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Macroeconomic Effects of Temperature Shocks on the Caribbean

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Macroeconomic Effects of Temperature Shocks Caribbean Economies

CERT Workstream 3: Future Paths to Regional Resilience

Team Members

Caribbean Development Bank Team Leads	Dindial Ramrattan Oronde Small Jaron Boyce
Eastern Caribbean Central Bank	Ms. Juletta Edinborough
Bank of Jamaica	Dr. Alvin Harris
Central Bank of Aruba	Ms. Daniella van den Berg
Central Bank of Belize	Ms. Candice Soutar
Central Bank of Suriname	Ms. Xanegay Huur

Macroeconomic Effects of Temperature Shocks on the Caribbean

CERT Workstream 3 Members

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Abstract

This research examines the effects of local and global temperature shocks on real Gross Domestic Product (GDP) per capita, selected industrial components of real GDP and key drivers of economic growth – investments and final consumption for Caribbean economies using local projection methods and annual data from 1980 to 2022. The findings suggest negative and statistically significant effects for regional GDP, transmitted through the construction, manufacturing and agriculture industries. In general, results suggest more acute sensitivities to local temperature shocks for the agriculture industry, while construction and manufacturing appear more reactive to shocks in global temperature. Growth effects are transmitted via lower investment and consumption and are larger for global *vis a viz* local temperature shocks. Aggregated results for the Caribbean mask heterogeneous growth effects across respective economies. Country specific results highlight varied industrial sensitivities to local and global temperature shocks. Null effects for some economies suggest a more advanced state of readiness to mitigate potentially negative heat effects. In general, larger effects from global temperature shocks may imply the existence of exogenous transmission channels that can challenge countries' adaptation capacity. Overall, the varied economic vulnerabilities across regional economies emphasize the need for targeted country and industry-specific adaptation strategies.

JEL Classification: E2, O10, O54

Keywords: climate change, temperature, economic activity, local projection

Corresponding authors' e-mail address: oronde.small@caribank.org; alvin.harris@boj.org.jm

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1. INTRODUCTION

Climate change is precipitated by greenhouse gas emissions (GHG) that lead to rising global temperatures which induce changes in weather patterns, ocean currents and atmospheric conditions that contribute to increased frequency and intensity of natural hazards such as hurricanes. With global average temperatures already more than 1.1 degree Celsius above pre-industrial levels and given the accelerated warming experienced over the last decade, the impact on people and ecosystems has been widespread and severe, and future risks are becoming more acute with fractional increases in warming (IPCC, 2023).

This research examines the effects of warming on real GDP per capita for a panel of 17 Caribbean economies over the period 1970 to 2022.[1] While the Caribbean is diverse in resources, economic growth and development generally depends critically on a few key industries - agriculture, tourism and other services, construction and manufacturing – and for some, oil production. Yet our knowledge is limited in relation to how these vital industries will be impacted by warming. In this regard, the paper also examines the effects of temperature shocks on key industrial components of GDP – real agricultural value added per capita, real manufacturing value added per capita, and real construction value added per capita. Given the Caribbean's relatively high dependence on tourism, the impact of warming on tourist arrivals was also examined. Further, to identify potential channels through which temperature affects output, the research examines the responses of investment and final consumption – key drivers of economic growth.

Because the Caribbean is non-monolithic with respect to resource endowments and associated comparative advantages, the relative severity of the effects of warming may differ across countries. This motivated a deeper investigation of the country-specific effects of temperature shocks. Further, to test for heterogeneity in the response to warming, this research examines the relative sensitivities to local and global temperature shocks across select Caribbean economies - Aruba, Barbados, Belize, Jamaica, Suriname, and Trinidad & Tobago.[2]

[1] The countries included in the panel are Aruba, Antigua and Barbuda, The Bahamas, Belize, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago

[2] Selected countries represent a broad cross section of commodity exporters and tourism dependent or services-oriented economies within the region that can provide a perspective on the potentially differential effects of warming.

The empirical strategy adopts a panel local projection model (LPM) (Jordà, 2005) to estimate the response of key macroeconomic variables to temperature shocks for the Caribbean region and standard LPMs to estimate country specific impulse responses to these same shocks. This study reveals that both local and global temperature shocks lead to a decline in real GDP per capita across the Caribbean region, with global temperature shocks having a more pronounced effect over a similar time horizon. A standard deviation shock in local and global temperatures decreases real GDP per capita for the Caribbean by a cumulative maximum of 1.51 and 1.73 percentage points after six and five years, respectively. When assessed as a response to a one-degree Celsius shock, results suggest a decrease in real GDP per capita by 6.73 per cent and 15.24 per cent in response to local and global temperature shocks, respectively. These results are consistent with recent literature (Bilal and Kanzig, 2024; Nath et al., 2024) that report larger impulse responses from equal sized global temperature shocks *vis a viz* local temperature shocks. Results are mainly driven by the construction and manufacturing industries and are channeled largely through decreases in investment per capita and final consumption per capita, with larger impulses for the former.

The results also highlight heterogenous responses across economic industries and countries. In general, the study finds relatively more acute sensitivities to local temperature shocks in the agriculture industry, while the construction and manufacturing industries are more significantly impacted by global temperature shocks. The relatively lager impact of global temperature shocks highlight potentially negative growth effects transmitted through the impact of extreme weather events on the domestic economy as well as spillover effects from the impact on trading partners which can be transmitted to regional economies, *inter alia*, in the form of lower investments in critical economic industries. Tourist arrivals respond to temperature shocks ambiguously but highlight a risk for tourism dependent economies. In general, cross-country analyses highlight differential warming effects for economies examined, suggesting a need for country specific adaptation policy responses.

The remaining sections of this paper are organized as follows. Section 2 reviews the growing body of literature on the macroeconomic effects of rising temperature. Section 3 discusses the data used in this study and Section 4 describes the methodology. Section 5 presents the results and Section 6 concludes and discusses potential policy recommendations.

2. LITERATURE REVIEW

A burgeoning literature examining the link between temperature fluctuations and macroeconomic performance report generally mixed results conditional on econometric methods, sample period and cross-sectional or geographical units. Earlier studies of the impact of temperature on economic growth that use cross sectional regression models (Sachs and Warner, 1997; Nordhaus, 2006) suffer from omitted variable bias resulting in less than robust results. Recent literature address this by adopting fixed effects panel models that better control for unobserved time invariant group specific heterogeneity (Dell et al., 2012; Burke et al., 2015; Hensler and Schumacher, 2019) and find generally negative and persistent growth effects from rising temperatures. In general, growth effects associated with temperature rise are transmitted through several key channels, namely agriculture (Schlenker and Roberts, 2009), industrial output (Chen and Yang, 2019), energy (Davis and Gertler, 2015), capital accumulation (Zhang et al., 2018), labour (Hensler and Schumacher, 2019), and productivity (Zhang et al., 2018). Seminal research by Dell et al. (2012) examines the impact of temperature on output per capita using a panel regression framework and finds that a one-degree Celsius increase in annual average temperature decreases output per capita by 1.3 percentage points, with persistent effects, but only for low-income countries. Additionally, they find that the impact on aggregate output is transmitted via constrained agricultural and industrial output and political instability. In similar work (Hensler and Schumacher, 2019; Letta and Tol, 2019) find significant negative growth effects from temperature increases for poor countries, transmitted through all factors of production - labour and capital, with the largest effects on total factor productivity (TFP). Other studies (Acevedo et al., 2020) also find disproportionately negative and persistent growth effects for lower income countries, transmitted through lower productivity in heat exposed industries – agriculture and construction, precipitated by reduced capital investments and labour supply.

Studies that use variations in country level average annual temperatures may suffer from confounding since temperatures can vary widely within a year and across regions or states and therefore may yield attenuated effects if the relationship with the outcome variable is non-linear – such that the negative effects from temperature increases may be offset by neutral or even positive effects associated with more benign changes in temperature. In that regard, other studies examine more dynamic relationships between temperature and economic output and find differential growth effects from temperature changes that are conditional on baseline temperatures rather than income. Burke et al. (2015) find that macroeconomic effects are non-linear, smooth and inverse U-shaped as a function of average annual temperature. They report positive and significant effects on economic productivity for average annual temperatures below 13 degrees Celsius and negative productivity effects when temperatures rise above this threshold, with the former being larger and more persistent. Results suggest that tropical countries such as those in the Caribbean may experience larger negative growth effects from increases in temperature because of their higher average baseline temperatures.

To mitigate potentially confounding effects from the use of annual average temperatures at country level, more recent research use identification strategies that exploit temperature variation in more granular geographic regions – essentially conditioning on the baseline temperature for specific regions within the same country (Burke and Tanutama, 2019; Kalkuhl and Wenz, 2020). Burke and Tanutama (2019) use district level temperature data over 11,000 districts across 37 countries and confirm a significant negative relationship between district level annual temperature and economic growth for hotter regions (>10 degrees Celsius) and larger effects for long run changes in temperature, which do not differ based on income levels. Similarly, Kalkuhl and Wenz (2020) using a panel of 1,500 regions across 77 countries find strong and robust evidence that gross regional product (GRP) responds to annual temperature shocks as well as long-run temperature levels (climate) - with larger negative growth effects for regions with annual average temperature of 26 degrees Celsius and above.

Other studies exploit seasonal variation in temperatures (Colacito et al., 2021; Nguyen and Pienknagura, 2024) under the premise that this more aptly captures the full effects of climate change. Colacito et al. (2018) exploits variation in summer and fall temperatures using US state level data and find that an increase in average summer temperatures negatively affects growth while increases in average fall temperatures have positive growth effects – with more robust effects for the former. Similarly, Nguyen and Pienknagura, (2024) exploits variation in seasonal temperatures across advanced economies and emerging market developing economies and find that for both country groups, negative effects of a hotter spring is larger and more persistent than the positive effect of a warmer winter, particularly for agriculture production.

While the previous literature examines the impact of changes in local temperature on macroeconomic outcomes, another strand seeks to distinguish between the effects of local and global temperature shocks (Bilal and Kanzig, 2024; Berg et al., 2021; Nath et al., 2024), with the latter thought to more closely reflect the impact of climate change. Bilal and Kanzig (2024) using a local projection framework find a large and sustained negative impulse response in global GDP per capita to a global temperature shock. In particular, the results suggest that a 1-degree Celsius shock in average global temperature leads to a decrease in global output by about 12.0 per cent after 6 years - sustained for 10 years after the shock. Compared to local temperature shocks, these impulses are an order of magnitude larger due in part to strong predictive power of global temperatures shocks for extreme climatic events which cause significant economic damage. Though the growth effects are more muted, Nath et al. (2024) also report generally larger impulses from global temperature shocks *vis a viz* local temperature shocks, which are more sustained, particularly for warmer countries.

This research contributes to this strand of literature by examining the effects of local and global temperature shocks on growth in GDP per capita for a panel of Caribbean economies – a largely overlooked country grouping despite more acute vulnerabilities to temperature rise, using the LPM framework. Further we examine the effects on key industrial components as well as the main drivers of growth in the region – final consumption per capita and investment per capita.

3. DATA AND DESCRIPTIVE STATISTICS

The data set comprises a combination of economic, temperature and natural hazard data in annual frequency over the period 1970-2022, for a panel of 16 Caribbean countries.[3] The primary dependent variables of interest are real GDP per capita (RGDP_PC) and key industrial components of GDP, namely real agricultural value added per capita (AGDP_PC), real manufacturing value added per capita (MGDP_PC) and real construction value added per capita (CGDP_PC). Given the Caribbean region's relatively high dependence on tourism, this research also explores the impact of warming on tourist arrivals (TOUR). Additionally, we examine the key growth channels through which temperature effects are potentially transmitted - namely investment and final consumption. Investment is proxied by gross fixed capital formation per capita (GFCF_PC) and final consumption per capita (FCONS_PC) is captured by the aggregate of government and household consumption. **Table 1** provides a comprehensive summary of the variables forming the core dataset, including their definitions and the source.

