Public Investment Profile for Climate Risk Reduction in Barbados

A Macroeconomic Cost-benefit Analysis for Reducing the Socio-economic Risk of Coastal Erosion

Inter-American Development Bank

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Public Investment Profile for Climate Risk Reduction in Barbados

A macroeconomic cost–benefit analysis for reducing the socio-economic risk of coastal erosion

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Abstract/Executive Summary

Through the Inter-American Development Bank (IDB) sponsored "Study on Disaster Risk Management – A macro perspective cost-benefit analysis for reducing vulnerability", a dynamic modelling approach was developed to quantify the macroeconomic costs and benefits of investment in disaster risk reduction. The goal of the developed tool was multifaceted, with emphasis on assessing mixes of disaster risk reduction and financial protection instruments, and with a focus on addressing shortfalls in current disaster risk modelling methods. This work serves as the final report of the project and presents the results of an application of the developed Dynamic Model of Multi-hazard Mitigation Co-benefits (DYNAMMICs) framework to the country case of Barbados, demonstrating the applicability of the approach through empirical assessment of DRR investment options to combat coastal hazards facing the island country.

The DYNAMMICs model allows for estimating the long-run benefits of DRR in macroeconomic terms and disentangles the benefits of risk reduction into three pathways (i) the avoidance of direct impacts; (ii) the increased economic potential due to reduction of risk to investments; and (iii) the co-benefits of DRR projects which can provide positive economic effects to the community beyond reduction of risk. With this context, this report aims to address three main policy questions to be addressed by the DYNAMMICs framework. The first relates to the level of public investment needed to reach a desired level of disaster risk reduction. Following this, the model is used to examine the potential optimal mix of resource allocation between DRR investment and risk transfer instruments. Lastly, the report seeks to identify the optimal balance of resources between disaster risk management instruments and other investments, to balance a desire for development with increased resilience.

This report examines a number of possible policy pathways for Barbados following calibration of the model using country-specific data, including DRR and hazard mitigation, risk financing, and combinations of such policies, as compared to a reference business-as-usual case. In all scenarios, long-run GDP is higher than in the reference case, and year-on-year changes in GDP are smoothed, compared to more volatile reference cases. However, decomposition of the effects of risk reduction measures find that some policy pathways lead to more positive outcomes than others, and that policies which include a significant fiscal component could lead to reduced total growth effects in the long term as compared to DRR pathways, due to increasing insurance premiums. However, the report emphasizes that these results are reliant on the quality of input data, and there is a strong need for improved national macroeconomic information and hazard modelling.

Project Background

The Inter-American Development Bank (IDB) implements the Technical Cooperation (TC) project entitled **Study on Disaster Risk Management – A macro perspective cost–benefit analysis for reducing vulnerability (RG-T3369)**. The general objective of this project is to support the systematic analysis of public-investment decisions in IDB member countries through the development and demonstration of a new analytical tool capable of simulating: (i) an optimal mix of public fund allocations for disaster risk reduction (i.e., structural/non-structural measures such as new protective infrastructures and structural retrofitting for existing vulnerable infrastructures) and (ii) financial protection instruments such as risk retention (or emergency funds), contingent credit line, (for instance, the Bank's Contingent Loan for Natural Disaster Emergencies) and risk transfer (or risk insurance and cat bonds).

The International Institute for Applied Systems Analysis (IIASA) has been tasked to advance the methodology for the above assignment and to demonstrate its applicability in the assessment of coastal erosion risks under climate change in Barbados. Under the previous project TC RG-T2434: Development of Public Investment Profile in Disaster Risk Reduction (https://www.iadb.org/en/project/RG-T2434), a general analytical framework and basic methods were developed and tested in selected countries at the national level (Bolivia, Honduras, and Peru) and one at the local level (Rio Rocha river basin in Bolivia). Based on this previous study, a new dynamic macroeconomic modelling was developed to address the remaining shortcomings of the first phase risk profile methodology. The developed framework is capable of quantifying the macroeconomic costs and benefits of investment in disaster risk reduction (DRR), including how the provision of safer environments fosters productive investments and private savings and how multi-purpose DRR investments bring co-benefits such as the improvement in public services provision and other socioeconomic gains. This Barbados case study report demonstrates the applicability of the newly developed macroeconomic modelling framework through an empirical assessment of DRR investment options against coastal hazards (namely, cyclone-triggered storm surge and beach erosion).

Barbados economy and hazard background

Country overview

Barbados, located at the south-eastern extent of the Caribbean, is a small – only 432 square km land area – island developing state. With a population of just over 287 thousand, it is also the 9th most densely populated country in the world (US Central Intelligence Agency, 2020). Historically reliant on agriculture in the form of sugarcane and processing into consumer goods (e.g., sugar, alcoholic beverages) the country pivoted to a focus on tourism in the latter half of the 20th century, and a concerted effort by the government to enhance the industry in the early 1990s (Greenidge and Greenidge 2007). It is one of the most highly developed countries in the region, boasting the fourth highest GDP per capita rate in Latin America and the Caribbean at over $18,000 per person (The World Bank, 2020a). It additionally scores highly in other development indicators, in 2018 reaching a value of 0.813, reaching a status of 'very high' and ranking 56 out of 189 nations (UNDP, 2019).

The economy of Barbados is highly tourism-driven, in 2019 making up 30.9% of the total economy and providing a full 33% of all employment. As seen in the sectoral breakdown of GDP shown in Figure 1, tourism-related sectors make up the bulk of the economy, however, some light manufacturing does occur as well (US Central Intelligence Agency, 2020). In terms of service exports, in 2016 personal travel made up $955 million, with other business services the next highest export at $241 million. In comparison, the total exports of all goods in the same year was $511 million (United Nations Statistics Division, 2020). In terms of trade balance, imports outpace exports by almost 3 to 1, with imports reaching $1.65 billion in 2016, and encompass everything from petroleum products (14% of all imports) to cars, chemical and pharmaceutical products, electronics, and foodstuffs.

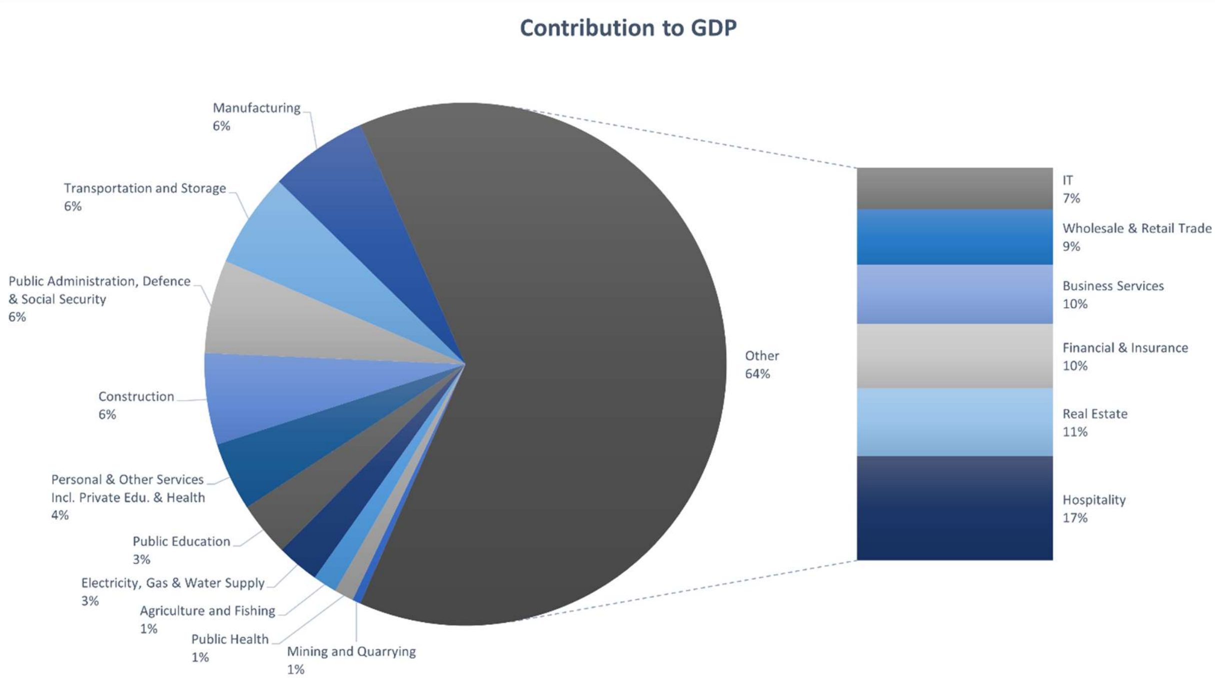


Figure 1. Sectoral GDP breakdown of Barbados, based on 2018 values (Barbados Statistical Service, 2019).

Being an open small economy, Barbados is heavily reliant on and subject to the prevailing economic situations of industrialized countries, both for the import of necessities (e.g., fuel for electricity generation) and tourism revenues. This has led to uneven growth over the past decades (as depicted in Figure 2), most notably in the early 2000's after terrorist attacks in the USA dampened air travel, and again during the 2008 global financial crisis. The 2001 impact led to a growth rate of -2.4 in 2001, rebounding to positive levels thereafter, but the 2008 crisis left a long-lasting impact, with growth not achieved again until 2015, and that only short-lived.

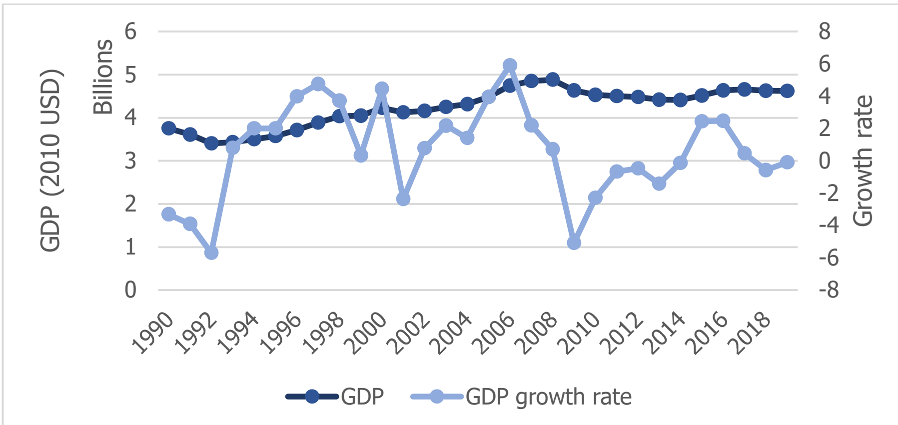


Figure 2. Barbados' GDP (dark blue) and yearly growth rate (light blue) for the period 1990 to 2019 (The World Bank, 2020a).

Barbados economy had gone through a recession in the early 1990s, again driven by global events (with the occurrence of a global economic downturn and the first Gulf War) and the country was on the verge of defaulting on loans due to an absence of private finance. The debt crisis led to support from both the International Monetary Fund and the IDB. Through the IMF, the atypically high public deficit of 5% of GDP in 1991 was brought down, and through 2008, any fiscal deficits were kept in check. The ratio of public debt to GDP was also kept at a relative stable level, and the short disruption of growth in 2002 did not lead to large deviations from these trends.

The 2008 financial crisis, on the other hand, led to worsening financial conditions over a sustained period, making the country's situation ever more tenuous. Fiscal deficits grew to over 15% in 2014, with the public sector debt to GDP ratio rising above 100% from 2012 to 2014 and even higher to 150% by 2018, and debt servicing making up over 50% of government revenues in 2014 (Hinds and Stephen, 2017). The worsening situation triggered enactment of the Barbados Economic Recovery and Transformation Plan (BERT), to lower debt to GDP ratios and recover fiscal surpluses.

The BERT is a five-year package of measures (namely austerity and stimulus) to avoid devaluation of the Barbados Dollar. The plan consists of three phases; phase 1 focuses on reviewing and increasing tax revenue and compliance, as well as increasing the tax base to foreign tourists. A second phase is meant to target the reduction of central government expenditures, along with state-owned businesses. The third phase is less concrete, but will be an iterative process of austerity measures, to determine in some participatory approach what government expenditures are vital, and what can be done without (Caribbean Insight, 2018).

Due to austerity measures (along with lower demand in non-trading sectors e.g., construction), GDP growth was negative in 2018, despite a recovering tourism industry, and was flat (0%) in 2019. With the help of IMF funding of $290 million to provide a source of foreign exchange, the situation appeared to be improving, although recovery was expected to last into 2020 (ECLAC, 2019), and debt to GDP ratio had slightly reduced somewhat to 118% in 2019 (although due to the pandemic (see Box 1) the ratio has increased as of the first quarter of 2021 to 150%), but unemployment remained relatively high at 10% due to laying off of public workers in the name of austerity. The goal of the Plan is to lower the debt to GDP ratio to 60% by 2033.

