies. Actually, some adaptive behavior is implicit in the model structure, for example when expensive and scarce factors are substituted in production and consumption processes. To address other policy measures, which may require specific intervention; it is first necessary to consider how climate change impacts may be curbed, in the various sectors and regions.

The model allows a comparison between a reference scenario, in which all climate impacts are considered, and another one, where “diminished impacts” may be taken into account. The difference between the two cases provides an assessment of the benefits of specific adaptation policies. Usually these benefits are compared with costs and, in principle, it would be possible to consider the cost effects in the CGE framework as well.

There are, however, some difficulties in the interpretation of such a simulation exercise. As an example, consider the case of sea level rise impacts. Suppose that it would be possible to protect some land from sea level rise through various measures, like dike building, beach nourishment, and the like. On the benefits side, this would mean that productivity or availability of land resources would not be reduced as much as initially assumed. This scenario is easy to implement in ECLAC-CIAM, by reducing the corresponding shocks to the Land variable from their values, as produced by the damage functions.

However, to consider the cost effect one should simulate the realization of some investment, possibly funded through taxes. On the aggregate, reducing household consumption while expanding investments would have a negligible impact on the GDP, as both consumption and investment are components of the national income. In other words, what is “cost” for some individuals would become “revenue” for other individuals inside the same economic system?

## **B. Mitigation policies and international climate agreements**

Mitigation policies are aimed at reducing the emissions of greenhouse gases worldwide, to curb the climate change phenomenon. International agreements, like the Kyoto protocol, are subscribed at the global or regional level. “Conferences of the Parties” (CoP) are regularly organized around the world to discuss technical issues of implementation of proposed mitigation schemes, and much of the debate centers around questions like: How costs and benefits of mitigation policies should be distributed among different countries, especially between developed and developing nations? How and how much developing countries should be compensated for harmful climate impacts?

ECLAC-CIAM is a tool that could be fruitfully used to inform the negotiation of mitigation policies for climate international agreements. This could be done by comparing different scenarios with the same model. For example, climate impacts could be first assessed in a “business as usual” scenario, in which no major reductions in greenhouse gases are devised, thereby using high temperature assumptions. On the other hand, specific, alternative mitigation scenarios could be tested by simply assuming a lower increase in GHGs concentration and temperature. The differences between the two cases would then highlight who would be the major beneficiaries of some proposed mitigation policy package.

## **C. Consistency between climate and other economic policies**

As already mentioned, Computable General Equilibrium models were not initially developed for purposes of climate change impact and policy assessment. Two very popular fields of application for CGE models have been fiscal reforms and trade liberalization.

The effects of a fiscal reform can be easily simulated in a CGE model by changing the exogenous tax rate parameters. This can be done under alternative assumptions (called “closures”) about the public sector budget. For example, it could be assumed that any variation in tax revenue is matched by a corresponding variation in public expenditure, or by allowing a public deficit (or surplus), or by making some tax rates automatically adjusted so as to keep the total tax revenue unchanged. For example, several simulation exercises with CGE models have considered the effects of introduction of “green taxes” (e.g., a tax on energy consumption proportional on CO<sub>2</sub> emissions), whose additional revenue would be used to cut distortionary taxes on labour. Fiscal reform simulation experiments are useful in highlighting the systemic effects of the reforms, identifying the winners and losers, as well as possible efficiency gains for the whole economic system.

Proposals of trade liberalization schemes have also been tested through CGE models. A counterfactual equilibrium is obtained by changing (normally by lowering) tariffs and non-tariff trade barriers, which are exogenous parameters in the model. For example, the effects of a proposed trade union could be tested. The major advantage of using a CGE approach is that the model allows assessing how trade flows would change and how terms of trade would be altered. By conducting a welfare analysis it is possible to detect efficiency gains or losses, as well as distributional consequences.

Since the same model could be used to assess different policies, some interesting questions would then be: How reciprocally consistent are climate policies and other economic policies? Are climate impacts going to amplify or to dampen the effects of other policies?

For example, suppose that the model is used to simulate the simultaneous effects of some fiscal reform and of climate change. In this case, after running the first module in ECLAC-CIAM, which provides changes in parameters as obtained from the damage functions, a number of additional changes in tax rate parameters could be introduced before realizing the CGE simulation run. The output of the model would therefore be determined by the simultaneous action of shocks induced by the climate change and shocks induced by the hypothetical fiscal reform.



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