Table 1: Data Description and Source

Variable	Description	Source
Real GDP per capita (RGDP_PC	Calculated as real GDP divided by the total population.	UN STATS, Authors calculation
Real Agriculture GDP (AGDP_PC)	Calculated as real agriculture valued added divided by the total population.	UN STATS, Authors calculation
Real Manufacturing GDP (MGDP_PC)	Calculated as real GDP per capita divided by the total population.	UN STATS, Authors calculation
Real Construction GDP (CGDP_PC)	Calculated as real GDP per capita divided by the total population.	UN STATS, Authors calculation
Tourist Arrivals (TOUR)[4]	The number of over-night visitors to the country	World Bank, WDI
Investment (GFKF_PC)	Gross fixed capital formation from the national accounts divided by total population	UN STATS, Authors calculation
Final Consumption (FCONS_PC)	Aggregate of government and household consumption from the national accounts divided by total population	UN STATS, Authors calculation
Local Temperature (LTEMP)	Annual average of mean surface air temperature within country, measured in degrees Celsius	World Bank: Climate Change Knowledge Portal

[3] This study implicitly accounts for location through regional and country-specific effects but does not explicitly incorporate topography, which may also be relevant for assessing economic resilience and vulnerability. The exclusion of topography reflects both data constraints and the lack of consensus on its macroeconomic modeling. Location is prioritized as it more effectively captures macro-level, regionally driven climate and economic vulnerabilities in Caribbean economies, whereas topography is better suited to micro-level or sectoral analyses, such as those focused on agriculture.

[4] In regression models examining the impact of temperature shocks on tourist arrivals, the log transformation of tourist arrivals is used as the dependent variable. The results are therefore interpreted as the percentage change in tourist arrivals in response to a standard deviation shock in temperatures.

Global Temperature (GTEMP)	Average of annual mean local surface air temperature all countries measured in degrees Celsius	World Bank: Climate Change Knowledge Portal and Authors calculation
Local Temperature Shock	The cyclical component of the HP filter applied to local temperature in degrees Celsius	Authors calculation
Global Temperature Shock	The cyclical component of the HP filter applied to global temperature in degrees Celsius	Authors calculation
Trade Openness (TRADE_GDP)	Calculated as the sum of import and export as a share of nominal GDP	UN STATS and IMF-WEO
Central Government Debt to GDP ratio (DEBT_GDP)	Calculated as the central government debt as a per cent of nominal GDP	WEO/WDI
Population (POP)	Total number of persons resident in the country each year	UN STATS and WDI
Storm	Indicator variable if a storm was recorded in a country in a given year and zero otherwise.	EM-DAT
Oil Price	West Texas Intermediate crude oil prices	Federal Reserve Economic Data (FRED), Federal Reserve Bank of St Louis.
10-year Treasury Yield	Yield on US 10-year treasury bonds	Federal Reserve Economic Data (FRED), Federal Reserve Bank of St Louis.

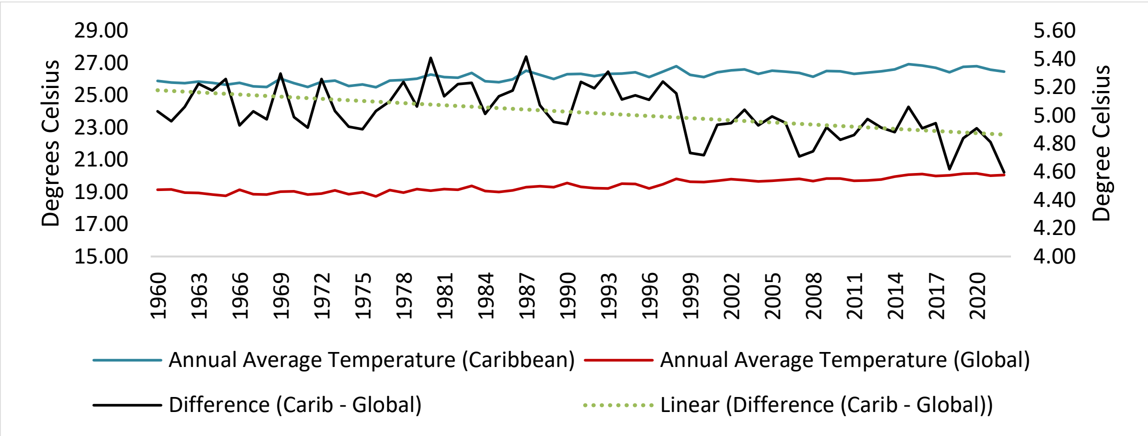
Given the structure of regional economies and the likely influence on economic performance, a measure of trade openness – defined as the sum of imports and exports as a share of GDP (TRADE_GDP) was included as controls.[5] Further, as exogeneous controls to capture changes in the global economy this study includes (commodity) oil prices, US 10-year treasury yields and dummy variables that capture the Great Financial Crisis (2008/2009) and the COVID-19 pandemic.

The key independent variables of interest are local and global temperature shocks. We obtain data on the average local surface area temperature from the World Bank Climate Knowledge Data Base (2024).[6] The data are sourced from the Climatic Research Unit (CRU) of the University of East Anglia at a spatial resolution 0.5°x 0.5° (50km x 50km). Local temperature is calculated as the annual average of the mean daily temperature within a country. Global temperature is calculated as the cross-sectional average of the country level (or local) annual mean temperatures.

[5] Alternative specifications included debt to GDP as an additional control variable, given the high indebtedness of Caribbean economies. However, due to significant missing observations and the desire to be consistent in the model specifications for regional and country specific analyses, the baseline results did not included debt to GDP. Notably, results for the Caribbean were largely unchanged when this variable is included. In addition, it is common in the literature to see the lags of the dependent and independent variables as the main covariates (see Berg et al (2024); Bilal and Känzig (2024); and Nath (2024)).
[6] World Bank, Climate Change Knowledge Portal (2024). URL: https://climateknowledgeportal.worldbank.org/. Accessed 26 May 2024.

Figure 1 compares trends in annual global average temperature with that for the Caribbean region between 1960 – 2022. Over the period, average global temperature increased by an estimated 0.91℃, compared to 0.58 ℃ for the Caribbean. An examination of the trajectory of regional and global temperatures highlights an interesting dynamic. While regional and global temperatures display a high level of correlation (91.0 per cent) over the period 1960 – 2022, there was a noticeable divergence in the trends beginning in the 1980's.[7] In particular, the data highlights a general increase in warming trends, beginning around 1980 but reflected more significant increases in global temperatures *visa viz* temperatures in the Caribbean – a narrowing of the temperature gap. Differential rates of warming implied by the observed changes in average global and regional temperatures over the period might suggest potentially differential implications for economic outcomes, *inter alia*, in direction, magnitude and transmission channels.

Figure 1: Average Annual Global and Caribbean (Regional) Temperatures, 1960-2022



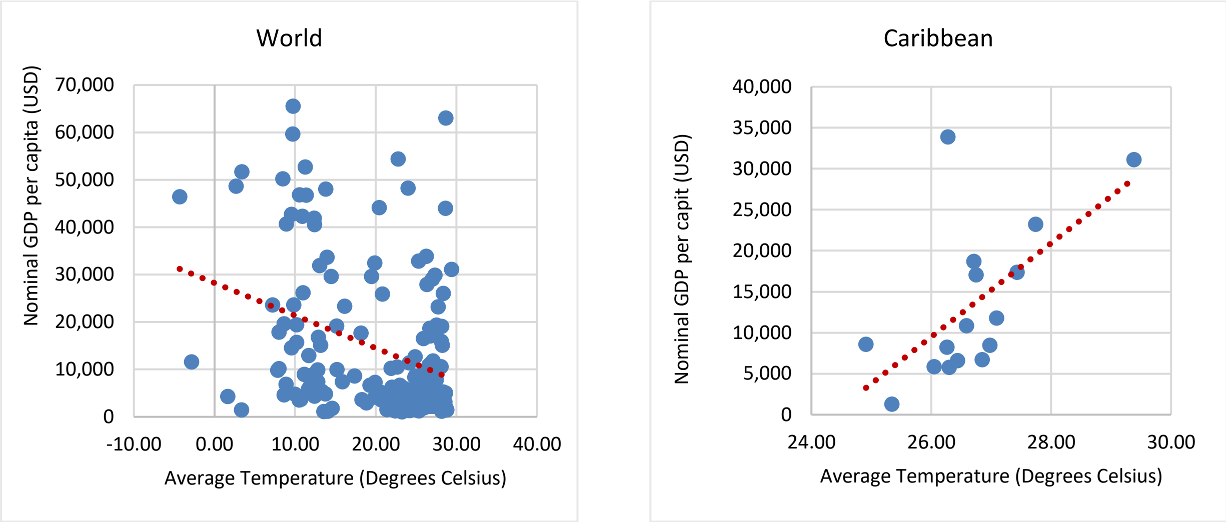
Note: Figure 1 compares the trajectory for average annual global temperature (in degrees Celsius) with for the average annual local temperature for the Caribbean between 1960-2022.
Source: World Bank Climate Knowledge Data Base (2024) and authors' calculation.

A non-parametric assessment of the relationship between local temperatures and nominal GDP (USD) per capita at the global level and for the Caribbean is presented in **Figure 2**. Scatterplots highlight a negative relationship between local temperatures and nominal GDP per capita for world economies on average, but positive for the Caribbean region. Abstracting from the directional contrast, the figures highlight potentially differential effects of warming for regional economies compared to the rest of the world. These results are, however, subject to more

[7] The correlation between average temperatures in the Caribbean and the average global temperature decreased to 73.7 per cent between 1980-2022.

careful empirical assessments using dynamic parametric methods in a local projection framework.

Figure 2: Scatter of Nominal GDP per capita against Average Temperature, 2019



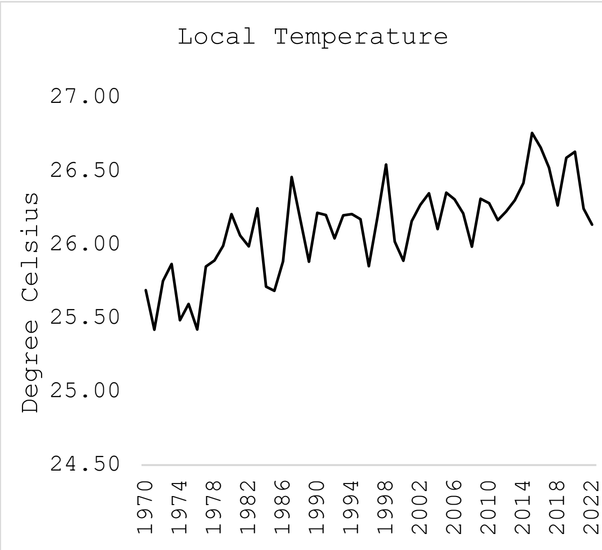
Notes: The figures above show scatter plots of average local temperature across all countries and for the Caribbean region (right panel) in 2019. The positive slope in the Caribbean region is mainly driven by four countries (Bahamas, Aruba, St. Kitts and Nevis and Barbados).

In line with the recent literature (Nath et al., 2024; Berg et al., 2024; Bilal & Känzig, 2024), this paper corrects for potential bias due to serial correlation in level temperature data by modelling the impact of temperature shocks.[8] **Figures 3** and **4** illustrate the levels and "shock" for local and global temperatures, respectively. Local and global temperature shocks are estimated as deviations from their long run trend, using the Hodrick Prescott (HP) filter, and the temperature shocks are proxied by the cyclical component from the HP process. Minimum and maximum shocks in local average temperature over the estimation period are estimated at -0.34 °C and 0.41°C. Global temperature shocks display slightly less variability and range from - 0.28°C to 0.25°C. Both local and global temperature shocks are orthogonal to the level data and are stationary by construction.[9]

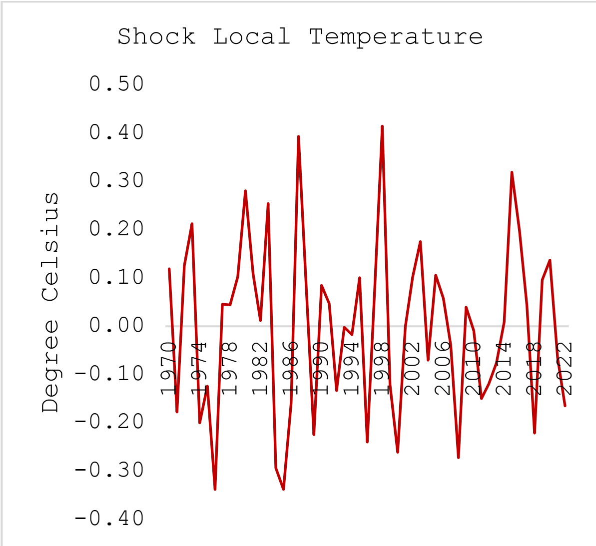
[8] The trending pattern in global and local temperature suggests the presence of serial correlation in levels. Using temperature data in levels as the key independent variables in the regressions on real GDP – that also displays a similar positive trend, may lead to spurious results.