Box 1: COVID's likely impact

While the COVID-19 pandemic is still ongoing as of the drafting of this work, it is guaranteed to have significant effect on Barbados, due to the country's reliance on (now non-existent) tourism. While the virus has not taken hold in the country to the degree seen elsewhere in the world (as of November 2020, there were only 243 confirmed cases in the country, and 7 deaths (World Health Organization, 2020)) but economic effects are guaranteed, due to a long-term closure of the tourism sector on the island, coupled with collapsing demand to travel from all industrial countries currently undergoing significant daily increases in infections.

The IMF has predicted a 7.8% decline in GDP for 2020, with a rebound of 7.1% in the following year, but these estimates are based on a reduction in pandemic impact in the second half of 2020 (International Monetary Fund, 2020). Analysis from the UNDP, UNICEF and UN Women predicts much more dire reductions, with a 16% reduction in 2020 followed by a 15% rebound in 2021. Unemployment, already at 10% prior to the pandemic, is predicted to reach 21% in 2020, and not fully recover to pre-COVID levels in 2021 (UNDP et al., 2020).

These events demonstrate well the fragility of Barbados' economy and vulnerability to external shocks. Its halting of debt payments and subsequent restructuring in 2018, leading to IMF assistance, has cut off its access to market-based finance, leaving the island reliant on funds from the IMF, Caribbean Development Bank, and IDB. The sum of loans made available for fiscal year 2019/20 reached 344 million (almost 7% of GDP). However, IDB has been active in the country long before 2018, as discussed in the following section.

MFI activities

The IDB, along with IMF and other MFIs, has been active in assisting Barbados most recently since the 2018 risk of default, but IDB has had an increasing presence in the country (in terms of increasing loan amounts) since the 1970's, with significant periods of funding in the early 1990s and after the 2008 financial crisis (see left panel of Figure 3). The most recent period of funding strategies (2015 to 2018) saw IDB approve loans worth $101 million, with additional co-financing coming from the China Co-Financing Fund for Latin America and the Caribbean, loans which were separate from the collaborative fiscal reform program with the IMF.

The 2015-2018 funding strategy focused on developing a number of areas, key among them tourism, transport, energy and the environment, social issues and improving labour markets and the private sector, resulting in several outcomes. In terms of energy and the environment, IDB financing has pushed the island towards energy independence and increasing renewable electricity generation, along with measures to increase efficiency. Beyond electricity, coastal zone management was encouraged to increase resilience to climate hazards. Funding for tourism and transport was developed to provide assistance in upgrading products and emphasizing 'heritage tourism'. Social protection is targeted with loans for supporting continuing education and training programs, with the goal of reducing the country's poverty rate and unemployment. Additional loans focus on supporting gender mainstreaming (de la Hoz et al., 2019). All told, as of 2020 a total of 261 million in loans is currently active in Barbados, focusing on these priority areas.

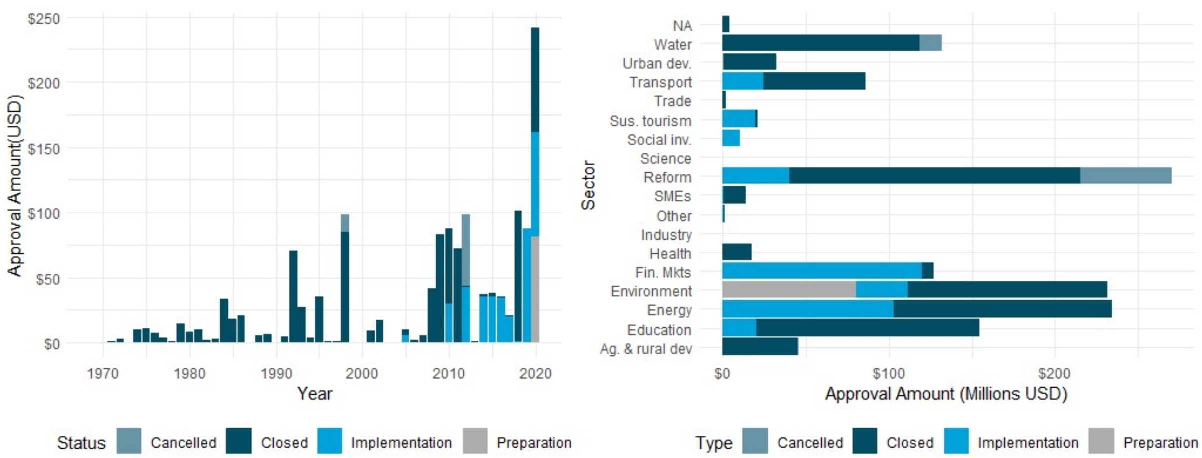


Figure 3. Yearly IDB loan amounts (left panel) and total loan amounts by sector or activity (right panel) (Inter-American Development Bank, 2020).

The current country strategy focuses on three priorities, (i) fiscal sustainability, (ii) social outcomes and (iii) increasing productivity and competitiveness (de la Hoz et al., 2019). In the first area, the strategy emphasizes increasing public sector efficiency, improving tax collection and improving management in the public sector. In safeguarding social outcomes, IDB aims to support eradication of extreme poverty and develop human capital with loans to support efficient provision of public services, as well as continuing support for work experience programs and education etc. In terms of improving productivity and competitiveness, IDB highlights the need for improvements in regulation to increase transparency and promote innovation, improve access to private finance, and work towards a long term (2030) target of carbon neutrality.

Given the country's evidenced economic instability, coupled with the current and likely (due to climate change) rising disaster risk as discussed in the following section, resilience against climate change and disaster risk is an important cross-cutting agenda to ensuring the stability of Barbados' economy in the anticipated COVID-19 recovery period. Against this backdrop, IDB has extended $80 million contingent loan for disaster emergencies in October 2020. [1]

[1] https://www.iadb.org/en/news/barbados-strengthen-its-risk-management-natural-disasters-and-climate-emergencies

DRR and CCA Policy and Programs in Barbados

To address the country's high exposure to cyclones and other risks posed by climate change, the government of Barbados has implemented several measures to strengthen its Disaster Risk Management and Climate Change Adaptation (DRM and CCA) institutional architecture. Barbados' DRM and CCA policies are guided by international, regional and national frameworks including but not limited to Paris Agreement under the United Nations Framework Convention for Climate Change (UNFCCC), the 2030 Agenda for Sustainable Development, Sendai Framework for Disaster Risk Reduction 2015-2030 at the global level; the Caribbean Disaster Emergency Management Agency agreements and its Comprehensive Disaster Management (CDM) framework[2] at the regional level; and the Emergency Management Act of 2006 at the national level. Barbados' Department of Emergency Management (DEM) is the focal agency for the country's DRR efforts, where the DEM has identified the following concerns as the main focus of its 2019-2023 Strategic Plan: (i) the deficiencies of the legislative and regulatory framework, (ii) human resource limitations, (iii) financial and budgetary constraints, (iv) a low organizational profile of the DEM, (v) internal and external communication limitations, (vi) lack of cohesion within the NEMS and (vii) insufficient technological resources.

In recent years, Barbados has taken a number of steps to strengthen its DRM and CCA management capacities, including but not limited to:

- introducing a Coastal Risk Assessment and Management Programme, in operation since 2011, covering aspects of coastal risk assessment, monitoring and management, development of coastal infrastructure and strengthening of institutional sustainability for integrated coastal zone management.[3]
- Establishment of a National Building Code, which serves as a guideline for the construction of structurally sound building stocks in the country, yet its full implementation as a legally binding code remains a challenge[4];
- Reform of the Community Emergency Management Programme, implemented by the Ministry of Home Affairs, encouraging greater engagement of civil society organisations;[5]
- Investment in fiscal preparedness against disasters, including contingent credit loans and catastrophe insurance purchase.

Barbados has been a member of the Caribbean Catastrophe Risk Insurance Facility Segregated Portfolio Company (CCRIF) since its creation. The CCRIF insures government risk and was created with the aim of limiting the financial impacts of hurricanes and earthquakes on Caribbean states, focusing on providing short-term liquidity rapidly after an event occurs (PreventionWeb, 2020). CCRIF does not pay out based on realized losses, but is parametric, providing funding regardless of loss as long as conditions (e.g., an event of a certain size or duration) are met. Through CCRIF, Barbados has received just over $11.5 million since its creation in 2007 (ECLAC, 2019).

[2] https://www.cdema.org/what_is_CDM.pdf
[3] http://www.coastal.gov.bb/content/coastal-risk-assessment-and-management-programme
[4] https://barbadostoday.bb/2019/09/07/call-for-mandatory-building-codes/
[5] https://info.undp.org/docs/pdc/Documents/R46/Barbados_HFA_Report_Jan2013.pdf

Hazard background

Being a small island developing state in the Caribbean, Barbados is subject to multiple hazards, key among them being hurricane-driven wind and storm surge. While earthquake hazard is prevalent as well, the majority of losses (77% of average annual losses) are due to wind and storm surge (UNISDR, 2015).

While the island is on the south-eastern border of the Caribbean and does not lie directly in the path of most tropical storms, it does sit at the southern edge for such storm tracks. The EM-DAT disaster database has records of eight severe tropical storms since 1980 which led to damages in the range of $107 million in total, but this small sample size may belie the underlying risk (EM-DAT, CRED, 2020). As seen in Figure 4, Barbados lies within the typical path of such storms, and given its small size and relatively flat topography (with its highest point of around 350 meters above sea level), it is highly exposed to wind and storm surge-caused flooding.

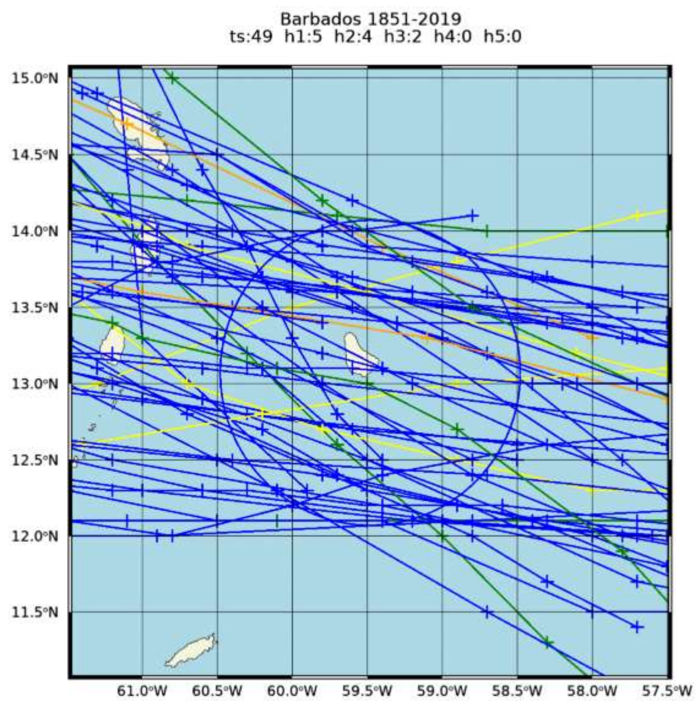


Figure 4. Tropical storm and hurricane tracks near Barbados for the period 1851-2019. According to historic data from the period, 64 tropical storms or hurricanes have passed within 100 kilometres of the island (Caribbean Hurricane Network, 2019).

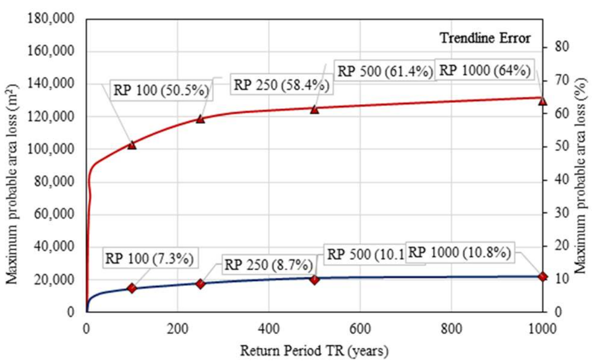
Even without a direct hit from a hurricane or tropical storm, passing systems can cause significant damage. Extreme rain can cause flooding to the west and south of the country, which is home to a quarter of the population (The World Bank, 2020b). This rain could be either extreme-storm-driven or by the rainfall in the rainy season, which can lead to flash flooding, capable of collapsing roads and buildings, and disrupting provision of essential services and access to water. Storm surge due to the storm can cause additional flooding in low-lying areas, damaging coasts and infrastructure vital to tourism revenues (Evanson, 2014).
In terms of the monetary impacts of such storms, the 2015 Global Assessment Report (GAR) from UNISDR estimates annual averages losses from wind and storm surge to be $35.5 and $45.3 million, respectively. As a

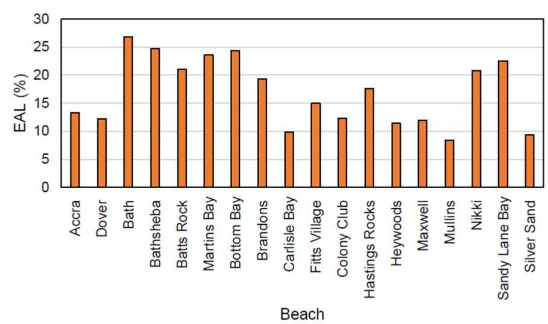
percentage of gross fixed capital formation, this translates to 4.6 and 5.8 percent (UNISDR, 2015). Wind damage from an event with a return period of 250 years would be estimated to cause losses totalling more than 80% of gross fixed capital formation (UNISDR, 2013).

Box 2: Beach Erosion Risk Estimate

The technical study titled *Disaster Risk Reduction Investment Profile Beach Erosion Risk Model for Barbados* prepared by ITEC and IDB estimated coastal hazard risk arising from both rapid and slow-onset events including: (i) hurricane-induced storm surge, (ii) chronic erosion, and (iii) additional erosion anticipated due to climate change. The country's coastline – stretching across 97 km – has been analysed, of which 33 km (or 659 beach segments) were found to be at risk of damage due to the above three hazards. As beach segments contribute significantly to the country's tourism sector, any damage to beach segments leads to considerable declines in visitor spending.

Evaluating the effectiveness of coastal risk reduction options including ecologically enhanced hard solutions (breakwaters, groynes, revetments, sidewalks) and/or nature-based solution options such as artificial coral reefs - with an estimated total investment cost of $115.5 million over 30 years - their study finds that risks posed to coastal areas under climate change may be significantly reduced from the original level of annual average physical damage estimated at 23,780 sqm of beach prior to DRR investment to annual average physical damage of 2,624 sqm after DRR investment.





While the GAR 2015 estimates show that the average annual losses only represent around 0.7% to 0.9% of 2018 GDP (0.25% and 0.32% damage to capital stock from wind and storm surge respectively), averages may lead to downplaying of extreme event risks (UNISDR, 2015). A 100-year storm surge event is predicted to cause damages in excess of $1.48 billion, representing over 7.5% of total capital stock in the country (FRED, 2020).

Increasing hazards due to climate change

Small island developing states like Barbados are particularly vulnerable to a changing climate, due to frequently high population densities in congested urban areas and coastal zones and flood-prone areas (Chmutina and Bosher, 2014). Adding to this is broad agreement in scientific literature that tropical cyclone intensity is likely to increase in the future due to anthropogenic climate change, particularly in the Caribbean (Sobel et al., 2016). Even if the world meets the 1.5- or 2-degree goals of the Paris Agreement, the likelihood of extreme rainfall due to hurricanes is likely to increase, although less so in a 1.5-degree world (Vosper et al., 2020).

Beyond increasing the strength of hurricanes, the Caribbean could see decreased rainy season length (and corresponding increase of dry season length), increasing frequency of intense rain, and sea level rise between 30-50 cm by 2080 (Pulwarty et al., 2010).

In its second National Communication under the UNFCCC, Barbados emphasized these hazards and highlighted the increasing potential impacts on:

- Health: due to increased water stress
- Tourism: via damage to infrastructure due to storm surge and winds
- Fisheries and agriculture: due to drought, flooding, saltwater intrusion, and ecosystem loss
- Financial risk and insurance (Government of Barbados, 2018)

Climate change may also lead to the increasing importance of new hazards. Temperatures are expected to increase (between 0.4 to 2.1 degrees Celsius by mid-century) and rainfall is expected to decrease, varying based on the model projection but ranging between an ensemble median of -7 to -18% less precipitation. While Barbados is currently a water-stressed country, drought has been less at the forefront compared to storm damage, but there are concerns that due to dwindling rainy seasons, water stress could increase, as well as due to saltwater intrusion into freshwater supplies due to either slow-onset sea level rise, or storm-surge-caused flooding (The World Bank, 2020b).

Climate change may also lead to changes on the demand side. As Barbados is heavily reliant on tourism, climate policy which discourages emissions from e.g., air transport, or a shifting global collective understanding about personal carbon footprints could lead to reduced tourism demand. On the supply side, tourism could face increased costs of operation due to more energy use for cooling as well as increasing insurance premiums for coastal zone properties at risk of storms and sea level rise (Cashman et al., 2012).

The following sections focuses on these important interlinkages between coastal hazards (storm surge and an increase in beach erosion risk due to climate change) as identified in (ITEC/IDB (2020) shown in box 2) and quantify the overall macroeconomic benefit of coastal risk reduction.

More specifically, the policy question being addressed are:

- *How much public investment is needed to achieve a desired level of disaster risk reduction against coastal hazard risk (storm surge and an increase in beach erosion risk due to climate change)?*
- *What is an optimal mix of public resource allocation between disaster risk reduction investment and risk retention/transfer instruments?*
- *What is an optimal public resource allocation between DRM policy instruments and other productive investments that balances the need for national development and resilience building?*

Application of the DYNAMMICs model to Barbados

To answer the above policy questions, this project developed and implemented the Dynamic Model of Multi-hazard Mitigation Co-benefits (DYNAMMICs) framework. The DYNAMMICs model allows for estimation for the long-run benefits of DRR investment in terms of economic growth (GDP). While an in-depth description of the model formulation is supplied in the Technical Report, we here provide a conceptual overview of the model, followed by a focus on the necessary assumptions and calibration of model parameters to the country case of Barbados.

Conceptual model description

As noted in the Technical Report, recent literature in the DRR field has come to understand the benefits of DRR investment as operating on multiple pathways; DYNAMMICs is designed to explicitly account for three significant benefits or dividends of DRR. The first dividend to arise from DRR is the most obvious; the avoidance or reduction of direct impacts, in terms of loss of life, property, agriculture, etc. Beyond this, DRR measures can also lead to enhanced economic potential, in terms of e.g., providing a social safety net which allows individuals or firms to invest in higher cost – but higher yielding – endeavours, due to the reduction of risk to said investment. Finally, the third dividend of DRR is focused on co-benefits, in that DRR investment can have multiple aims, e.g., a hydroelectric dam to mitigate flood risk, provide power and water access to a community. DYNAMMICs disentangles these three dividends and quantifies their effects over a long term, at a national level.

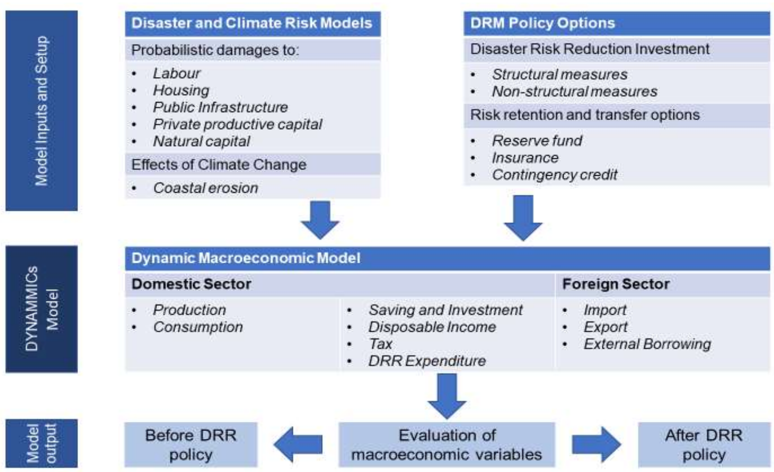


Figure 5: Macroeconomic Framework
Source: The Authors.

At the simplest level, the model uses input data in the form of probabilistic damage estimates to various parts of an economy (i.e. private dwellings, public infrastructure, labour, private capital and natural capital), combined with policy options that specify e.g. levels of disaster risk reduction investment, or risk transfer options such as insurance, and uses a macroeconomic model calibrated to national accounts data to produce an evaluation of the potential country growth paths before/after and with/without DRR policy interventions.

DYNAMMICs integrates biophysical and macroeconomic modelling as such falls within the category of 'integrated assessment models' such as the Dynamic Integrated Climate-Economy (DICE) model developed by the Nobel Laureate Dr. William Nordhaus. The DYNAMMCIS is built on an underlying Real Business Cycle (RBC) model framing. Since the mid 1980's, RBC models have become widely used in terms of assessing the impacts of potential policies and studying optimal policy levels. RBC models traditionally have been used to assess the impacts technological change, but have found wider applicability; initially focused on the economic fluctuations caused by a technological shock, it has been adapted here to alternatively examine the impacts of disaster shocks – and the impacts of DRR investment policies – on national accounts and long-term country growth. In the vein of RBC and other theoretically focused macroeconomic models, DNYAMMICs is a *dynamic* (in that it represents a system which changes over time) model which uses microeconomic foundations, specifically the concept of rational representative agents, to simulate how a disaster affects investment, savings and consumption of such agents.

In the setup used for this analysis, the model depicts an open economy (one where international trade can occur) with a representative agent representing households, two business sectors – traded and non-traded goods – and two regions, coast and inland areas, which area differentiated as the hazard risk each region faces differs considerably. The two goods represented are used as intermediate input of production, as well as fulfilling investment and consumption. The differentiation between traded and non-traded pertains to the ability to export the good; non-traded goods are used to represent e.g., the tourism sector, and as such cannot be exported, but can be demanded by foreign visitors. The model incudes a government, which acts to implement taxes and obtain loans, as well as provide transfers to households in terms of providing public spending for infrastructure development either for production or risk reduction.

As the model is dynamic, technology and changing population needs to be accounted for. At any period, firms can use either a traded or non-traded good, plus some combination of labour, capital, and natural resources, to produce output, via a Leontief production function, indicating that factors are not substitutable and must be used in a fixed proportion to one another. However, the natural resource component is made up of land, natural assets, and infrastructure for production, which is obtained from two areas (either coastal or inland areas). Technological progress is incorporated via use of Harrod-neutral technical progress, which increases labour efficiency. In terms of the supply of that labour, it is assumed that the population grows at a fixed growth rate.

Given the above, the DYNAMMICs model determines an economy's resource allocation by solving a dynamic optimization problem of the representative agent (households). Households, which are risk averse, perfectly rational, and have infinite lifespans and perfect information regarding disaster risks, gain utility by consuming traded or non-traded goods and household assets and try to maximize their expected lifetime utility. As households are risk averse and have knowledge about disaster risk, the model allows for them to change behaviour in response by e.g., changing levels of their consumption, investment, or savings.

Up to this point, the model description is not unique in the sense of incorporating disaster shocks and resembles other similar dynamic equilibrium models. DYNAMMICs incorporates exogenous shocks in the form of natural disasters, in Barbados these disasters arrive in the form of tropical storms. At every time step, a random variable determines the occurrence (and if so, the size) of a cyclone impacting the country. Such impacts can be felt in several ways. Coastal flood, storm surge and/or high winds can lead to loss of public infrastructure or private capital, particularly related to non-tradeable (e.g., tourism) goods, land, and labour. Flooding can also affect the stock of housing, which impacts household's utility function and maximization.

We now have the components of a model which can assess the long-term growth paths of a country with a given disaster risk profile. By comparing a benchmark scenario with no DRR policies to a set of model results where such a policy is introduced, we can identify the dividends of DRR investment. Policies can include e.g., hazard mitigation, where a percentage of the country's GDP is allocated to creating DRR stock, or risk financing, where such a proportion of GDP instead goes to risk financing instruments such as insurance or contingent credit, or a combination of the two policy options.

Model outputs

By comparing the results of a number of model simulations (known as Monte Carlo simulation) differences in trends between benchmark and policy scenarios can be identified. The difference between the average growth path seen in a benchmark versus a DRR investment scenario is the *Total Growth Effect* (TGE) of DRR investment. DYNAMMICs further decomposes this modelled TGE into the different quantities, which correspond to three identified dividends of DRR investment mentioned at the beginning of this section:

- **The Ex-Post Damage Mitigation Effect (PDME)** which depicts the difference in size of a disaster impact to the macroeconomy in the benchmark compared to the DRR policy scenario, is representative of the first DRR dividend of avoiding direct impacts.
- **The Ex-Ante Risk Reduction Effect (ARRE)** indicates the level to which DRR investment encourages other productive investment and thus increases GDP, by reducing hazard risk thus allowing for shifting investment to more productive pathways. This clearly represents the second DRR dividend.
- **The Co-benefit Production Expansion Effect (CPEE)** as output by the model indicates the improvement to GDP resulting from the co-benefits produced due to DRR investment, corresponding to the third DRR dividend.