[9] As an alternative, global and local temperature shocks were calculated as a standardized Z score and used to test robustness of the baseline results.

Figure 3: Average Local Temperature in Levels and Shocks for the Caribbean

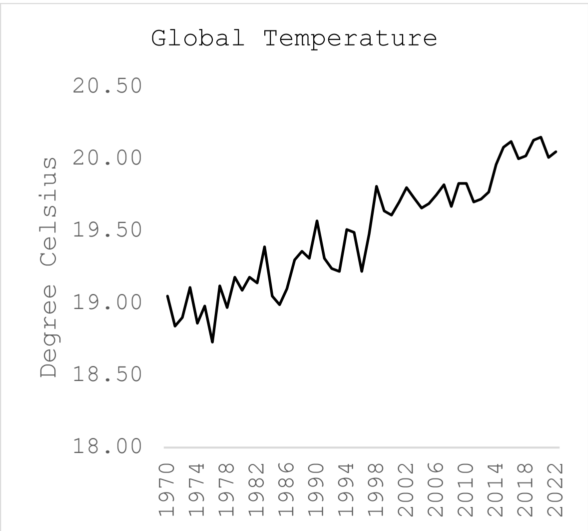


Source: World Bank Climate Knowledge Data Base (2024).

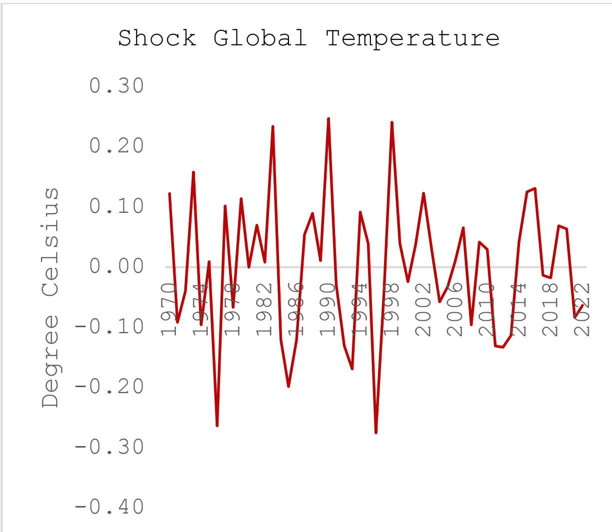


Note: Figure 3 shows global temperature shocks, calculated as the deviation in average global temperature from its long run trend (in degrees Celsius), calculated using the HP filter with smoothing parameter, λ = 100. Source: World Bank Climate Knowledge Data Base (2024) and authors calculation.

Figure 4: Global Temperature in Levels and Shocks



Source: World Bank Climate Knowledge Data Base (2024).



Note: Figure 4 shows global temperature shocks, calculated as the deviation in average global temperature from its long run trend (in degrees Celsius), calculated using the HP filter with smoothing parameter, λ = 100. Source: World Bank Climate Knowledge Data Base (2024) and authors calculation.

Additionally, to examine the relationship between temperature shocks and extreme weather, this paper utilizes data on climatic events, namely tropical cyclones, floods and drought, sourced from the Centre for Research on the Epidemiology of Disasters (CRED) Emergency

Events Database (EM-DAT) (2024). The EM-DAT database records country-level mass disasters as well as their health and economic impacts. It records disasters that fit at least one of four criteria: 1) at least 10 fatalities occur, 2) 100 or more individuals are affected, 3) a state of emergency is declared, 4) international assistance is requested by the nation. Data on storms (tropical cyclones) are recorded once it satisfies the criteria above and additional information on the strength of the storm and people affected are recorded. An indicator variable is used to capture the occurrence of any of the aforementioned climatic events over the period 1980-2022.[10] **Table 2** presents descriptive statistics for the variable employed in the analysis.

Table 2: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
GDP per capita (USD)	881	9105.47	7952.35	829.56	34043.83
Agriculture per capita (USD)	881	398.96	267.87	0.47	1513.49
Construction per capita (USD)	881	606.46	598.07	-591.33	3908.01
Transportation per capita	881	675.88	625.90	20.77	2831.95
Investment per capita (USD)	881	2055.90	1988.98	91.77	10321.53
Final consumption per capita (USD)	881	7556.13	6025.08	412.52	25888.66
Tourist Arrivals	499	1339100	1459324	51400	7551000
Local Temperature (Degrees Celsius)	971	26.13	1.34	20.94	29.78
Global Temperature (Degrees Celsius)	971	19.51	0.39	18.73	20.15
Oil Price (US$)	971	39.19	29.98	1.21	105.01
US 10-year Treasury Yield (%)	971	5.89	3.10	0.89	13.92

Notes: Table provides summary statistics for the variables used in the regression models.

[10] Additionally, as a way of capturing intensive margin effects from natural disaster shocks [hurricanes], we interact with our dichotomous shock variable with estimates of the number of persons affected by a particular event. Results suggest that while both local and global temperatures shocks had a positive impact on the severity of storms, they were not statistically significant.

4. METHODOLOGY

The empirical strategy implements a panel local projection model (LPM) introduced by Jordà (2005) and offers several advantages over the standard vector autoregressive (VAR) models. VARs use global linear approximations of the data generating process (DGP) to produce optimal one period ahead forecasts. However, impulse response functions (IRFs) are forecast functions at ever increasing horizons which can compound misspecification errors in VAR models. LPMs are multistep sequential regressions that produce projections local to each forecast horizon and therefore allow greater flexibility in the estimation of IRFs without imposing strong parametric assumptions. Unlike VARs that iterate through a system of equations, LPMs directly generate estimates of the impact on the dependent variable at each horizon, potentially reducing misspecification errors and more effectively handles non-linearities and structural breaks in the DGP.

We capture the dynamic response to temperature shocks for Caribbean economies by estimating a panel LPM (Jorda et al., 2020). The baseline model estimates a series of panel regressions for each horizon $h = 1, \dots., 8$ and takes the form:[11]

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_h + \beta_h T_{i,t}^{lshock} + \gamma_h X_{i,t} + \omega_h Z_t + \mu_t + \mu_i + \varepsilon_{i,t+h} \qquad (1)$$

The key dependent variable of interest in the baseline model, $Y_{i,t}$, is the log of real GDP per capita (LRGDPPC) for country i in year t. The left-hand side of equation one (1) expresses the dependent variable in log differences between its value in the period prior to the shock and h periods after the shock. In alternative specifications of the model, we decompose the effects of the temperature shocks on GDP by examining the impulse response of important sub-components - agriculture value added per capita, manufacturing value added per capita, construction value added and tourist arrivals, as well as investment per capita, and final consumption per capita.

The key independent variable of interest, $T_{i,t}^{lshock}$, captures the local or country specific contemporaneous temperature shock. An alternative specification of the model examines the

[11] We use eight (8) horizons to minimize loss of degrees of freedom that occurs as we increase the estimation horizon and to remain consistent with the presentation of results for the country specific analysis as data availability for some countries are more limited.

impact of a contemporaneous shock in global temperature (T_t^{gshock}) on the respective outcome variables in the panel regression models. The coefficient of interest, β_h gives the dynamic effect of a shock in temperature on the respective dependent variables after h periods and can be interpreted as the (accumulated) impulse response at horizon h.[12] In general, the temperature shock variables used in this paper are broadly consistent with the recent literature (Berg et al. 2024, Nath, 2024, and Bilal and Kanzig, 2024) and are employed to reduce the likelihood of obtaining spurious results. Using temperature in levels or the trend component may obfuscate the results, biasing the interpretation of the economic impact of increases in temperature.[13] Therefore, this paper follows the literature by utilizing a measure for temperature shocks that are orthogonal to the outcome variables of interest and as such offers greater support to more plausible causal inference.

$X_{i,t}$ is a vector of country-specific controls and include p lags of the dependent variables and the local temperature shock to control for potential bias that may arise due to persistence – serial correlation in real GDP per capita and temperature. We include two lags of the dependent variables and the temperature shock in the baseline regression models.[14] To control for other country-specific factors, trade openness was included in $X_{i,t}$. The vector Z_t includes global controls that do not vary across countries such as oil prices (OIL), US ten-year treasury yield (TREASURY), world GDP growth, and dummies to control for the great financial crisis (GFC) and the COVID-19 pandemic (COVID). The parameters γ_h and ω_h are vectors of coefficients for the local and global controls, respectively. Panel regressions that model the effects of local temperature shocks include year (μ_t) and country fixed effects (μ_i) to control for unobserved time invariant factors and common time specific factors, respectively. However, since global temperature shocks do not vary across countries, associated models only include country fixed effects. Finally, $\varepsilon_{i,t+h}$ are independent, identically and normally distributed errors such that $\varepsilon \sim i.i.d.(0, \Sigma)$.

[12] Note that the temperature shock is contemporaneous, and the effects are traced over h horizons. The LP model estimates the cumulative impulse response of real GDP per capita to local and global temperature shocks.

[13] Bilal and Kanzig (2024) highlight that reverse causality challenges emerge in regressions of temperature (in levels) on GDP, that potentially introduces attenuation bias in the results. However, they assess that the size of the bias may be small since the short run impact on temperature from increased emissions due to increased economic activity will be negligible.

[14] Alternative specifications of the baseline models using one lag of dependent variable and temperature shock variables did not yield significantly different results.

We also conduct country-specific assessments of the local temperature shocks by separately re-estimating linear LP models for select countries, namely Aruba, Barbados, Belize, Jamaica, Suriname, and Trinidad and Tobago. The country-specific analysis lends for greater flexibility with regards to variable selection (modelling) and allows for an assessment of differential responses to temperature shocks across countries, that could inform country specific policy responses to climate change.

We also examine potential exogenous channels through which the effects of temperature may propagate. In supplementary analyses, we examine the impact of global temperature shocks on the probability of the occurrence of a natural disaster – tropical cyclone, in the Caribbean by estimating the following parsimonious panel model:

$$Storm_{i,t} = \alpha + \beta \, T_{i,t}^{shock} + \varepsilon_t \qquad (2)$$

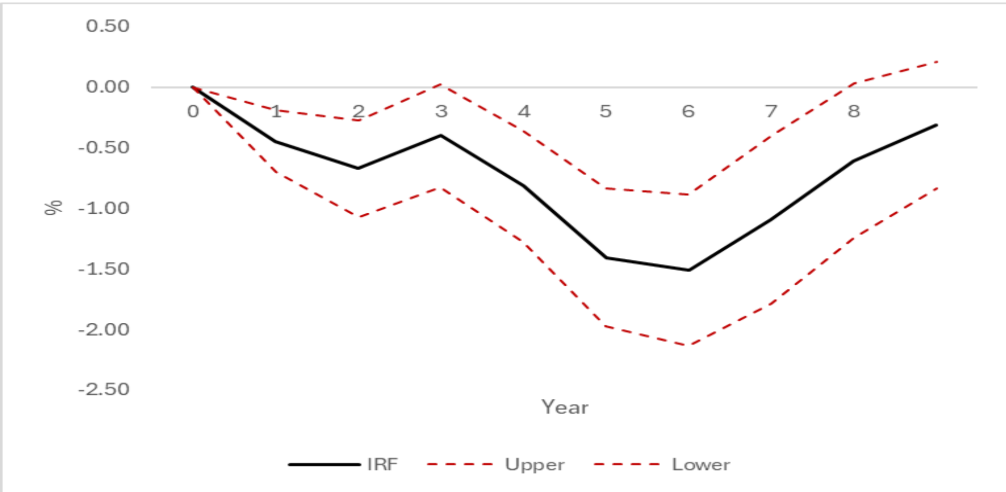
where the dependent variable $Storm_{i,t}$ is dichotomous and set equal to one if a storm was recorded in a country in a given year and zero otherwise. The key independent variables are the shocks in local $T_{i,t}^{shock}$ or global (T_t^{shock}) temperatures and β can be interpreted as the probability of a storm.

5. RESULTS

5.1 Macroeconomic Effects of Local and Global Temperature Shocks for the Caribbean

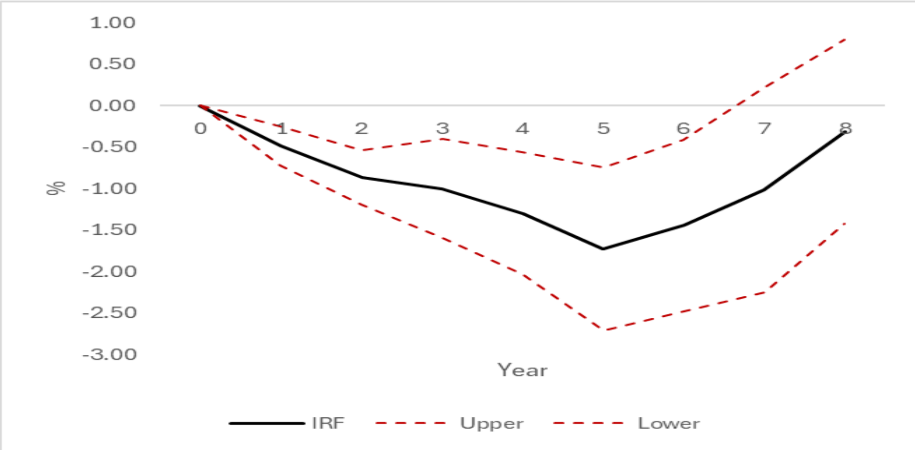
This section presents results for the effect on real GDP per capita and several key economic industries from shocks to local and global temperatures for the region as well as for select Caribbean countries. **Figures 5** and **6** show the impulse responses of real GDP per capita for the Caribbean in response to a one standard deviation (1SD) shock in local and global temperatures, respectively. In **Figure 5**, the results suggest an average accumulated reduction in real GDP per capita of approximately 1.51 per cent by year six in response to a standard deviation shock in local temperatures. This compares to an estimated cumulative reduction in real GDP per capita of 1.73 per cent five years after a global temperature shock (see **Figure 6**). For both the local and global temperature shocks, the effects germinate the year after the shock and are sustained over the medium term at relatively high levels of significance.

Figure 5: IRF for Real GDP per capita to a Local Temperature Shock, Caribbean



Notes: Figure 5 shows the impulse response of real GDP per capita in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Figure 6: IRF for Real GDP per capita to a Global Temperature Shock, Caribbean

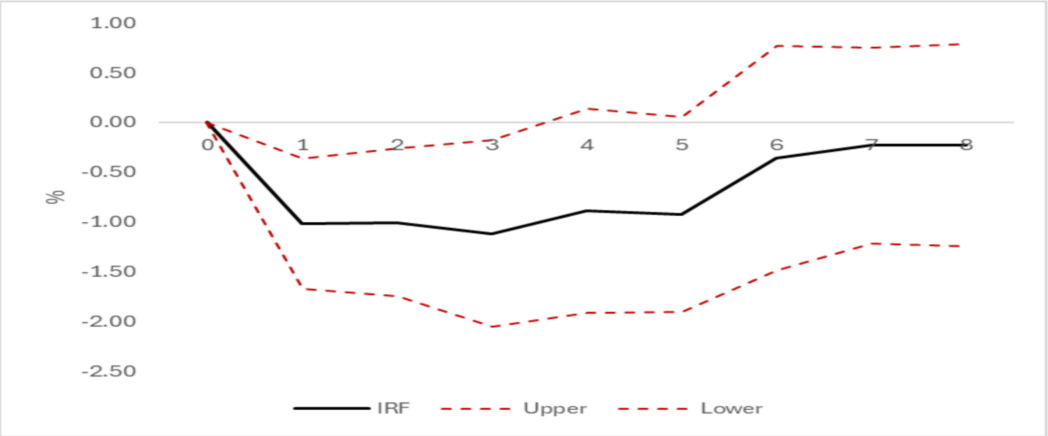


Notes: Figure shows the impulse response of real GDP per capita in the Caribbean to a one standard deviation shock in global temperature. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

These results are comparable to those reported in the recent literature (Bilal and Kanzig, 2024). When expressed as a one-degree Celsius shock, our results suggest much larger cumulative reduction in real GDP per capita in response to both a local and global temperature shocks– a maximum reduction of 6.73 per cent compared to 15.24 per cent in years six and five, respectively. The larger effect of equi-proportionate global temperature shocks may reflect the (combined) combined impact of a relatively strong correlation with local temperature shocks, the indirect effects on output through its influence on the extreme weather events – in the case of the Caribbean, more frequent and intense hurricanes and pass-through and spillover effects from the negative impact on major economies – main trading partners or source markets for foreign direct investments (FDI).

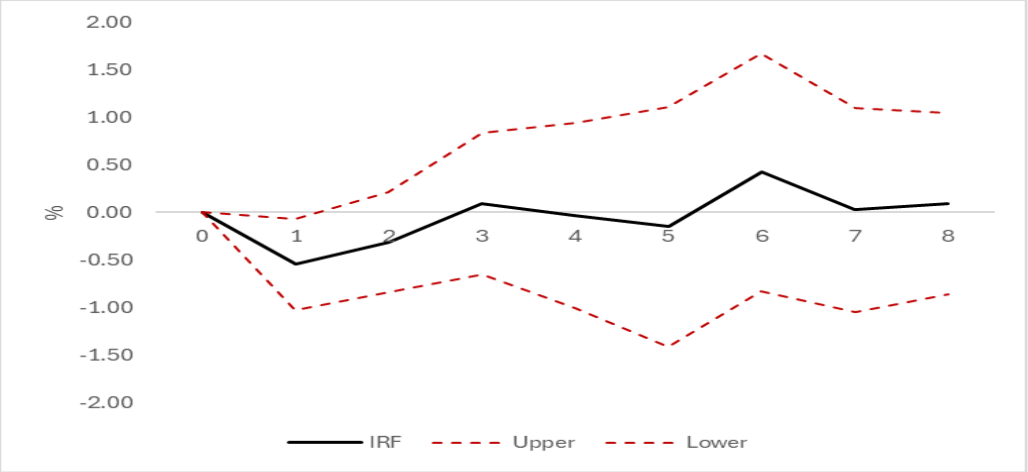
An industrial decomposition of GDP can highlight potentially differential effects from warming, conditional on the industry of the economy. A priori, we expect that climate exposed industries in the Caribbean are more likely to suffer disproportionate losses from temperature increase compared to less exposed industries. **Figures 7** and **8** present results for the agriculture industry. The results suggest that local temperature shocks have a larger and more prolonged negative effect on agriculture output relative to global temperature shocks. The IRFs show a maximum cumulative contraction in agriculture output of 1.13 per cent by the third year in response to a standard deviation shock in local temperature, compared with 0.55 per cent in year one in response to shock in global temperature. Compared to the global temperature shock, the effects of local shocks on agriculture output are also more prolonged, remaining depressed for at least eight years, though statistically significant for only three. These results suggest that direct effects of warming are more critical determinants of output in the agriculture industry and point to the potential usefulness of local interventions to mitigate the negative growth effects for the industry.

Figure 7: IRF for Real Agriculture GDP per capita to a Local Temperature Shock, Caribbean



Notes: Figure 7 shows the impulse response of real agriculture value added per capita in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

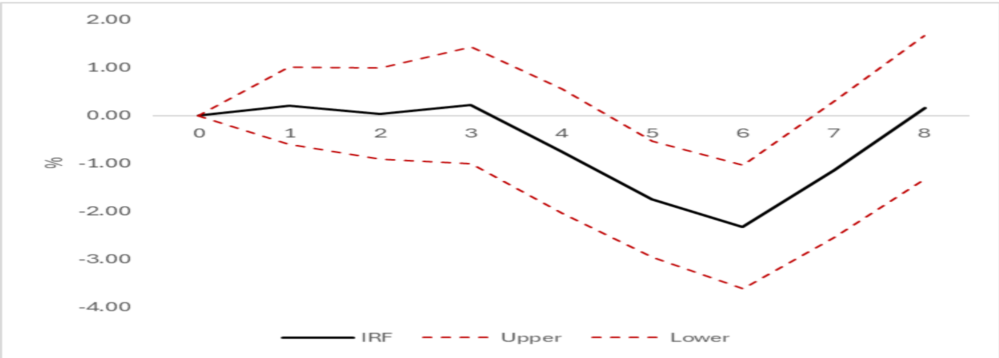
Figure 8: IRF for Real Agriculture GDP per capita to a Global Temperature Shock, Caribbean



Notes: Figure 8 shows the impulse response of real agriculture per capita in the Caribbean to a one standard deviation shock in global temperature. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

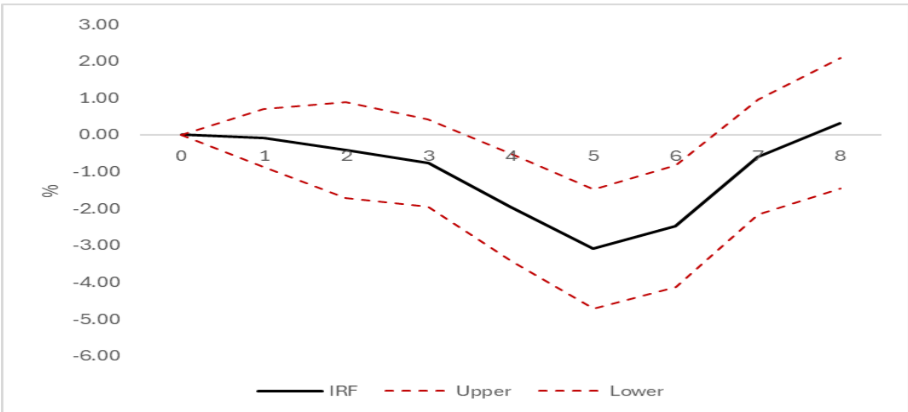
The results for the construction industry are reported in **Figures 9** and **10**. Results suggest an average cumulative and statistically significant decline in construction value added beginning in year five, with a trough of 2.33 per cent in year six, in response to local temperature shocks. Following a similar pattern, the results in **Figure 10** suggest that a one standard deviation shock in global temperature reduces construction output after four years with maximum decline of 3.31 per cent in year five. The effects of global temperature shocks are not only marginally larger but are also slightly more sustained *vis a viz* local temperature shocks. The dynamics, particularly for the local shock, highlight delayed impulse responses, perhaps due to the nature of investments in the construction industry, where projects that have already been financed are more likely to proceed while new construction projects are more likely to be impacted.