  Disaster Risk Reduction Effect (DRRE) is additionally output by the model and represents a combination of both the PDME and ARRE components of TGE.

In order to apply the DYNAMMICs framework to the case of Barbados, significant effort must first be devoted to calibration of the necessary input data, both in terms of national account data and hazard occurrence. As the Barbados government does not publish national-level input-output data explaining inter-industry linkages across sectors and contribution of capital, land and other inputs for the country's production activities, estimates of such have been derived using the Barbados IO table for 2015 as estimated by the Eora Global MRIO[6]. This section provides an overview of the key parameters and assumptions used as input for the modelling, beginning with macroeconomic parameters, followed by hazard assumptions, and concluding with details of the policy scenarios implemented in the model.

[6] https://www.worldmrio.com/

Macroeconomic parameters

As mentioned, the model depicts an economy with two sectors (here, traded and non-traded goods) and two regions (inland and coastal). As IO tables are made up of more conventional sectoral delineations (e.g. agriculture, construction, services, manufacturing sectors, etc.) the conventional IO table obtained from Eora was first aggregated into a two-sector representation. The Eora sectors making up the traded and non-traded goods sectors can be found in *Table 1* below.

Table 1. Sectoral aggregation from Eora MRIO to two-sector IO table used in the DYNAMMICs model.

Traded-good (T) sector	**Non-Traded good (N) sector**
Agriculture	Construction
Fishing	Hotels and Restaurants
Mining and Quarrying	Transport
Food & Beverages	Post and Telecommunications
Textiles and Wearing Apparel	Financial Intermediation and Business Activities
Wood and Paper	Public Administration
Petroleum, Chemical and Non-Metallic Mineral Products	Education, Health and Other Services
Metal Products	Private Households
Electrical and Machinery	
Transport Equipment	
Other Manufacturing	
Re-export & Re-import	
Recycling	
Electricity, Gas and Water	
Maintenance and Repair	
Wholesale Trade	
Retail Trade	
Others	

The resulting IO table consisting of two sectors can be found in Table A1A1 in the appendix. This table is a basis for generating the production functions of the T and N sectors as well as households' and tourists' utility functions, etc., but as the model is multiregional – consisting of coastal and inland areas – further disaggregation is needed.

To order to calculate allocation of value added for T and N sectors into e.g. payment to labor and capital, land, natural assets, and infrastructure rents (both inland and coastal), GDP by sector and area is necessary. This is accomplished by deriving the shares of GDP resulting from tourism and non-tourism activity for the T and N sectors in inland and coastal areas. The shares of tourism and non-tourism activities of total GDP is assumed to be 21.6% and 78.4% respectively, adapted from BTI (2020). Given the estimate from BSS (2016) that coastal areas make up 80% of total tourism GDP contributions[7], the resulting GDP by area and sector can be found in *Table 2*.

This disaggregation of GDP, combined with the assumptions found in Table A2 and TableA3 in the appendix, which describe the allocation of e.g. wages and salaries, consumption of fixed capital, other net taxes on production etc., allow for calculating the allocation of value added of the T and N sectors to payments of labor

[7] Derivation of GDP by area contains the additional assumptions that non-tourism production in coastal areas includes 100% of fishing sector production, 1% of agriculture, 1% of re-export and re-import, 1% of wholesale trade, and 1% of retail trade.

and capital, land rents, natural asset rents, and infrastructure rents, which are used as inputs into sectoral production functions.

Table 2. GDP (2015, $ billion unless otherwise noted) by area and sector.

Sector	T	N	Total	Share
Inland area	1.012	2.085	3.097	81.3%
Coastal area	0.053	0.658	0.711	18.7%
Total	**1.065**	**2.743**	**3.808**	**100%**

Beyond calibration of production functions and household / tourist utility functions made possible by the IO table and assumptions described above, the final major input necessary is an estimate of the sizes of initial asset stocks, such as capital, housing, government assets, land, natural capital, and DRR stocks, broken down between inland and coastal areas. The values – and underlying assumptions – for these stocks can be found in *Table 3*.

Table 3. Initial values and underlying assumptions and calculations for asset stocks[8] used in the model. All values in $ billion unless otherwise indicated.

Asset	Assumption	Result (Inland)	Result (Coastal)	References
Capital stock (K)	Total country K ($ 21.14 bn) is divided based on regional share of value added	17.19	3.94	Total country K from Penn World Tables (Feenstra et al. 2015)
Land (L)	Calculated present value of rent, given an interest rate of 4%, and calculation of value added of land rent as described in text.	6.98	1.61	Calculated based on IO table-derived value added
Natural capital (N)	Similar to Land above, based on the present value of rent	6.98	1.61	Calculated based on IO table-derived value added
DRR assets (D)	Coastal asset stock based on assumed yearly investment in DRR stock of $ 3 million, divided by a 4% interest rate plus 0.5% depreciation rate. For inland area, the estimated stock size is the coastal area multiplied by the ratio of inland to coastal value-added share.	0.29	0.07	Estimated based on the recent coastal resilience investment in Barbados as reported in the ITEC/IDB (2020)

The table above provides the majority of the necessary parameters to calibrate production functions and utility functions of households and tourists. Further remaining inputs relate to government debt and foreign assets,

[8] For housing stock (H) and government (G) assets, data for Barbados was unavailable. For calibration of these asset sizes for inland and coastal regions, calculations were based on relationships commonly observed in similar developed island economies. For housing stock, estimates are based on the ratio of total housing assets to GDP (3.2, derived from van Onselen, 2010), with an inland H stock of 12.18, and coastal of $ 0.01 billion. For G infrastructure, calculation is based on the ratio of production infrastructure to GDP of 1.415 (again commonly observed in similar economies) and divided into regions based on the share of value added, for a resulting inland G stock of 4.38 and coastal of $ 1.01 billion.

needed to calibrate household and government bond holding. Government net debt in 2015 is calculated at $ 5.55 billion, based on a net debt to GDP ratio of 1.458 (Deyal et al. 2019). Net foreign assets in 2015 are estimated as $ 1.02 billion (IndexMundi 2019).

The above inputs and parameters can thus be used to calibrate e.g. utility functions of representative households in the dynamic optimization model. Households aim to maximize their utility, which they receive by consuming traded goods (both foreign and domestic), non-traded goods and household assets. The exact single-period utility function is described briefly below, to aid in description of the calibration of values such as degree of risk aversion. For a full explanation of households' utility function, see the Technical Report from March 2021. Household's utility is defined as:

$$U = \frac{A}{1-\theta}\left\{\left(\tilde{q}_{TT}(t)^{\gamma_{TT}}\tilde{q}_N(t)^{\gamma_N}\right)^{1-\theta} + \chi_H \tilde{h}(t)^{1-\theta}\right\} + Au_0 \cdot P_b\left(\tilde{b}_H, \tilde{b}_G, t\right)$$

where the bracketed portion of the equation (of greatest interest in terms of calibration) defines the household's consumption of a traded good composite (T-sector goods either from abroad or domestically sourced, here indicated as $\tilde{q}_{TT}(t)$) non-traded (N-sector) goods (here indicated as $\tilde{q}_N$) and household assets ($\tilde{h}(t)$); all consumed in time period t. The parameter θ represents the degree of relative risk aversion, and for the Barbados case, is assumed to be 2. γ_{TT} and γ_N are the share parameters of the sub-utility of non-durable goods, calibrated as 0.26 and 0.74 (respectively). The final requirement for calibrating consumption of households is χ_H, which represents the relative strength of the preference for household assets over non-durable goods, here approximated to be 18.6. The remainder of the utility function is defined by $P_b\left(\tilde{b}_H, \tilde{b}_G, t\right)$, which penalizes households for holding too large debts represented by household ($\tilde{b}_H$) and government ($\tilde{b}_G$) bonds. Initial household assets are calibrated from the two-factor IO table to be $ 12.2 billion; household bonds are estimated as $ 6.6 billion, and government bond at $ -5.5 billion.

Hazard and DRR assumptions

Beyond macroeconomic data to calibrate the model's production and utility functions, assumptions on the incidence of hazard and the capability and effectiveness of DRR are required. The hazard can be broken down into damage due to hurricane, with the addition of impacts due to slow-onset erosion, which are calculated as follows.

The function describing coastal damage due to hurricanes is based on ITEC/IDB (2020) and UNISDR (2015). For the capital categories of coastal land and natural capital, an average annual loss (AAL) of 24% is assumed, based on ITEC/IDB (2020). For all other capital assets (K, H, G, D), the AAL was obtained from estimates in UNISDR (2015), for both inland and coastal areas, of 0.011%. The introduction of disaster risk reduction investment correspondingly reduces the expected AAL. Based on estimates in ITEC/IDB (2020), the loss of land and natural capital due to hurricane is reduced from 24% to 2% after DRR investment. This reduction is carried over and applied to the GAR estimates for other asset classes, leading to an AAL for inland and coastal capital assets (besides land and natural capital) of 0.00347%.

These AAL estimates described above are used to derive estimates of damages for each asset class using an exponential damage rate function. As described in the Technical Report from March 2021, the calculations for damage rates are generalized as follows:

$$\omega_{Jl\phi} = \Omega_{Jl\phi}\left(\{D_\iota, Z_\iota, N_\iota\}_{\iota=I,C}, J_l^-\right)$$

where $\omega_{Jl\phi}$ represents the damage for each asset type J (consisting of production capital (K), infrastructure (G), household assets (H), land area (Z) natural assets (N) and labor (L)). l indicates location (either coastal or inland), and ϕ the scale of a disaster. Thus impacts are disaggregated by asset type, location and are dependent on disaster size. Damages are additionally a function ($\Omega_{Jl\phi}$) of DRR structural measures (D_ι), land areas (Z_ι) and natural assets (N_ι) – i.e. nature-based solutions, and the initial value of asset stock J in location l.

For application to Barbados, an exponential damage rate is defined, based on a number of regressions. The resulting damage equation is specified as:

$$\omega_{Jl\phi} = \Omega_{J\iota\phi 0} + \Omega_{J\iota\phi 0} \cdot exp\left\{-\frac{\Omega_{J\iota\phi 1} D_{II}{}^{\nu_{DIIJ\iota\phi}} D_{CC}{}^{\nu_{DCCJ\iota\phi}} (ALZ_{CC}^-)^{\nu_{ZCCJ}} \quad (ALN_{CC}^-)^{\nu_{NCCJ\iota\phi}}}{A(t)L(t)\tilde{J}_\iota^-(0)}\right\}$$

which incorporates labor (L) and technological change (A) changing over time (t). The parameters $\Omega_{J\iota\phi 00}$, $\Omega_{J\iota\phi 0}$, $\Omega_{J\iota\phi 1}$, $\nu_{DCCJ\iota\phi}$, $\nu_{ZCCJ\iota\phi}$, $\nu_{NCCJ\iota\phi}$ are estimated by a series of multiple linear regressions to calibrate the damage function to the Barbados country case.

Given the above-derived damage rate functions, the model can assess the projected impacts of a disaster event on Barbados, but for scenarios incorporating risk financing, a final set of inputs is required regarding sources of disaster recovery funding. Figure 6 below depicts how disaster risk financing is addressed via a risk layering scheme.

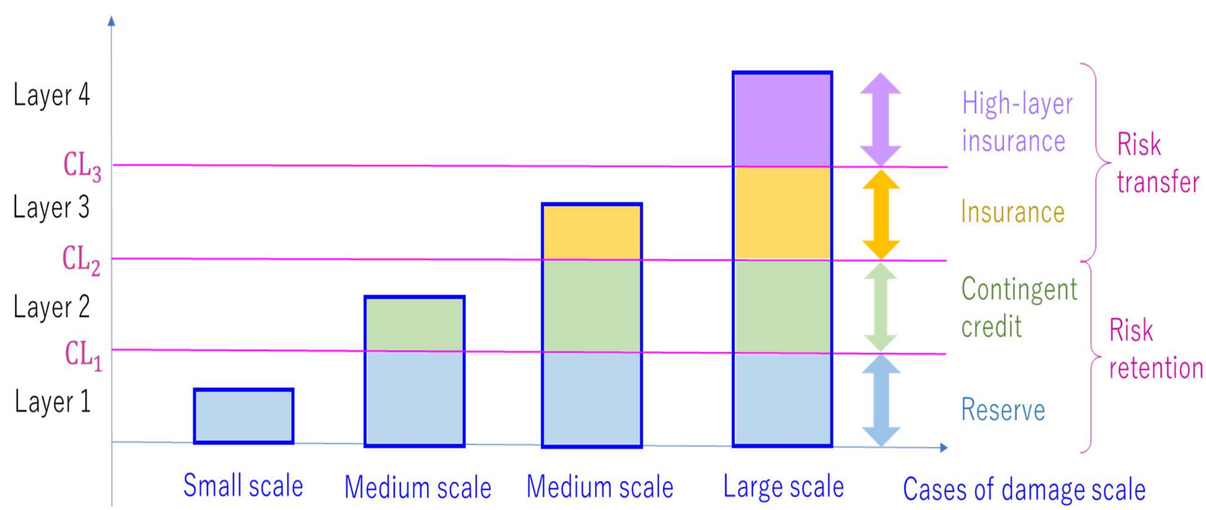


Figure 6. The risk-layering approach taken in the DYNAMMICs modelling framework. Based on the scale of a disaster's impact, post-event financing is provided by one or a combination of sources.