Figure 9: IRF for Real Construction GDP per capita to a Local Temperature Shock, Caribbean



Notes: Figure 9 shows the impulse response of real construction value added per capita in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

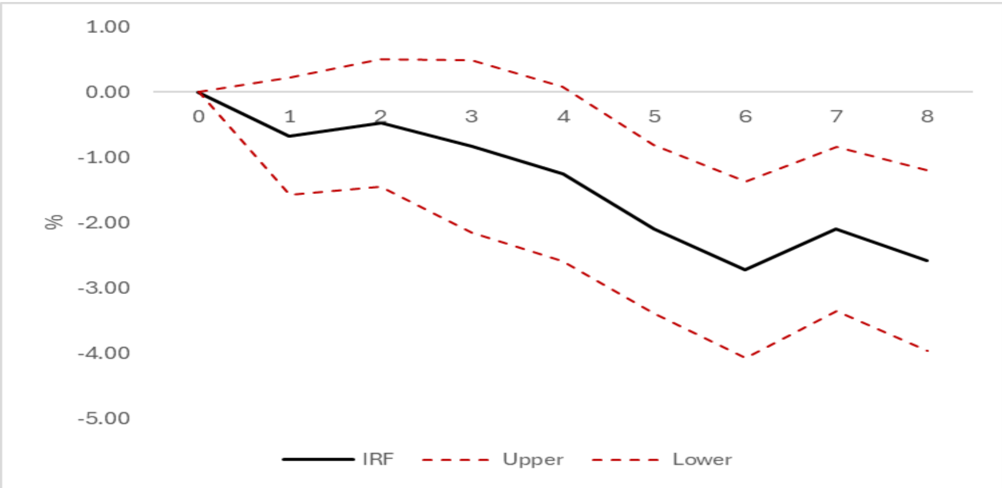
Figure 10: IRF for Real Construction GDP per capita to a Global Temperature Shock, Caribbean



Notes: Figure 10 shows the impulse response of real construction value added per capita in the Caribbean to a one standard deviation shock in global temperature. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

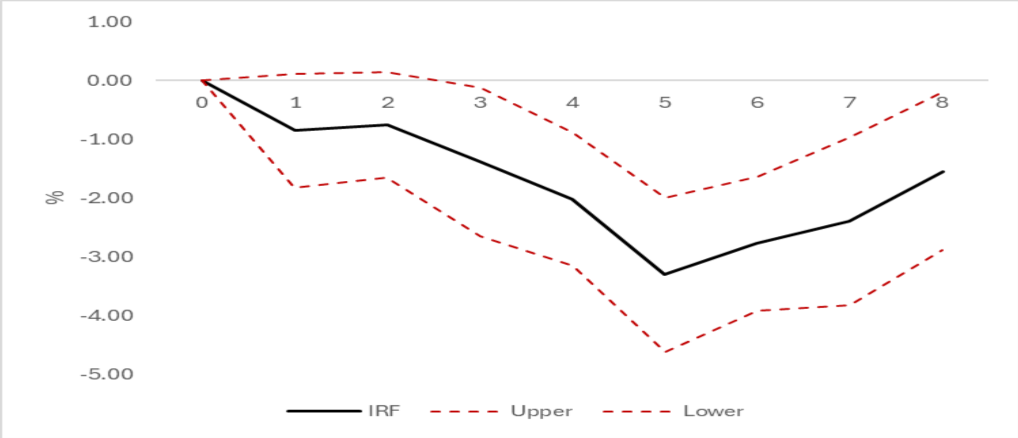
The results presented in **Figures 11** and **12** suggest that manufacturing output in the Caribbean is also quite sensitive to temperature rise. Maximum cumulative reduction in manufacturing value added per capita of 2.72 per cent (in year six) in response to a standard deviation shock in local temperatures is less than the estimated 3.31 per cent (in year five) for the global temperature shock. In general, the results are in line with other studies which find strong negative responses for manufacturing productivity in developing economies, due inter alia to relatively high levels of thermal stress among workers and inadequate climate-controlled working conditions. Further, manufacturing processes are sensitive to the ambient temperature within and around the factory space as temperature changes can result in increased need for more frequent and intensive preventative maintenance, leading to significant increases in production costs, equipment failure, production downtime and reductions in output.

Figure 11: IRF for Real Manufacturing GDP per capita to a Local Temperature Shock, Caribbean



Notes: Figure 11 shows the impulse response of real manufacturing value added per capita in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

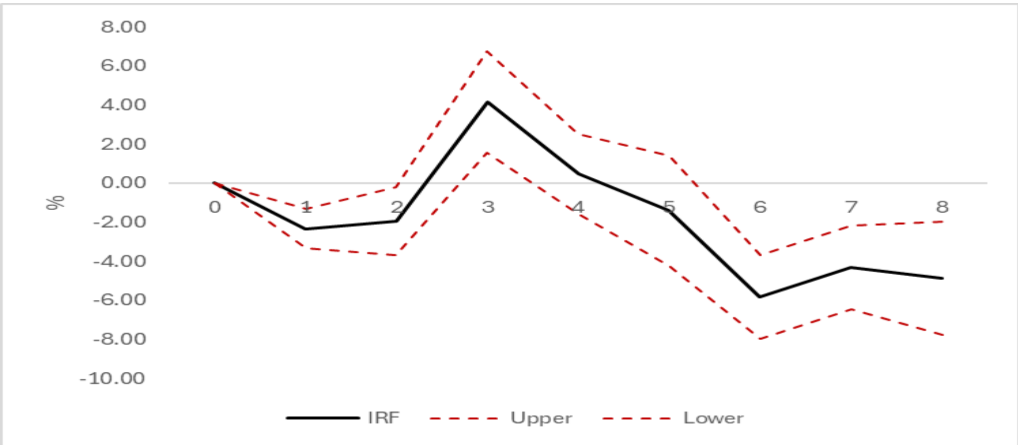
Figure 12: IRF for Real Manufacturing GDP per capita to a Global Temperature Shock, Caribbean



Notes: Figure 12 shows the impulse response of real manufacturing value added per capita in the Caribbean to a one standard deviation shock in global temperature. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

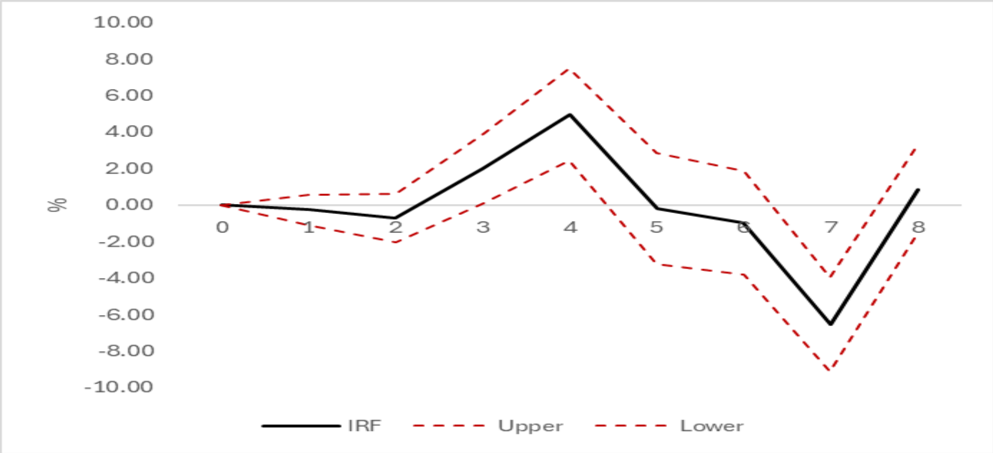
The impact of local and global temperature shocks on tourist arrivals to the Caribbean is ambiguous, reflecting both positive and negative impulses over the estimation horizon (see **Figure 13-14**). Results suggest an initial reduction in arrivals the year after the shock which is more than offset by subsequent increases in arrivals, cumulating four years after the local temperature shock. Subsequent reductions in arrivals resulted in an estimated cumulative decrease of 5.82 per cent over six years. A similar pattern is observed for the global temperature shock – an increase in arrivals in year four, offset by reductions culminating in a 6.56 per cent decrease in year seven.

Figure 13: IRF for Tourist Arrivals to Local Temperature Shocks, Caribbean



Notes: Figure 13 shows the impulse response for tourist arrivals to the Caribbean to a one standard deviation shock in global temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

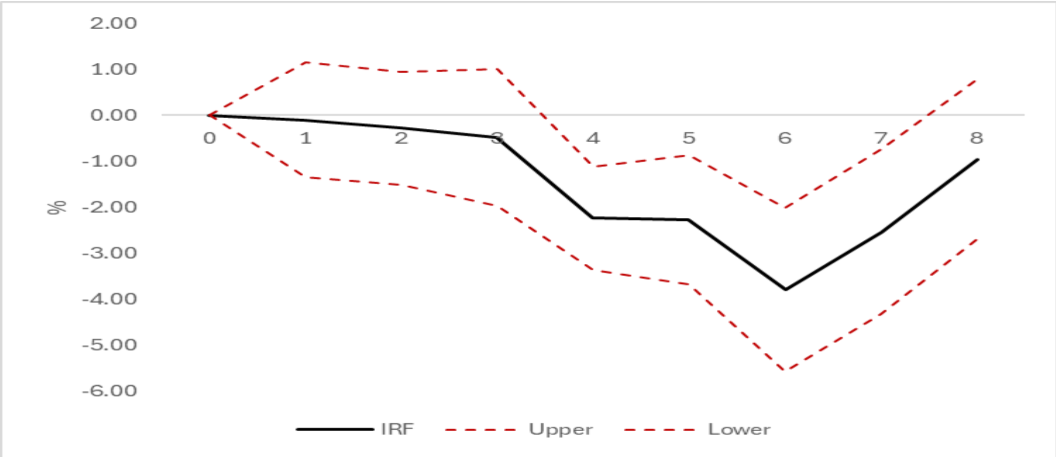
Figure 14: IRF for Tourist Arrivals to a Global Temperature Shock, Caribbean



Notes: Figure 14 shows the impulse response for tourist arrivals to the Caribbean to a one standard deviation shock in global temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

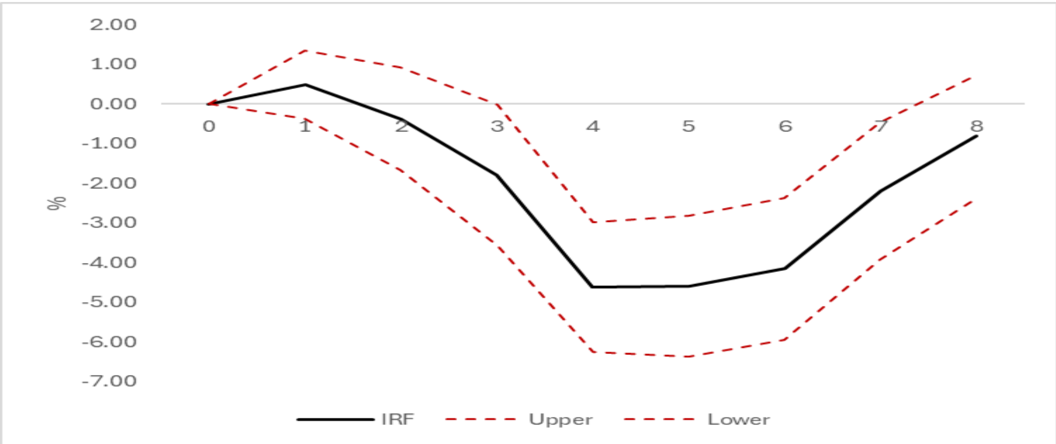
Figures 15 and **16** present results for the effects of local and global temperature shocks on investment, proxied by gross fixed capital formation per capita. In response to local temperature shocks, investment in the Caribbean decreases by as much as 3.80 per cent after six years and remains depressed through the estimation horizon. The effect of the global temperature shock is larger, suggesting a maximum cumulated decrease in investment of 4.61 per cent four years after the shock and is slightly more prolonged compared to the local temperature shock. These results may be explained by the generally negative impact of temperature rise on output and productivity, which implies higher risks for potential investors and serves as a disincentive for capital investment. The larger impulses from the global temperature shock suggests potential transmission through an additional channel – for example where negative economic outcomes associated with climate change in source foreign direct investment (FDI) markets spills over and reduces their proclivity for outward investments in regional economies.

Figure 15: IRF for Investment to Local Temperature Shocks, Caribbean



Notes: Figure 15 shows the impulse response of investment [proxied by gross fixed capital formation per capita] in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

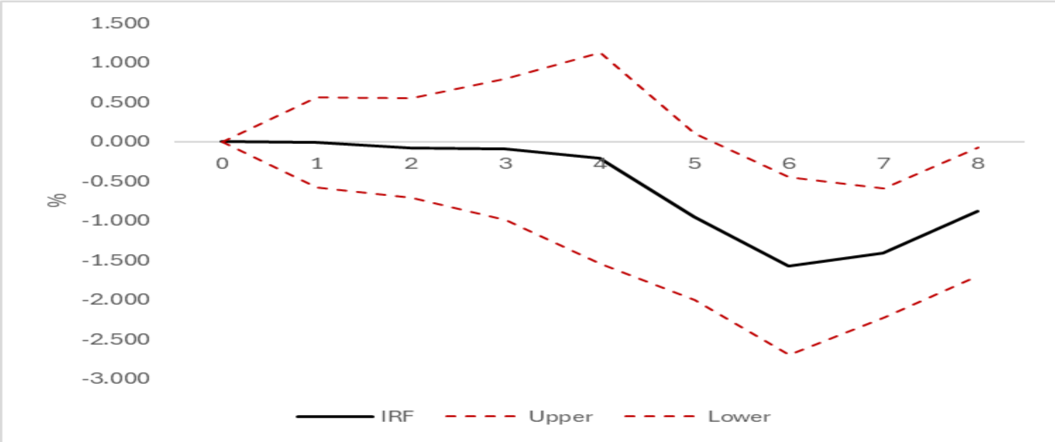
Figure 16: IRF for Investment to a Global Temperature Shock, Caribbean



Notes: Figure 16 shows the impulse response of investment [proxied by gross fixed capital formation) in the Caribbean to a one standard deviation shock in global temperature. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

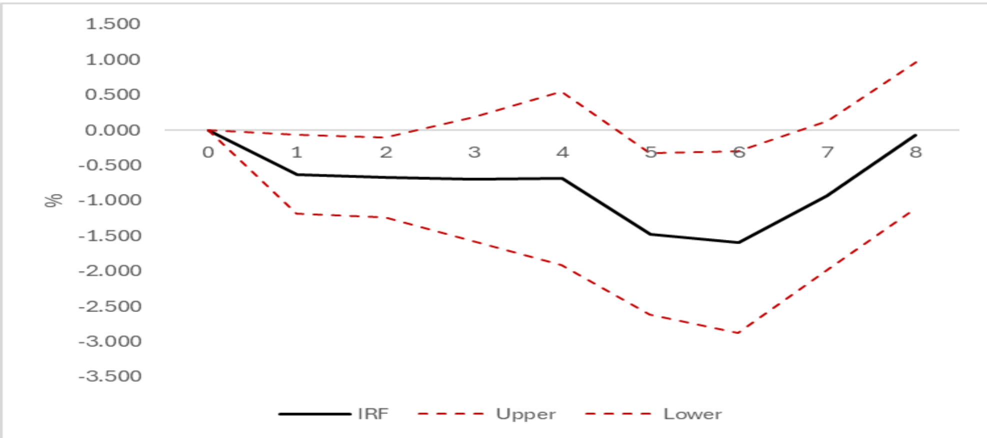
Turning to final consumption per capita, the impulse responses show a negative effect of local and global shocks. In **Figure 17**, the results show that a one standard deviation shock in local temperature reduces final consumption per capita by a cumulative 1.58 per cent over six years. Similarly, in **Figure 18**, a standard deviation shock in global temperature reduces final consumption per capita by as much as 1.59 per cent (in year six). Results suggest that potentially positive responses of consumption due to increased spending on cooling may be offset by negative responses associated with lower productivity and income. Literature examining the effect of temperature rise on aggregate consumption is scant, but nascent evidence suggests potential heterogenous effects conditional on consumption patterns and occupations (Aggarawl, 2020).

Figure 17: IRF for Final Consumption to Local Temperature Shocks, Caribbean



Notes: Figure 17 shows the impulse response of final consumption per capita in the Caribbean to a one standard deviation shock in local temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Figure 18: IRF for Final Consumption to a Global Temperature Shock, Caribbean



Notes: Figure 18 shows the impulse response of final consumption per capita in the Caribbean to a one standard deviation shock in global temperatures. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

5.1.1. Impact of Temperature Shocks on Likelihood of Storms, Flooding, and Drought in the Caribbean

In general, the effects of global temperature shocks on the respective macroeconomic variables are larger compared to local shocks of a similar magnitude. We assess that the difference may be due to a combination of the direct temperature effects given the strong correlation between local and global temperature, as well as indirect effects including, *inter alia* spillover effects from main trading partners and source markets as well as the impact of extreme weather events such as hurricanes. We test the third hypothesis by examining the relationship between local and global temperature and the formation of storms in the Caribbean. **Table 3** presents the results from linear probability panel regressions examining the impact of local and global temperature shocks on the probability that the Caribbean will experience either of three climatic events. With respect to the probability of a storm, while the coefficient on local temperature shock (0.11) is positive, it is not statistically significant. On the other hand, the global temperature shock has a positive and significant effect on the probability of a storm and is almost three times as large (0.29) as the local shock. Local temperature shocks were found to increase the probability of droughts while the effects from the global shocks were not statistically significant. Results for flooding were not consistent with *a priori* expectations – suggesting a negative and statistically significant impact from global shocks. In general, our findings are parallel to Bilal and Kanzig (2024) findings that global shocks are a key driver of extreme weather events which act as exacerbators, resulting in stronger negative impulses for real GDP per capita across advanced and emerging market economies.

Table 3: Impact of Temperature Shocks on the Probability of a Storm in the Caribbean

	Storm	Drought	Flood
Local Temp	0.11	0.08**	-0.01
	(0.08)	(0.03)	(0.03)
Global Temp	0.29**	0.04	-0.18**
	(0.12)	(0.02)	(0.07)

This table reports the results for the estimation of local and global temperature on extreme events. In column (1) is the probability of storm, column (2) is the probability of flooding, and in column (3) is the probability of drought. Numbers in parentheses are robust standard errors. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

5.2 Macroeconomic Effects of Local and Global Temperature Shocks for Selected Caribbean Economies

This section examines the cross-country effects of warming on key macroeconomic outcomes for select Caribbean countries.[15] In general, results suggest heterogenous effects from local and global temperature shocks for the countries examined.

Results for Aruba

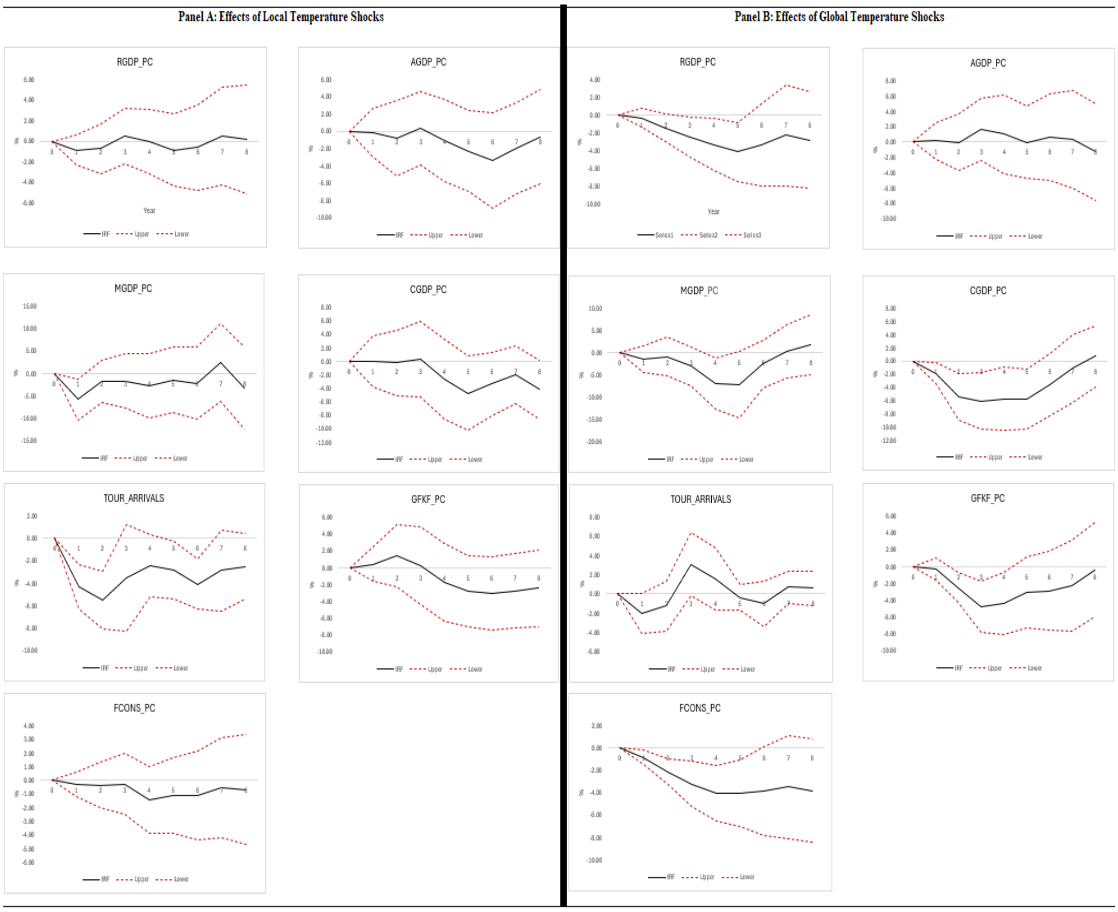
The results for Aruba are presented in **Figure 19** and suggest that the overall economy is generally robust to local temperature shocks, reflected in an economically and statistically insignificant impulse response for real GDP per capita. On the other hand, the global temperature shock results in a cumulative 4.13 per cent reduction in real GDP per capita in year five. However, the results mask varied sensitivity to temperature changes across respective industries in the economy. Though marginally significant and ephemeral, manufacturing output declines by a cumulative 5.84 per cent one year after the local temperature shock and 7.07 per cent five years after the global temperature shock. The global temperature shock results in a statistically significant decrease in construction value added per capita by a cumulative 5.80 per cent five years after the shock, while the effect from the local temperature shock is muted in the near term and statistically insignificant over the estimation horizon. Tourist arrivals decrease by a cumulative 4.10 per cent after year six in response to a local temperature shock, while results for the global shock, though positive, are not statistically significant. Impulses to real GDP and the respective components appear to be driven, at least in part, by the investment and consumption channels. We find negative and significant responses to the global temperature shock for investment and final consumption per capita, cumulating to 4.77 per cent after three years and 4.07 per cent after four years, respectively. Responses to the local temperature shock are not statistically significant.

The relative impact of local *vis a viz* global temperature shocks potentially highlights Aruba's dependence on external capital – where adverse shocks in source markets decrease investment flows into the local economy resulting in compressed output across key industries, particularly construction. The effects on consumption reflect the net impact of heat induced expenditures –

[15] Countries selected are representative of the Caribbean region and include a mix of tourist dependent and oil exporting economies.

including increased energy consumption for cooling *viz a viz* reductions in consumption on account of the adverse economic effects of warming.