For small, relatively frequent events, it is assumed that recovery will be financed via a country's reserve funds. However, events which cause damages exceeding a threshold (here depicted as a ceiling CL_1), will exhaust this reserve fund and must be financed via a contingent credit mechanism. Larger events may also exhaust that option, leading to residual losses being financed through insurance. Finally, extreme losses will exhaust all previous options, and require the assistance of a high-risk layer insurance.

In this work, the layer ceilings are defined as follows. Reserves are assumed to be able to cover losses up to 6% of base year GDP; contingent credit adds another 3% coverage, for a total of 9%, with insurance adding a further 3%, with any losses greater than 12% of base year GDP being covered by a high-risk layer insurance mechanism. These values apply to the base year, and are assumed to rise over time, in baseline cases growing at 2.0% per year.

Policy scenario implementation

The final model application compares the growth of Barbados' economy in terms of gross domestic product and other key figures in a reference case using only currently implemented DRR measures to several target policies. The three main options considered for target policies are: mitigation measures only, financial instruments only, a combination of both and a combination with additional infrastructure investment. Augmented versions of the policies are assessed in addition. The augmented policies include other types of infrastructure investments and sensitivity analysis of the mix of mitigation measures and financial instruments. The final number of assessed policies in this report thus includes five policy pathways with two additional sensitivity analysis pathways. As discussed in the detailed model description, the structure of the macroeconomic model allows for disaggregation of the growth effect of these measures into several components and can capture indirect benefits not commonly part of standard economic evaluations of DRR measures.

The reference policy pathway is derived from ITEC/IDB (2020) and assumes a consistent investment in coastal area management. Given the estimated investment of \$ 115 million over 30 years from ITEC/IDB (2020), yearly investment is assumed to be 0.13% of 2015 GDP, or \$ 4.918 million (given a 4% compound interest rate). This portion of GDP is invested into coastal land assets (e.g. construction of off-shore breakwaters, seawalls, revetments, and groynes). The 0.13% of GDP is further divided in the model into fixed investment (0.10% of GDP) and recovery investment (0.06%) for a hurricane of probability 0.5 (thus totalling 0.13%).

The model implements five policy pathways and two additional sensitivity checks described in tables 4 and 5. They all include additional investments of \$ 318 million which represent an increase of yearly investment of 200% as compared to the reference policy evaluated in the model. Table 4 below provides an overview of the possible policies, while table 5 lays out the allocation of budget in detail.

In order to implement the above scenario pathways, the total investment costs must be converted first into its present value over project duration, then to annualised cost. The total budget allocated to any of the policies is derived from ITEC-IDB (2020). It amounts to an addition of \$ 318 million to the reference policy's \$ 155 million over the total time horizon of 30 years. Reference policy spending is equivalent to \$ 4.918 million per year assuming a compound interest rate of 4%. In relation to economic output this budget corresponds to 0.13% of yearly GDP in base year 2015. The base year 2015 is assumed in the subsequent analysis due to data availability. It is the last year for which Input-Output tables are available. In table 5 below the allocation of yearly budget across policies and the realization of payments dependent on hurricane arrival as well as the difference to the reference policy are summarized as percentages of yearly GDP.

Table 4. DRM Policy Pathways evaluated in this study.

DRR policy	**Hazard mitigation only policy** - where funds equivalent to 0.13% of GDP of the reference policy are increased by 0.36% of GDP and allocated for additional beach erosion mitigation and construction of DRR facilities in coastal areas over 30 years.
DRR+DI policy	**Hazard mitigation policy beach plus inland –** corresponds to DRR policy with an additional investment of 0.10% to DRR in inland areas.
DRR+INFRA policy	**Hazard mitigation policy with infrastructure investment** – which corresponds to DRR policy above with additional 1%-investment in infrastructure for production
FIN policy	**Risk financing only policy** – where the additional resource equivalent to 0.36% of GDP will be allocated to layer-based risk financing instruments (reserve, contingency credit and sovereign insurance) over 30 years. Yearly shares vary depending on onset of disaster.
INT policy	**Combined DRR and risk financing policy**- where the 0.36%-GDP resource allocation will be equally split into DRR and risk financing options over 30 years.
INT policy-SA1	INT policy with 75% DRR policy, 25% FIN policy split for sensitivity analysis (SA)
INT policy-SA2	INT policy with 25% DRR policy, 75% FIN policy split for sensitivity analysis (SA)

Note that all policy options including the reference option already include investment in beach erosion mitigation. Without these investments and assuming values from the ITEC report, very severe damages would occur in the latter half of the planning period of 30 years due to repeated hurricane occurrence and depreciation. In the reference policy however, there is substantial damage incurred and associated with declining investment and thus declining tourism. Therefore, additional investments as laid out in the target policies here are needed.

Table 5: Investment costs assumed for each policy per year in percentage points of GDP.

	Distribution of investments across instruments				Types of investments across all instruments		Difference
	Investment in beach erosion mitigation	*Investment in DRR stock*	*Financial contracts cost (average over all years)*	*Investment in Infrastructure for production*	*Fixed investment*	*Recovery investment (p=0.5)*	*to reference policy*
Reference policy	0.13%				0.10%	0.06%	±0.00%
DRR policy	0.39%	0.10%			0.30%	0.18%	+0.36%
DRR+DI policy	0.39%	0.10% (coastal) + 0.10% (inland)			0.30%	0.18%	+0.36%
DRR+ INFRA policy	0.39%	0.10%		1.00%	0.30%	0.18%	+1.36%
FIN policy	0.13%		0.36%		0.10%	0.06%	+0.36%
INT policy	0.26%	0.05%	0.18%		0.20%	0.12%	+0.36%
INT policy-SA1	0.325%	0.075%	0.09%		0.25%	0.15%	+0.36%
INT policy-SA2	0.195%	0.025%	0.27%		0.15%	0.09%	+0.36%

Note: The recovery investment is only needed for disaster recovery in years with hurricane arrival which are assumed to occur with a probability of 50% each year

Model results

Using the modelling approach with calibration and selected policies described above the model can be used to assess policies in comparison to a reference case without any of the above policies. The strength of the model is its ability to highlight the advantage of each of the policies over the reference policy which is best represented in a graphical representation of paths of GDP, its growth rates and volatility as well as other key economic variables driving these dynamics.

Economic growth over time under several policy regimes

The economic model as described in the previous sections and in detail in the technical report is first calibrated, then used to produce 1,000 Monte-Carlo simulations of the model outcomes. This technique provides sample paths for all variables and GDP over time which can be summarized in a mean path. Considering the stochastic nature of parts of the model it is important to highlight once more that conclusive inference cannot be drawn from the results of the sample paths. Instead, they serve to illustrate the dynamics within a single simulation run such as the possibility of increasing growth even after hurricane arrival. The former being attributable to hurricanes hitting the island multiple times in consecutive years thus incurring less damage in later years. Figure 6 below illustrates the development of GDP over time in one of the simulations run in the application of the model. The remainder of this section and the graphical representations of results included represent mean paths of all simulation runs. Results are therefore more generalizable since they depend less on the realization of certain variables in the model.

Sample paths in figure 6 show a general growth trend for the Barbadian economy, with minor setbacks. These occur most frequently after the arrival of hurricanes. However, hurricane arrival does not necessarily immediately adversely affect GDP, and in cases where it does, the magnitude of these adverse effects can differ from event to event. These characteristics can be attributed to two factors. On the one hand, the impact of hurricanes is not uniform across time as they differ in their magnitude, timing and location. On the other hand, damages may not only be caused by disasters but also incorporates other important dynamics in the economy. Several conclusions can be drawn from this illustrative example. For all target policy cases, Barbados economy achieves higher growth.

Key messages of sample path analysis:

For a particular sample path selected

- *For all policies including DRR and risk finance, GDP growth paths were higher as compared to the reference case.*
- *DRR-DI01 policy archives highest growth while FIN policy achieves the least benefit.*
- *It is important to keep in mind that the sample path analysis shows only one potential path among many possibilities – and a decisive conclusion cannot be drawn based on one sample path analysis.*

The policy cases with DRR investment in this sample path exhibit higher output in the economy than the case in which the government only invests into financial assets. Additionally, in target policy cases with additional DRR investments, negative impacts of hurricanes on GDP are smaller, mainly as a result of direct DRR effects. In the sample paths for policies which include increased DRR measures, the strong negative impacts of disaster observable in the target policy trajectory towards the end of the simulation time horizon are entirely prevented.

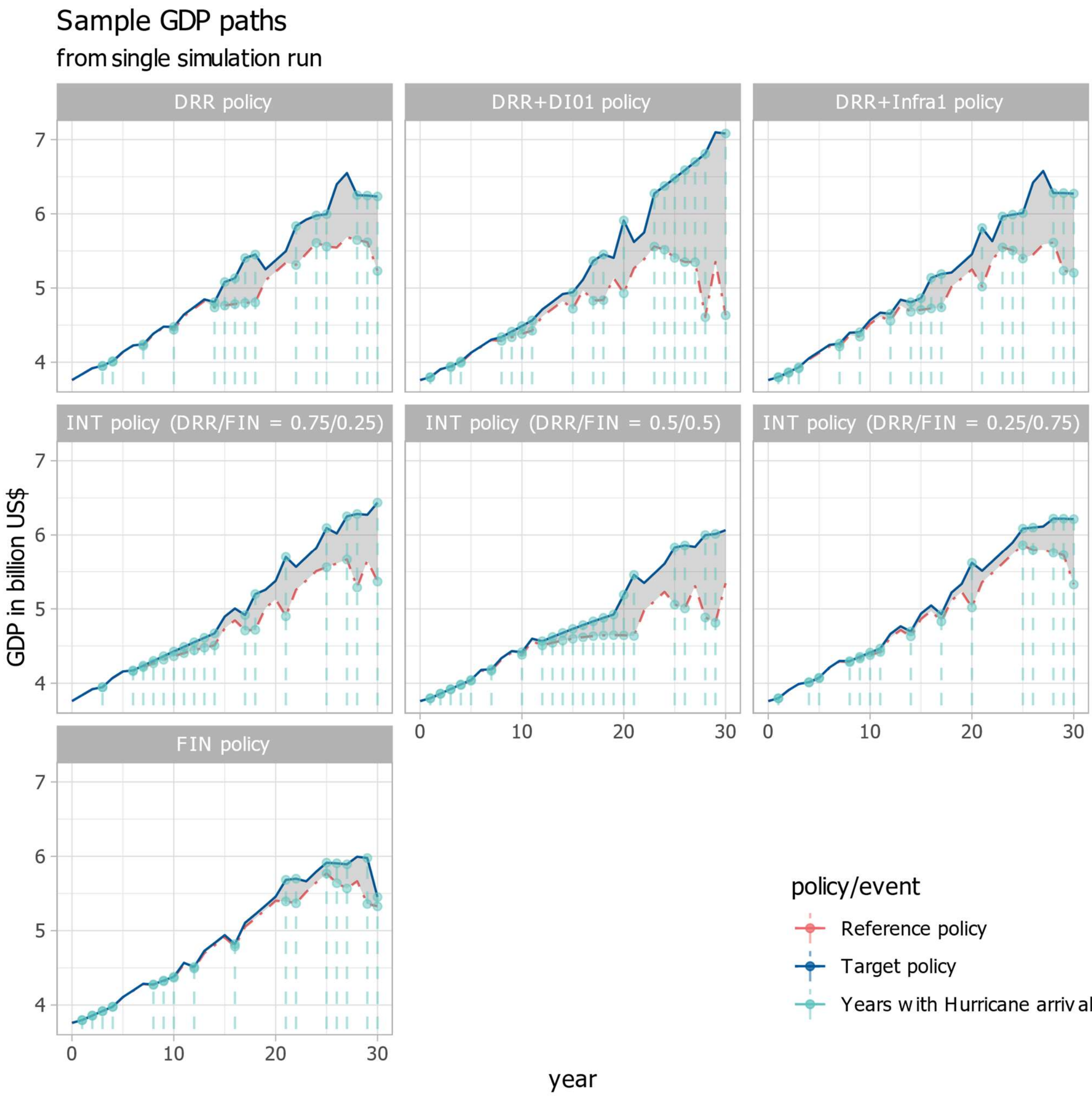


Figure 7: Sample GDP paths from a single simulation run of the DYNAMMICS model showing GDP over time

Furthermore, an increase in GDP growth trajectories are seen even in the absence of disasters. However, it must be emphasized that paths in figure 6 are only results of a single simulation run illustrating one possible trajectory that the Barbadian economy could take. Figure 7 onwards discuss the analysis of all simulated paths which show mean effects of policies.