Figure 19: Effects of Local and Global Temperature Shocks on Macroeconomic Outcome for Aruba

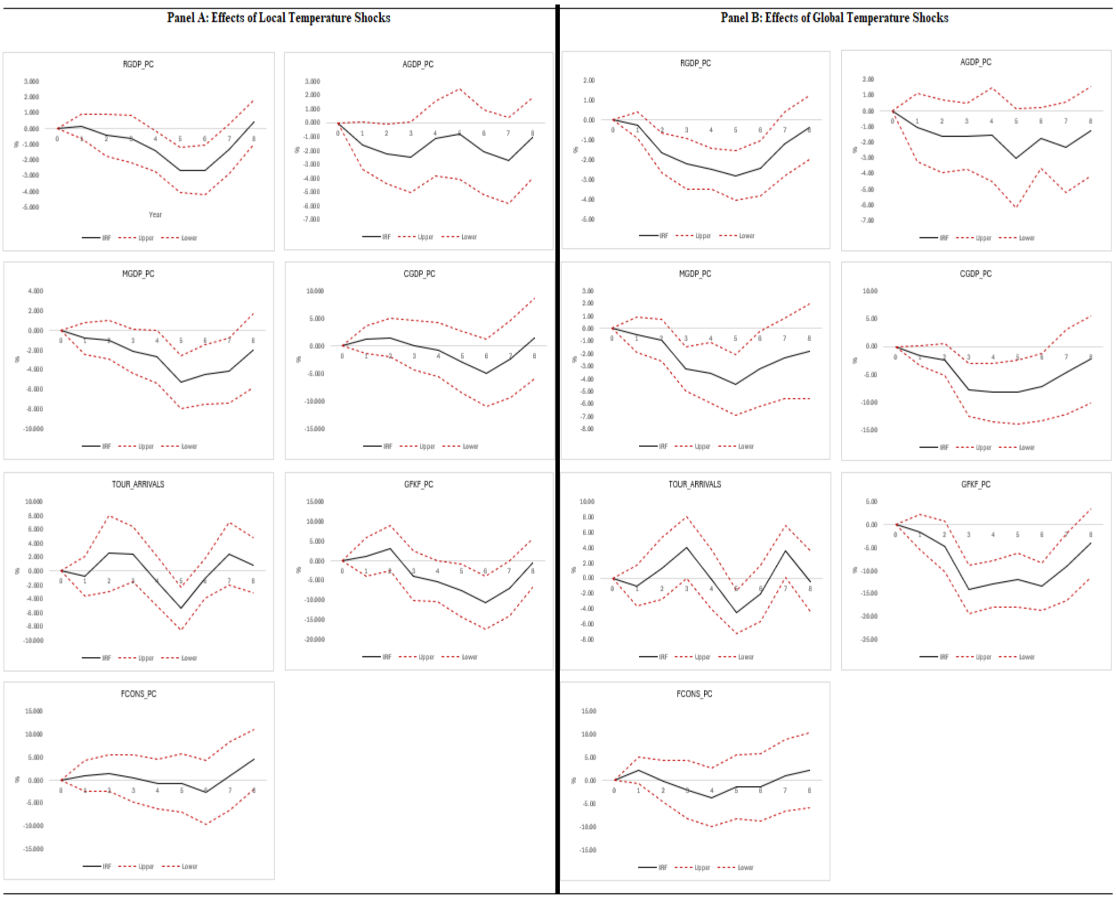


Notes: Figure 19 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Aruba. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Results for Barbados

Results for Barbados highlight sensitivities in aggregate output to both local and global temperature shocks (see **Figure 20**). We find maximum cumulative decreases in real GDP per capita of 2.66 per cent (in year six) and 2.83 per cent (in year five) in response to local and global temperature shocks, respectively. Results are mainly driven by the manufacturing and construction industries. Manufacturing value added per capita decreases by a cumulative 5.26 per cent and 4.48 per cent six years after the local and global temperature shocks, with more sustained effects from the latter. Construction output was not significantly impacted by the local temperature shock but registered as cumulative decrease of 8.28 per cent after four years in response to the global temperature shock. Agriculture value added was only marginally reduced by the local temperature shock. Results for tourist arrivals suggest a cumulative decline of 5.38 per cent and 4.5 per cent for the local and global temperature shocks in year five, respectively. Investment in the Barbadian economy appears sensitive to changes in both local and global temperature, with more acute effects from the latter. A standard deviation shock in the global temperature results in a maximum cumulative decrease in investment of 14.12 per cent in year three and the effects are more persistent over the estimation horizon compared to the local temperature shock with a maximum cumulative reduction of 10.5 per cent in year six. Temperature effects on final consumption per capita are not statistically significant.

Figure 20: Effects of Local and Global Temperature Shocks on Macroeconomic Outcome for Barbados

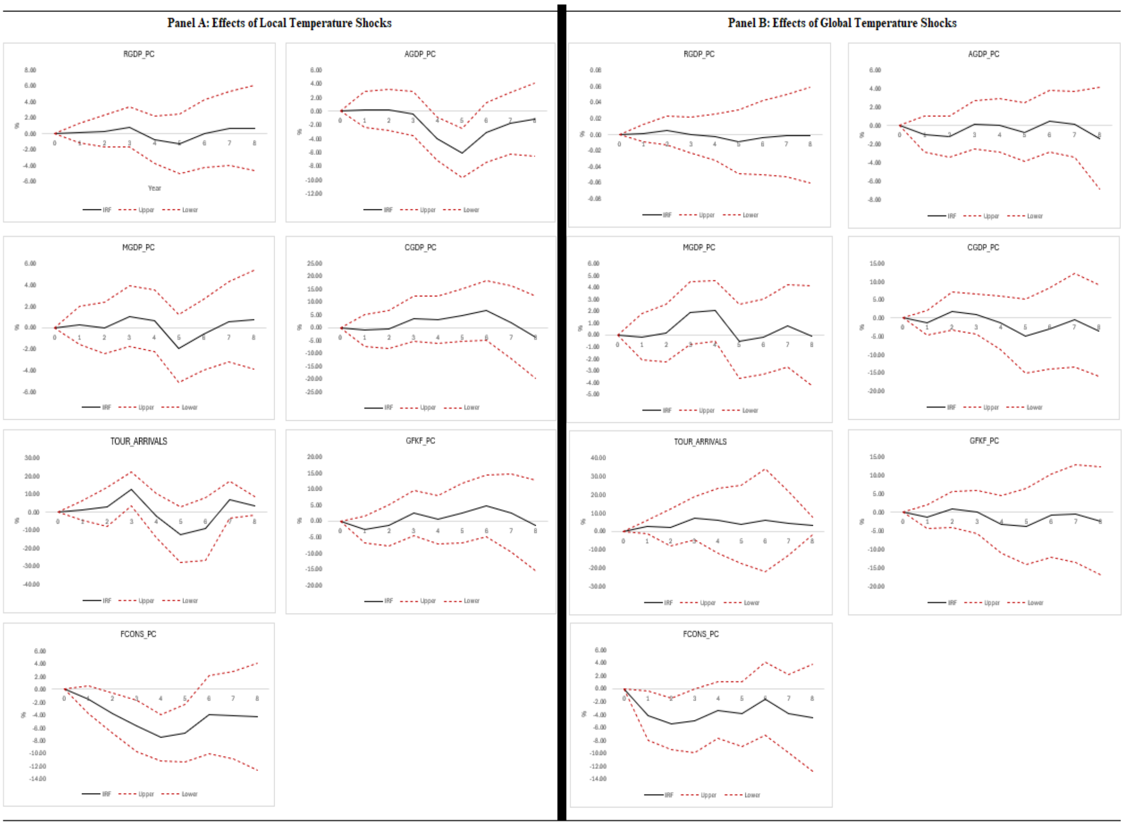


Notes: Figure 20 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Barbados. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Results for Belize

Real GDP for Belize is not significantly affected by shocks in either local or global temperatures, but these aggregate results mask industrial sensitivity, in particular for the agriculture industry (see **Figure 21**). Agriculture value added per capita decreased by a cumulative 6.16 per cent in year five. While the lower output persists over the estimation horizon, effects are statistically significant for the fourth and fifth years only. An estimated cumulative increase in tourist arrivals of 12.72 per cent in year three was only marginally statistically significant. Effects on the other industries are not statistically significant for either local or global temperature shocks. Negative and statistically significant impulses are also found for final consumption – a maximum cumulative reduction of 7.54 per cent in year four and 3.95 per cent in year five for the local and global temperature shocks, respectively, but the null effects for real GDP suggest relatively weak passthrough to the aggregate level. In contrast to the results for the Caribbean on a whole as well as the select countries examined, temperature sensitivities in Belize appear stronger in respect of local *vis a viz* the global temperature shock.

Figure 21: Effects of Local and Global Temperature Shocks on Macroeconomic Outcomes for Belize

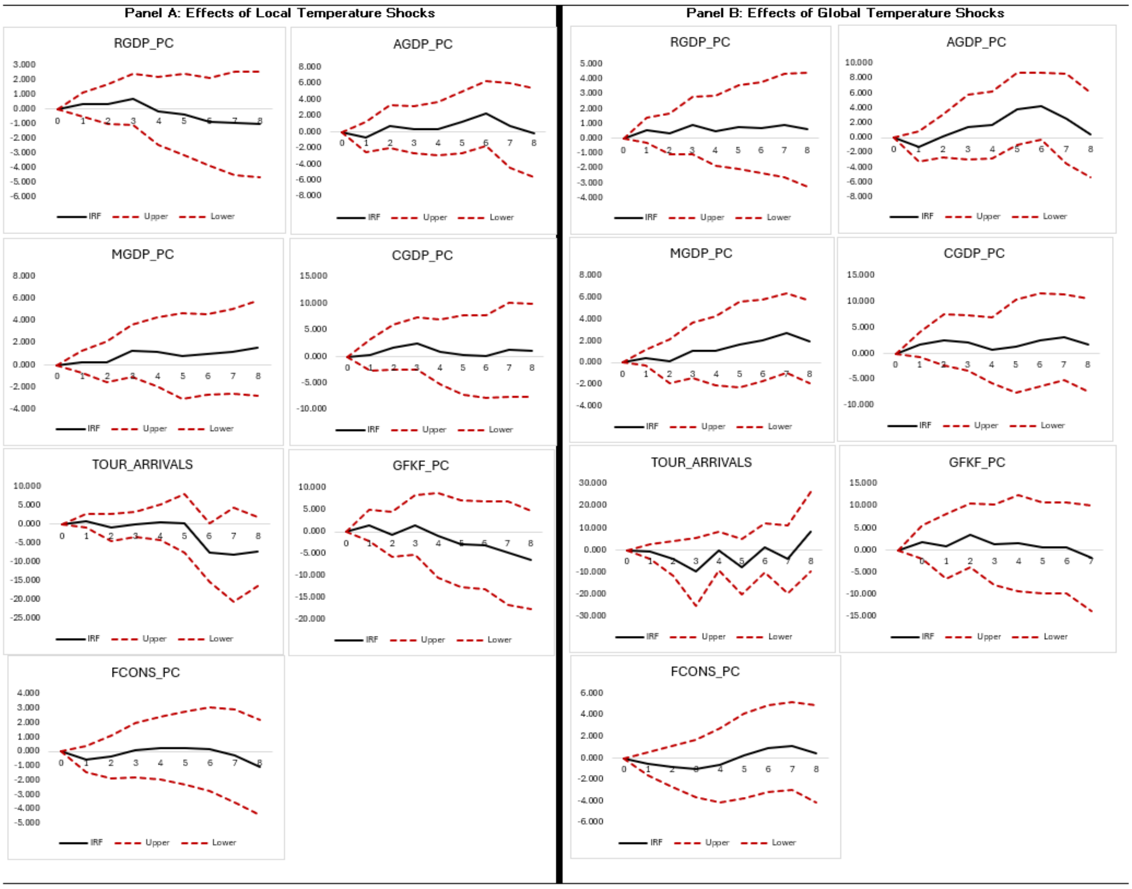


Notes: Figure 21 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Belize. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Results for Jamaica

For Jamaica, the results shown in **Figure 22** suggest that neither local nor global temperature shocks have a statistically significant impact on real GDP per capita. When looking at the sub-components of GDP, the results show that agriculture value added per capita responds positively to a standard deviation shock in local and global temperature. However, in both cases, the effect is statistically insignificant. For the manufacturing and construction sub industries, the results show a statistically insignificant response to both shocks. Showing an erratic pattern, tourist arrival also responds insignificantly to the local and temperature shocks. The results show that both investment and final consumption do not react to an increase in global or local temperature shocks. These results suggest that on an aggregate level, temperature does not alter economic activity in Jamaica in these industries.