The key insight and novelty of the model lies in the integration of indirect benefit effects of DRR investment and risk financing options for an economy, thereby fulling accounting for benefits in terms of GDP growth. Total growth effects (TGE) and its decomposition for each policy compared to the reference policy is shown in figure 7. Decomposition of the total growth effect of the evaluated policy packages shows how each of the individual benefits compare to each other in terms of contributions to economic growth.

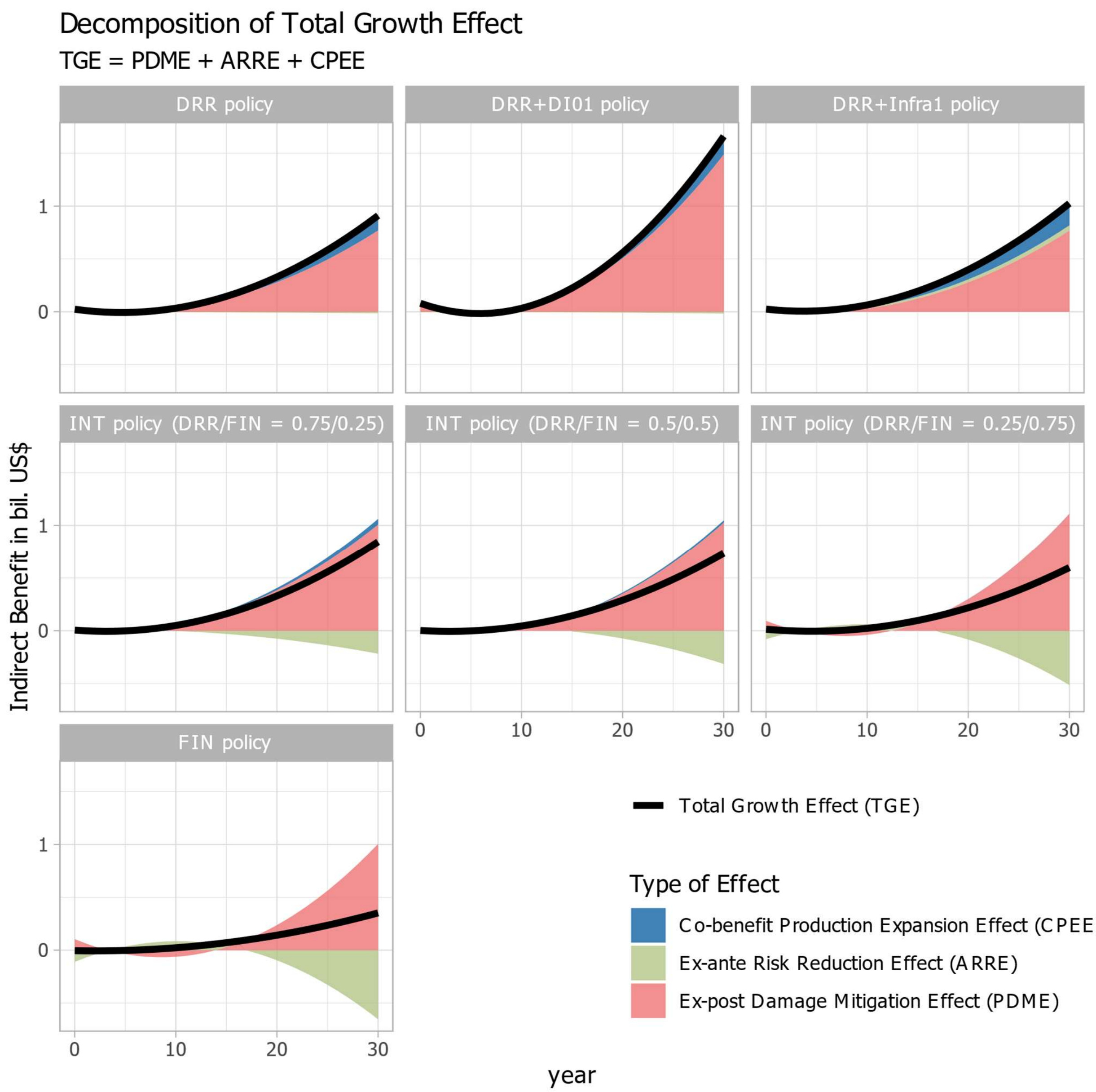


Figure 8: Decomposition of all growth effects obtained by implementing the target policy (benefits in $ billion)

For all policies, the largest share of the total growth effect is generated by the ex-post damage mitigation effect (PDME). However, we see that excluding the other two types of effects in the analysis introduces bias, as assessing the benefits of policy cases reliant mainly on DRR measures (top row of figure 7) using only PDME would underestimate the TGE.

In contrast, for cases including financial contracts, neglecting to account for ex-ante reduction effects (ARRE) would lead to overestimation of the TGE, since high mark-up rates for government insurance in later periods after multiple disaster occurrences introduce a significant negative ARRE. The size of this negative effect grows with the fraction of budget allocated to financial contracts in the target policy. The significantly lower results for growth effects for policies including insurance are mainly attributable to the increasing premiums over time (as premiums would increase when the country files a significant number of claims). In short, the negative ARRE lowers total growth effects for financial instruments. For further information, refer to figure 12 for a graphical representation of the increasing costs of insurance over the model time horizon of 30 years. The figure and subsequent discussion also provide a rationale for possible economic benefits of financial contracts beyond increasing GDP growth rates in levels.

A major result derived from the analysis is that the largest share of TGE occur more than a decade after the implementation of the DRR policy package. However, when they occur, the effects are significant. Comparing policy options against each other, it is evident that those which combine multiple instruments of DRR investment in coastal areas with either (i) additional infrastructure investment or (ii) investment in DRR measures in inland areas yield the highest TGE on average.

The co-benefit production expansion effect only somewhat contributes to additional growth. It has a slightly smaller impact and a later onset than the disaster risk reduction and ex-post damage mitigation effects in the top two panels of Figure 7. Traditional models which do not account for co-benefits often lack this component and hence do not completely capture the economic benefits of DRR. The illustrative example in Figure 7 shows the advancement of the DYNAMMICs framework over previous models and provides support to the hypothesis that there are sizable co-benefit production expansion effects of DRR investments and risk financing.

Key messages of Decomposition analysis:

Taking averages of 1000 samples,

- *DRR+DI01 policy achieves TGE among all scenarios.*
- *Among INT policies, the more funding allocated to DRR the greater TGE.*
- *TGE are dominated by PDME in all cases.*
- *For all cases with financing instruments, negative ARRE offsets positive PDME/CPPE.*

Given modelled total growth effects and GDP levels, GDP growth rate can be calculated. Figure 8 depicts the development of this growth rate over time and on average over the total time horizon of 30 years. The average growth rates over the total time horizon (dashed lines) reaffirm that growth is indeed higher for any target policy pathway, compared to the reference case. Comparing the reference case and target, the yearly GDP growth rate is consistently higher in almost all years. This outweighs the few years in which the target policy yields lower growth rates due to higher costs of implementation and other dynamic factors. In addition, the growth rates observed in the target policy state are steadier over time. This decreased volatility is potentially desirable for policy makers since it eases planning of economic and other policy decisions. Simple graphical analysis provides some evidence for lower volatility of growth rates in the INT policy cases. Intuitively, this can be explained by the diversification of mechanisms to cope with disaster impacts and prevent damage. The diversification can be seen as means of reducing vulnerability to disaster in various dimensions.

The growth rate representation in figure 8 further confirms the differences in average growth rates obtainable by implementing any of the four policy packages. The reference policy yields an average growth rate of GDP of 1.31 percent per year. In contrast all four target policy options significantly increase this average yearly growth rate on the mean of all simulated growth paths. It is 1.87% for the DRR policy, 1.52% for FIN policy, 1.92% for DRR+Infra1 policy, 2.22% for the DRR+DI01 policy and 1.85%, 1.77% and 1.71% for INT policies in the order of appearance in figure 8.

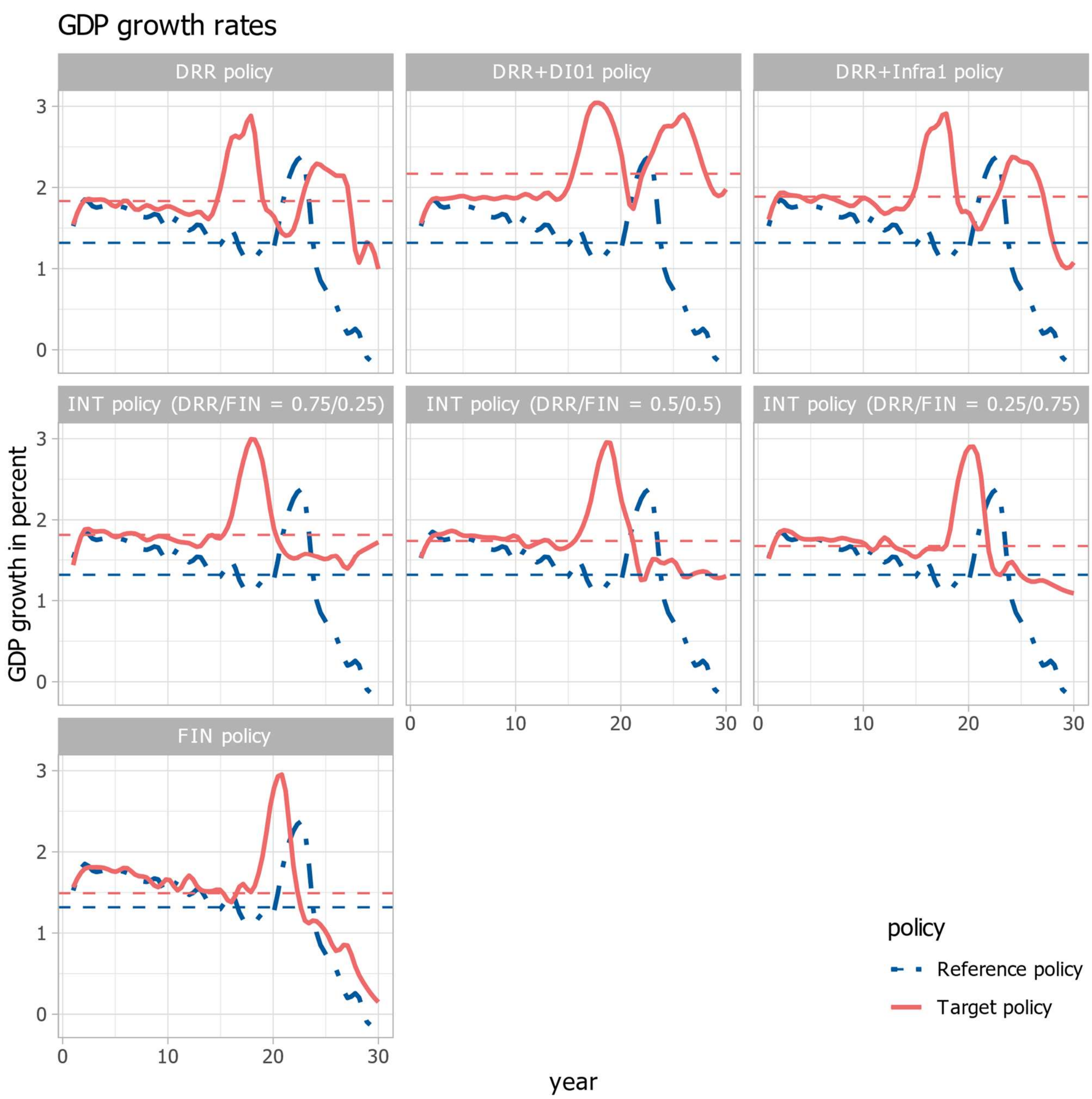


Figure 9: Mean GDP growth rates in percent under target and reference policies. Dashed lines show average growth rates over the total time horizon of 30 years.