Figure 22 Effects of Local and Global Temperature Shocks on Macroeconomic Outcomes for Jamaica

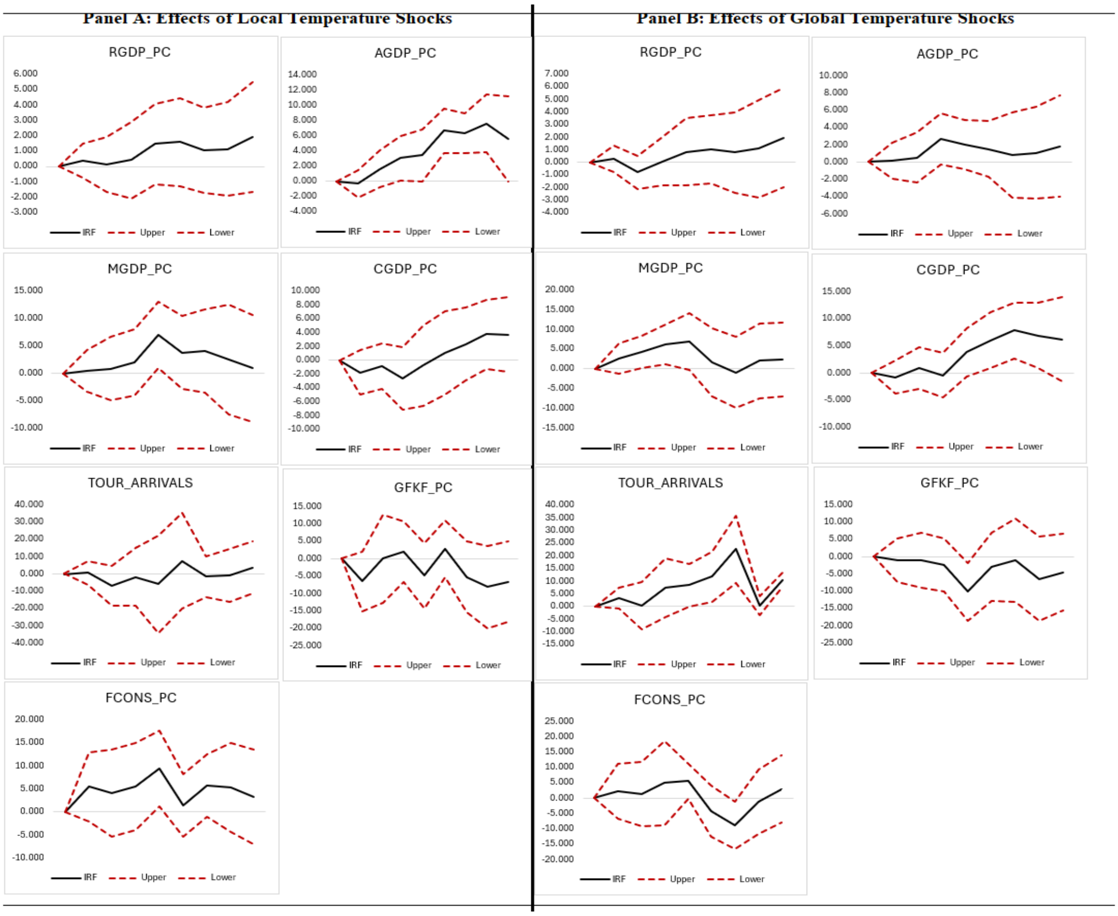


Notes: Figure 22 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Jamaica. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Results for Suriname

Figure 23 shows the results for Suriname. As indicated in Panels A and B, the impact of local and global temperature shocks on the Suriname's economy is not statistically significant. However, when looking at the sub-components of GDP, the results show differential but generally positive effects across selected industries. In Panel A, the results show that a standard deviation shock in local temperature raises agriculture value added per capita by 7.62 per cent over seven years while the impact of the global temperature shock is statistically insignificant. Like agriculture, a standard deviation shock in local temperature raises manufacture output by 6.9 per cent over four years. However, after this period, the effect becomes statistically indistinguishable from zero. The effects of a global temperature shock on manufacturing value added appear to show more persistence, increasing output by 6.2 per cent over 3 to 5 years. In the construction industry, the results indicate that while local temperature shocks may not significantly affect output, a global temperature shock raises construction value added per capita in Suriname by a high of 7.9 per cent after six years. Tourist arrivals are also positively impacted by the global temperature shock, increasing by a cumulative 22.7 per cent in year six. Looking at investment and consumption, the results show that global temperature shocks have the dominant role as it reduces investment per capita by 10.1 per cent over five years and reduces final consumption by 8.9 per cent over seven years. These results suggest that while overall, GDP is not significantly impacted by local and global shocks, this null effect is due to the industrial heterogeneity. While temperature shocks may raise the output of agriculture, manufacturing and construction and tourism, it reduces consumption and investment.

Figure 23: Effects of Local and Global Temperature Shocks on Macroeconomic Outcomes for Suriname



Notes: Figure 23 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Suriname. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

Results for Trinidad and Tobago

When looking at Trinidad and Tobago, the results in **Figure 24** show that both local and global temperature adversely impact real GDP per capita. Specifically, the results show that a standard deviation shock in the local temperature reduces real GDP per capita by a cumulative 5.87 per cent after eight years. A standard deviation shock in global temperature reduces real GDP per capita by cumulative 6.09 per cent over the six years following the event. However, the impact on real GDP per capita cannot be readily attributable to the industries examined - agriculture, manufacturing, and construction, as they are not significantly impacted by local and global shocks. The results show that tourism arrivals only decline in response to a global temperature shock. In contrast to the regional results, neither local nor global temperatures had a statistically significant effect on investments and final consumption in Trinidad and Tobago.

Figure 24 Effects of Local and Global Temperature Shocks on Macroeconomic Outcomes for Trinidad and Tobago

Notes: Figure 24 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for Trinidad and Tobago. Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

5.3 Robustness Checks

To test the robustness of the baseline results, alternative temperature shock variables were constructed and applied to regional models.

A standardized temperature shock variable is derived using the following formula:

$$T_i^s = \frac{T_i - \bar{T}_i}{\sigma_{T_i}}$$

Where T_i^s represents the standardized local or global temperature that follows a distribution of mean zero and standard deviation of one. This is calculated as the difference between the observed temperature (local and global) and the average temperature divided by the standard deviation. The dynamics effect on real GDP per capita, its respective components as well as the main drivers – final consumption and investment, are similar to the baseline results for both local and global temperature shocks. Though more muted, the impact of local and global temperature shocks on real GDP per capita are negative and statistically significant, this time driven by lower manufacturing output as the effects on construction are only marginally significant and ephemeral (see Figure 25).While the differential effects of local and global temperature shocks on the macroeconomic variables examined suggest larger local impact, equi-proportional shocks confirm the baseline finding – larger effects from global temperature shock.

Figure 25: Robustness Check: Macroeconomic Effects of a Standardized Temperature Shock on the Caribbean

Notes: Figure 25 shows the impulse response functions (IRFs) for respective macroeconomic outcome variables in response to a standard deviation shock in local (Panel A) and global (Panel B) temperatures for the Caribbean. Temperature shock variables are calculated as the difference between the observed local and global temperature and the average as a ratio of the standard deviation (Z score). Red dashed lines represent the upper and lower confidence bands (95.0%) around the point estimates which are represented by the solid black line. Period zero (0) corresponds with the year of the shock and impulses are traced over an eight (8) year horizon.

6. CONCLUSION AND POLICY IMPLICATIONS

This study examined the effects of local and global temperature shocks on real GDP per capita and for key industrial components for Caribbean economies using local projection methods. Results suggest that on average, Caribbean economies are sensitive to temperature rise, with statistically significant reductions in real GDP per capita in response to both local and global temperature shocks. In general, growth effects for the Caribbean are channeled through reductions in investment and final consumption, with larger impulses from the former. Consistent with recent studies using data for advanced and emerging markets and developing economies, this research confirms generally stronger and more persistent negative effects from global *vis a viz* local temperature shocks on regional GDP. Larger effects from global temperature shocks point to the existence of additional channels through which warming may be precipitated – such as through spillovers from effect on more advanced economies and main trading partners as well as through the effects on extreme weather events.

Cross industrial assessment reveals heterogenous responses across economic industries to local and global temperature shocks. The decline in real GDP per capita can be largely attributed to reduced output in construction, manufacturing, and agriculture. While agriculture was found to be more severely impacted by local temperature shocks, construction and manufacturing, experienced larger and more persistent declines in response to the global shock. Implications for tourist arrivals are ambiguous – positive and negative effects over the estimation horizon but highlight potential risks to tourist dependent economies from temperature rise.

The heterogeneity extends to the country specific analyses, where Caribbean economies display varied levels of sensitivity to local and global temperature shocks on the aggregate and at the industrial level. Results suggest that Barbados is more acutely sensitive to the risks of warming, where both local and global temperature shocks induced reductions in real GDP per capita, largely due to lower manufacturing and construction output, precipitated by lower investment. Negative growth effects for Aruba and Trinidad and Tobago from both local and global temperature shocks, though only marginally significant, are economically material and suggest potential risks to these economies associated with warming.

In general, construction and to a lesser extent manufacturing activity across the region appears more reactive to global temperature shocks, with significant declines observed in the case of Barbados and Aruba, perhaps reflecting the major role played by foreign investors in the industry. There is suggestive evidence that local temperature shocks are more critical for the agriculture and tourism industries, implied by larger shock induced declines in Belize and Aruba, respectively. While heat effects for Jamaica are relatively more benign, the Surinamese economy appears to be positively impacted, with growth inducements in agriculture in response to the local temperature shock and in construction and tourist arrivals in response to the global temperature shock.

The results have important implications for economic policy and climate action (adaptation and mitigation) across regional economies. First, the results highlight the negative impact of warming on climate exposed industries on which regional economies are heavily dependent – suggesting that efforts toward economic diversification may be beneficial to reduce vulnerability to local and global temperature shocks. Therefore, it is important for Caribbean countries to broaden their investment focus to include technology-intensive industries and financial service delivery that are less sensitive to temperature variations. Digitalisation and the digital transformation of the productive process can induce efficiency gains, and aid in the region building its resilience to climatic events.

Second, given the regions' reliance climate exposed industries, strategies to boot adaptation should be considered to mitigate any potential impairment in productivity. For example, adaptation of climate smart agriculture practices including resilient water management and irrigation practices, precision agricultures and cultivation and marketing of heat resilient crops. Eco-tourism is another way countries can position themselves to adopt and exploit opportunities that accompany hotter climatic conditions.

Third, Caribbean economies should advance progress toward the green energy transition (GET) – thus, significantly lowering their dependence on fossil fuels. The benefits from the GET are twofold. Notwithstanding the relatively small contribution of the region to overall greenhouse gas (GHG) emissions, reductions will contribute to the slowing of the rate of climate warming and inure to the benefit of vulnerable Caribbean economies. Further, access to lower cost alternative energy sources (solar, wind, geothermal) can help to satisfy increased energy demand for cooling, reduce overall cost and risks associated with economic activity and thereby mitigate any downward pressures on investment and growth. Embedding climate adaptation measures in infrastructure development – beyond the energy industry – and supply chains can bolster productivity despite a changing climate, de-risk regional investment and support resilient growth.

Fourth, international cooperation and participation in global climate fora are critical in securing regional resilience to temperature shocks. In this context, commitments made by larger more advanced economies under the Paris agreement to reduce GHG are critical in stemming the rate of warming and the negative associated effects for regional economies. At the regional level, collaboration to address transboundary climate issues and sharing of best (adaptive) practices can bolster resilience and mitigate the negative economic and social effects of warming.

Successfully implementing these policies in the Caribbean is wrought with challenges. In general, regional economies lack the financial resources and institutional capacity to effectively address the economic and social risks associated with global warming. In this regard multilateral institutions have an important role to play by assisting Caribbean economies in leveraging climate financing modalities building out institutional capacity to support effective and efficient climate response.

While the results in this paper are interesting and have implications for climate policy development in the Caribbean, there are limitations to the study that are worth noting. Firstly, the research used average rather than population weighted temperature data, which is used in more recent studies. Use of population weighted temperature data would align more closely with economic nexus within countries and could allow for more accurate estimates of the effects on the macroeconomy. Secondly, the research did not examine potential non-linearities in the relationship between temperature and key macroeconomic outcomes. Third, data limitations precluded a more comprehensive assessment of the potential channels through which temperature might impact the economy. Notably however, the small size and the relatively flat distribution of temperature in the countries sampled suggest that these might not significantly affect the results. Future work could seek to address these and other important questions.

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