Our analysis also finds that one of the factors contributing largely to the growth trajectory and its increase when implementing the DRR measures is the increase in private production capital. Through mitigation of hurricane damages and risk, DRR measures contribute to deepening of private capital. In figure 9 mean paths for the stock of private production capital are displayed. The model results show a strong increase in capital volume for all policies which include DRR measures. The total effect of these measures on capital in the model is induced in the dynamic macroeconomic model by reduced losses due to protection and by increased investment due to lower risk.

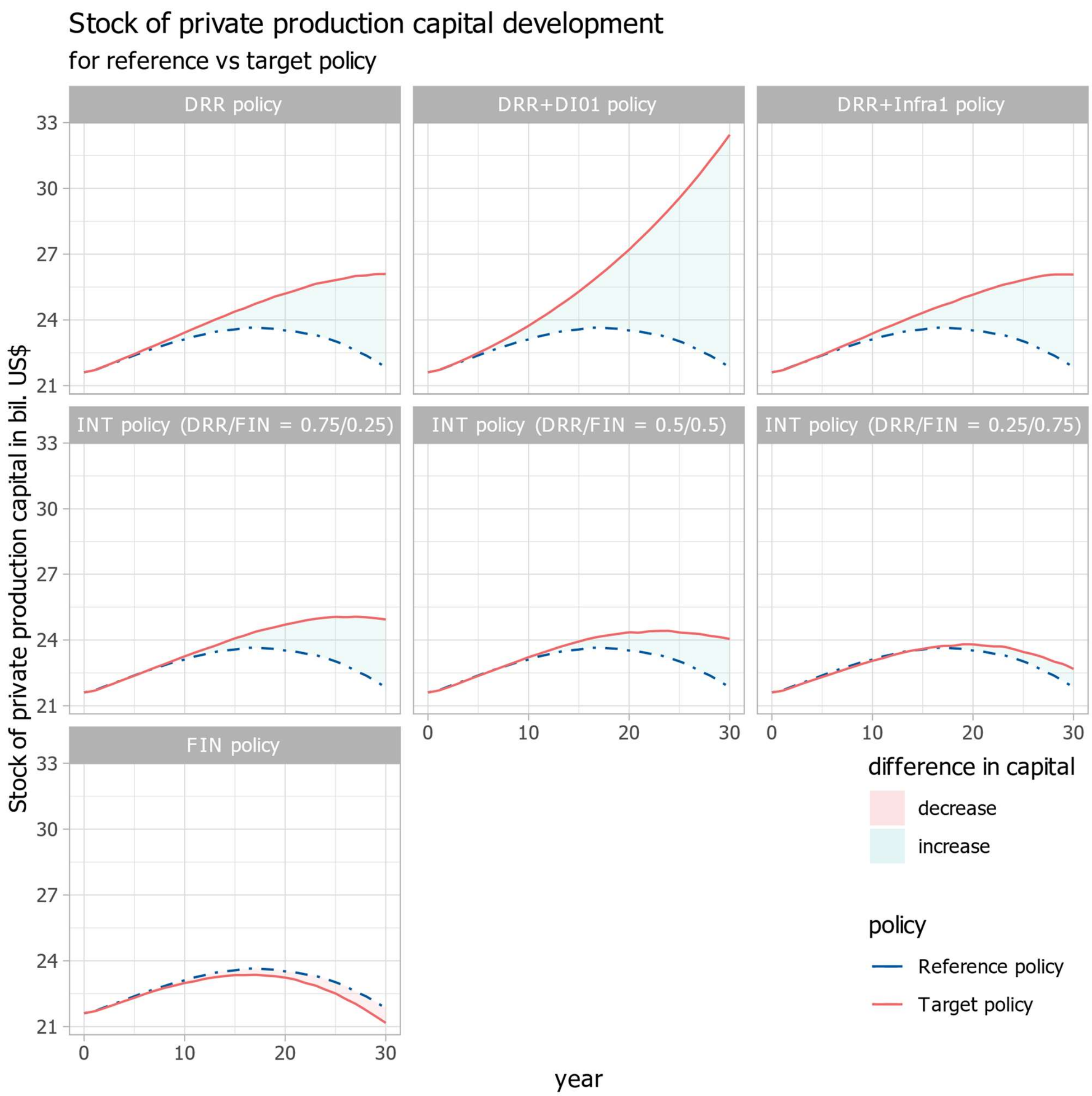


Figure 10: Stock of private production capital in the economy under reference and target policies

In contrast, the policy option with only financial contracts exhibits a lower stock of private production capital compared to the reference policy, while integrated policies have declining initial growth and see a contraction of private production capital towards the end of the study period of 30 years. This reduction is due to the

Key messages regarding private capital accumulation:

Taking averages of 1000 samples,

- *DRR+DI01 policy achieves TGE highest private capital accumulation.*
- *Among INT policies, the more funding allocated to DRR the greater private capital accumulation.*
- *FIN policy leads to decrease in private capital accumulation.*

inclusion of financial contracts. These effects are more pronounced the higher the share of FIN policies in the integrated target policy. The main drivers of capital reduction in the FIN policy case are the higher damage resulting from disaster which is not mitigated by additional DRR measures and the cost of financial contracts.

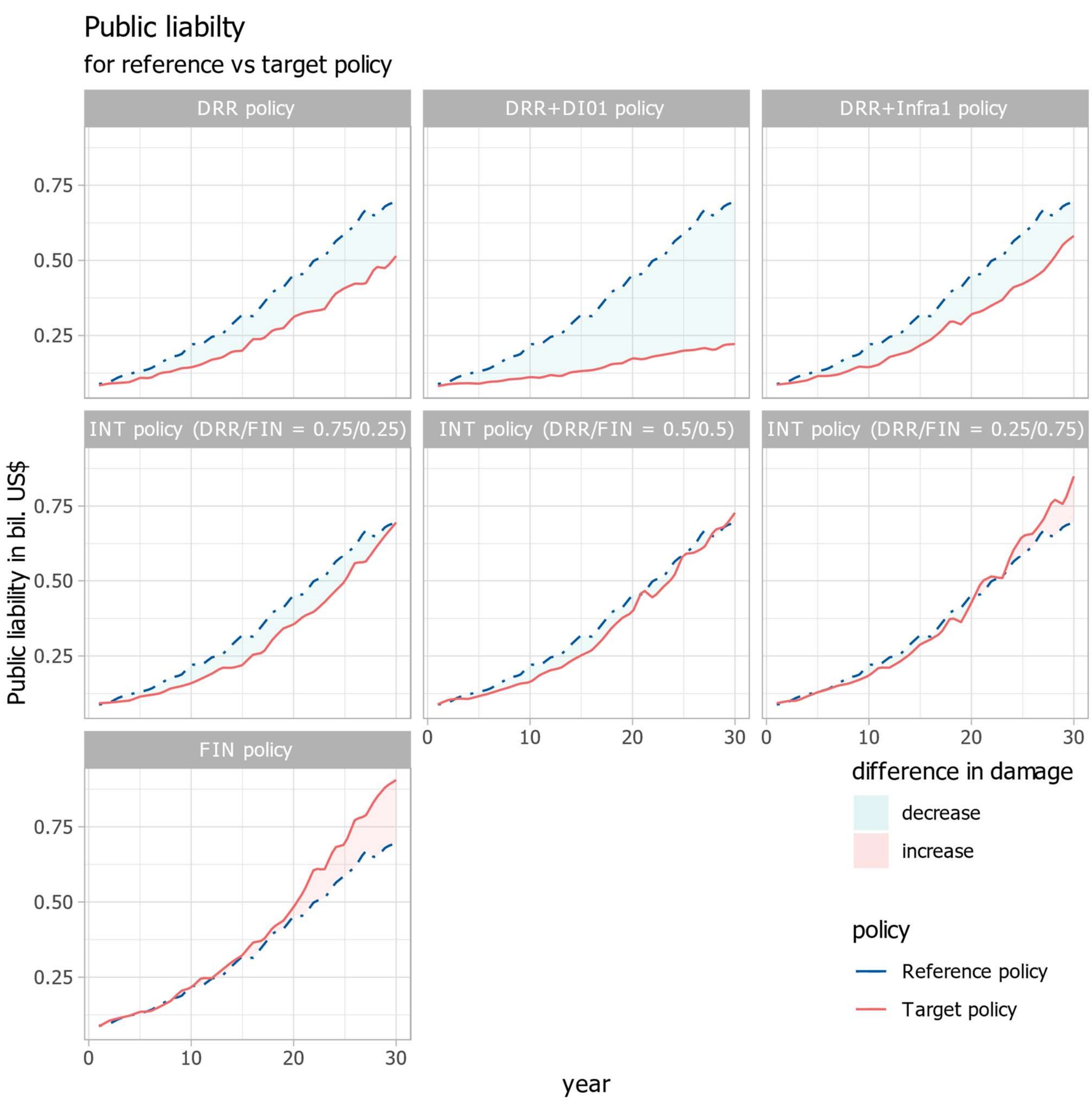


Figure 11: Public liability under reference and target policies

The reduction in capital is linked to the damage which disasters incur in the economy. Figure 10 depicts the public liability suffered by the economy under all analysed policy regimes. Per definition the cases with DRR policies in place, especially those without financial contracts (top panels of figure 10) exhibit significantly lower levels of liability as compared to the reference policy. The integrated policy cases which divide investments into DRR and financial contract spending can help reduce damage suffered slightly. However, in some years the DRR measures are not sufficient in the model to reduce impacts compared to the reference case. In the financial contracts (FIN) case the target policy is responsible for a higher incurred damage than in the reference.

Key messages regarding public liability

Taking averages of 1000 samples,

- *DRR+DI01 policy achieves highest reduction in public liability.*
- *The larger the share of FIN policy, the higher public liability.*
- *Additional infrastructure investment does not yield higher reduction in public liability than DRR policy alone.*

The role of financial contracts

As discussed previously in the calibration and data sections of this report, the lack of availability of data constrains the ability of the model at the current point to be used for specific decision making. In particular, allocation of the shares of financial and DRR policies can be discussed in a general fashion but would need updated data on capital values, investment costs and local input-output tables. Therefore, the financial contracts included in the model serve an illustrative purpose and can provide a general direction of the development of the growth rate of the economy. To make specific policy prescriptions the model inputs would need to be more refined, possibly requiring additional preceding studies to deliver the data needed. The current values assumed in our assessment, especially 1) the initial value of beach land, $Z_C(0)$, and 2) the cost of unit investment in DRR stock that is assumed to equal other investment cost, favours DRR over FIN policies. With the current set-up, $Z_C(0)$ – calibrated based on the IO table derived from the global dataset - is likely over-estimated. DRR-investment cost is likely under-valued. The insurance cost in turn becomes high due to high exposed values. The DRR policies result in large PDME by reducing damages to Z_C that is given the large value, this combined with under-estimated DRR cost leads to the current high benefit-cost ratio of DRR policy relative to FIN policy. Better calibration of land- and natural capital values therefore, should be an important pre-requisite before this modelling results could be used for public resource allocation decisions.

The remainder of this section therefore discusses how general results are obtained for the FIN policy cases and the role of financial contracts without addressing in detail ideal levels of investment into each type of financial and/or DRR instrument.

Many of the previous results derived for the financial contracts and their limited ability to boost economic growth occur because of the high cost associated with financial contracts. Hampered growth, more damage and lower levels of private capital stock are more pronounced towards the end of the study period of 30 years. The reason is the increasing cost of financial contracts over time. Costs increase because of increasing premium payments after the occurrence of multiple disasters. Figure 11 illustrates the government's payments for the main policies. Graphically, the difference in total payments between the two options including some or only financial contracts corresponds to the area between the light blue and other colour lines in figure 11. In the DRR policy, no payments are made (the same is true in the reference case). In cases which only apply financial contracts, payments occur after ten years. In the integrated policy cases, yearly payments only start later and do not catch up with the FIN case by the end of the study period. Thus, financial contract payment levels are higher, the higher the share of financial instruments in the policy mix.

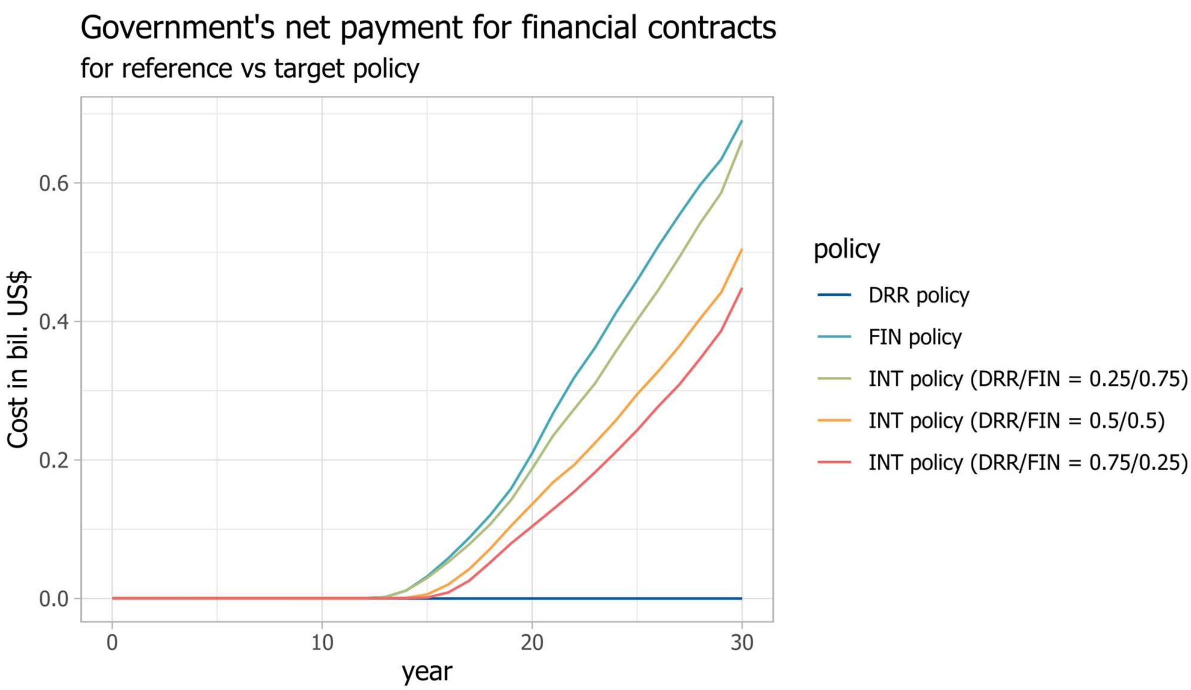


Figure 12: Government's net payments for financial contracts under different policy options

Considering the growth effects and the higher TGE of DRR policies, they could appear to be more useful than financial contracts. However, it is important to note that the marginal effect of DRR measures is decreasing. This means that after a certain threshold, the additional growth effects from more DRR investment could be lower than if the same additional budget had been allocated to financial instruments. This analysis is based on comparing the differences in discounted present values of the total growth effect across varying levels of inclusion of financial contracts in the target policy. Thus, the importance of DRR measures for enhanced economic growth in the model hinges on the strong impact of the first small increases in the target policy DRR

Key messages regarding Government's net payments for financial contracts

Taking averages of 1000 samples,

- *Cost of financial instruments increase over-time as Barbados experience more frequent disasters/number of payouts;*
- *In general, DRR investment leads to lower net financial payments by the government.*
- *Need for improved calibration and detailed data for a more prescriptive analysis on budget allocation.*

investments. This implies that a small increase in DRR investment is quite effective in an economy with small stocks of DRR facilities.

The ceilings of the financial contract layers fall with an increase of the share of the DRR policy equivalent to a decrease of the share of the FIN policy. The intuition that larger resources allocated for FIN policy results in larger coverage (i.e. lower CL_2) of the external financial contracts does not apply. Instead, larger shares of DRR investment decrease potential damages, followed by a decrease in payment of insurance premium, and finally, wider insurance coverage of Government's damage. Hence, DRR policy contributes to capacity (larger availability) of FIN policy. They have complementary effects.

Conclusions

This report represents the conclusion of the IDB sponsored project focusing on a macroeconomic cost-benefit analysis for reducing disaster vulnerability through the use of the developed DYNAMMICs framework. With the goal of supporting systematic analysis of investment decisions in IDB member countries, the project was tasked with deploying DYNAMMICs to focus on identifying optimal allocations of public funds for disaster risk reduction measures (such as protective infrastructure) and financial protection instruments (such as insurance or contingent credit lines). The final report presented here builds on the previous Technical Report of March 2021 which presented the DYNAMMICs model in detail, applying the model to the country case of Barbados.

As discussed in the country economy and hazard background section, Barbados is an apt choice for testing of the DYNAMMICs framework; while a developed country, it is heavily reliant on income from tourism, and recent events have demonstrated its economic fragility and vulnerability to external shocks. In 2018, defaulting on debt payments led to an inability to access market-based finance, leaving the island reliant on funding from the IMF and development banks. In this context, the country faces significant and growing hazards in the form of hurricane-driven wind and storm surge, which are likely to increase due to climate change.

The case of Barbados has demonstrated the applicability of the newly developed DYNAMMICs framework to assess applicability of DRR investment options against coastal hazard, focusing on assessment of three policy questions. The model has shown the ability to provide answers to questions related to the level of investment needed to reach a given level of disaster risk reduction and can assist in discussions on optimal mixes of resource allocation between different types of disaster risk reduction / management / transfer instruments, as well as balancing the desire for increased economic development and increasing resilience. DYNAMMICs is additionally novel in its disaggregation of the benefits of DRR investment into three components: (i) ex-post damage mitigation, (ii) ex-ante risk reduction, and (iii) co-benefit production expansion effects.

Given a number of possible policy pathways, from pure DRR or financial measures paths to mixtures of the two or combinations with e.g. increased infrastructure developments, the model has produced a number of key conclusions. The most salient relates to long-term economic growth. Comparing a business-as-usual case to any policy pathway, long-run GDP is assessed to be higher and less volatile under the introduced policy; DRR or risk financing policies, or their combinations, all lead to more stable growth paths over the study period, which outweigh the periods in which the target policy results in lower growth rates due to implementation costs or other factors. Such stability is also likely preferable for policymakers in terms of ease of planning and other policymaking decisions.

The decomposition of the benefits of DRR investment additionally provides informative conclusions. Model results indicate that while the total growth effect of a policy pathway is positive in all scenarios, results are much higher for policies focused on DRR (i.e. pure DRR or DRR-heavy integrated policies) than those with a stronger risk financing component. With financing-focused policies, high ex-post damage mitigation effects are offset by negative ex-ante reduction risk reduction effects. As a result, policies which combine DRR investment in coastal areas with investment in either additional infrastructure or DRR in inland areas result in the highest average total growth effects.

The model also provides insights into varying levels of private capital accumulation and government burden of financial contracts. In terms of private capital, DRR and integrated policy pathways lead to higher levels of capital accumulation; the higher the level of DRR, the higher the accumulation. The converse is true for risk financing pathways, which result in decreasing levels of private capital. Financing pathways also lead to increasing costs over time, as Barbados is expected to experience more frequent disasters and thus more frequent pay-outs. As expected, DRR investment pathways alternatively lead to lower net financial payments by the government.

While results would seem to indicate that DRR-based pathways lead to overall more positive results for the case of Barbados, it must be emphasized that results are contingent on the data inputs, and in order to form more robust conclusions in this regard, there is a need for improved data. The model calibration as described in this report is based on Input-Output tables estimated for the country by the Eora Global MRIO, as no country tables exist; this input forms the basis of a simplified two-sector model which relies on a number of assumptions relating to the size of various asset stocks and other parameters of the model. Parameterization of the hazard component could also be improved with better data. Thus, while the results described here can provide an indication of possible pathway results, they should not be taken as prescriptive, but rather as an indication of avenues to further explore regarding feasibility and likely impacts of proposed policies.

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Appendix 1 Model calibration details

Table A1. Two-sector IO table for Barbados based on Eora MRIO tables. The original data is based on 2015 values, and unless otherwise noted, all values are expressed in $ billion. Note: GFCF: gross fixed capital formation; Cons.: consumption

Industry (Row) / Industry (Column)	T-good sector	Non-T-good sector	Total intermediate demand	Household final consumption expenditure	Gov final consumption	NPISH final consumption	Acquisitions less disposals of valuables	Cons.	GFCF	Invest-ment	Exports, fob	Total final demand	Total demand	Total final use	Total use at basic prices
T-good sector	1.34	0.97	2.32	1.15	0.03	0.00	0.00	1.18	0.38	0.38	0.82	2.38	4.70		
T-good sector	1.08	0.64	1.72	1.06	0.03	0.00	0.00	1.10	0.33	0.33	19.13	20.56	22.28	20.56	22.28
CIF/FOB, Net taxes	0.27	0.33	0.60	0.09	0.00	0.00	0.00	0.08	0.05	0.05	-18.31	-18.18	-17.58		
Non-T-good sector	0.76	2.15	2.91	2.07	0.96	0.00	0.00	3.18	0.97	0.97	0.15	4.14	7.05		
Non-T-good sector	0.61	1.42	2.02	1.92	0.96	0.00	0.00	6.44	0.84	0.84	3.56	7.27	9.30	7.27	9.30
CIF/FOB, Net taxes	0.15	0.73	0.88	0.15	-0.01	0.00	0.00	-3.26	0.13	0.13	-3.41	-3.13	-2.25		
Imports at basic prices	0.59	0.47	1.06	0.45	0.01	0.26	0.13	0.84	0.13	0.13		0.97	2.03	0.97	2.03
Use at Basic Prices	1.68	2.06	3.74	2.98	0.99	0.00	0.00	3.97	1.17	1.17	22.69	27.83	31.58	27.83	31.58
CIF/FOB								0.00		0.00		0.00	0.00		
Net Taxes	0.42	1.06	1.48	0.24	-0.01	0.00	0.00	0.23	0.18	0.18	-21.72	-21.31	-19.83	-21.31	-19.83
Total Use at Purchasers Price	2.10	3.12	5.22	3.22	0.99	0.00	0.00	4.21	1.35	1.35	0.97	6.53	11.75	6.53	11.75
Wages and salaries	0.47	1.17	1.64												
Social contribution	-0.01	-0.02	-0.03												
Consumption of fixed capital	0.11	0.31	0.42												
Other net taxes on production	0.03	0.03	0.06												
Mixed income	0.13	0.37	0.50												
Net operating surplus	0.34	0.89	1.22												
Sector GDP	1.07	2.74	3.8079	= 2015 GDP											
Total output	3.76	6.33													

Table A2. Assumptions on the allocation of shares of value-added of the traded good (T) sector.

				Capital Stocks					
				Land		**Natural assets**		**Infrastructure**	
		Labor	**Capital**	*Inland*	*Coastal*	*Inland*	*Coastal*	*Inland*	*Coastal*
Traded good sector	**Wages and salaries**	**1**	0	0	0	0	0	0	0
	Social contribution	0	**1**	0	0	0	0	0	0
	Consumption of fixed capital	0	**1**	0	0	0	0	0	0
	Other net taxes on production	0	0	0	0	0	0	T-sector inland area share of GDP **(0.95)**	T-sector coastal area share of GDP **(0.05)**
	Mixed Income	**0.1**	**0.1**	20% of inland area T sector GDP share **(0.19)**	20% of coastal area T sector GDP share **(0.01)**	20% of inland area T sector GDP share **(0.19)**	20% of coastal area T sector GDP share **(0.01)**	40% of inland area T sector GDP share **(0.38)**	40% of coastal area T sector GDP share **(0.02)**
	Net Operating Surplus - Inter. Ele & Wat	0	**0.2**	20% of inland area T sector GDP share **(0.19)**	20% of coastal area T sector GDP share **(0.01)**	20% of inland area T sector GDP share **(0.19)**	20% of coastal area T sector GDP share **(0.01)**	40% of inland area T sector GDP share **(0.38)**	40% of coastal area T sector GDP share **(0.02)**

Table A3. Assumptions on the allocation of shares of value-added of the non-traded good (N) sector.

				Capital Stocks					
				Land		**Natural assets**		**Infrastructure**	
		Labor	**Capital**	*Inland*	*Coastal*	*Inland*	*Coastal*	*Inland*	*Coastal*
Non-Traded good sector	**Wages and salaries**	1	0	0	0	0	0	0	0
	Social contribution	0	1	0	0	0	0	0	0
	Consumption of fixed capital	0	1	0	0	0	0	0	0
	Other net taxes on production	0	0	0	0	0	0	N-sector inland area share of GDP (0.76)	N-sector coastal area share of GDP (0.24)
	Mixed Income	0.1	0.1	20% of inland area N sector GDP share (0.15)	20% of coastal area N sector GDP share (0.05)	20% of inland area N sector GDP share (0.15)	20% of coastal area N sector GDP share (0.05)	40% of inland area N sector GDP share (0.30)	40% of coastal area N sector GDP share (0.1)
	Net Operating Surplus - Inter. Ele & Wat	0	0.2	20% of inland area N sector GDP share (0.15)	20% of coastal area N sector GDP share (0.05)	20% of inland area N sector GDP share (0.15)	20% of coastal area N sector GDP share (0.05)	40% of inland area N sector GDP share (0.30)	40% of coastal area N sector GDP share (0.1)