GLOBAL TROPICAL CYCLONE DAMAGES UNDER CLIMATE CHANGE

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Abstract

Building on the analysis of Mendelsohn, Emanuel, and Chonabayashi (2011), the present study advances the understanding of the impact of climate change on tropical cyclones by refining the global tropical cyclone damages function. It differentiates marginal impacts on developed and developing countries and estimates, for the first time, the marginal impact of global tropical cyclone characteristics on damages. With this refined understanding of damages, the estimated relationships are applied to calculate expected damages of simulated hurricane tracks in the years 2008 and 2100 under four different climate scenarios. Finally, the impact of climate change on aggregate damages, as well as the global distribution of damages, is calculated. The results show that, while tropical cyclones currently cause approximately $25 billion per year in real damages, socioeconomic change will add approximately $112 billion in real damages to the global total. Climate change will result in additional damages of $110 billion. Future damages will be heterogeneous across the globe, with the United States and small island nations being harmed disproportionately more than other regions. This paper adds to the public policy debate by furthering the understanding of the vulnerability of countries to tropical cyclones across geographies and development levels and is part of a larger research effort to better understand, predict, and reduce tropical cyclone damages around the world. In addition, while past literature relied on the application of the U.S. estimated hurricane characteristics coefficients applied to a global context, the current study calculates the estimated marginal impacts of historical global (U.S. and non-U.S.) hurricanes on damages around the Earth.

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1. Introduction

Tropical cyclones are large, low pressure meteorological events with circular wind patterns and organized precipitation in tropical to sub-tropical waters. Hurricanes and typhoons are both tropical cyclones, but different terms are used to describe where they occur in the world. Hurricanes form in the North Atlantic Ocean, Northeast Pacific Ocean and the eastern South Pacific Ocean (NHC, 2010; Holland, 1993). Typhoons generally occur in the Western Pacific Ocean. The main variables in determining tropical cyclone strength and path include water temperature, vertical air temperature, humidity, low wind shear, the distance from the equator, and also an initial trigger or disturbance. Oceans store huge quantities of potential energy for hurricanes and conditions conducive to tropical cyclone formation are present often, so researchers wonder why an average of only 85 tropical cyclones form annually and not more (Emanuel, 2005).

Hurricanes currently cause approximately $9 billion per year in damages in the United States (Nordhaus, 2010). Current work by Mendelsohn, Emanuel, and Chonabayashi (2011) suggest future inflation-adjusted damages incurred in the United States without climate change will rise to about $27 billion per year in 2100 because more of the country will be situated in harm's way. Climate change impacts on storms will result in additional annual damages of $40 billion in the United States. Further study of damages is fundamental to understanding how to properly reduce coastal and inland vulnerability to future hurricane damages through appropriate public policy, insurance, education, and adaptation efforts.

To date, much of the academic literature has focused on modeling aggregate damages, mostly in the United States. Wind forces and storm surge cause most recorded hurricane damages, but inland flooding also results in damages and deaths. Further analysis of global tropical cyclone damages incorporating new significant variables, as well as new data on historical storm characteristics around the globe, will help shed light on both the issue of damages and appropriate adaptations.

1.1 Previous Results and the Current Research

The current research effort builds on the 2011 analysis of Mendelsohn, Emanuel, and Chonabayashi. In their initial work, Mendelsohn et al. (2011a) used the Hurricane Integrated Assessment Model (HIAM), which links climate conditions with hurricane damages to predict both the distribution and magnitude of hurricane damages in the United States by 2100, under four climate scenarios. As part of the model, 5,000 simulated hurricane tracks were generated for present climate and also four future climate scenarios in the year 2100, including wind speeds, barometric pressure, and landfall location. Then, a historical damage function was estimated by regressing local socioeconomic and hurricane characteristics on aggregate hurricane damage data. The resulting estimated relationship is used to calculate the aggregate damages for each of the four climate scenarios in the year 2100. It was also found that the minimum barometric pressure of a hurricane is a better predictor of resulting damages than maximum sustained wind speed, which had been used in previous literature.

The results showed that at the present time the United States has an annual expected hurricane damage of $9 billion per year. In the year 2100, due only to population and economic growth, the U.S. is expected to incur $27 to $55 billion per year in real damages, with an additional $25 billion per year of predicted damages due to climate change. Although these are expected values, predicting damages in a single year remains elusive, and the distribution of damages is such that the largest storms produce a very large percentage of expected damages.

In addition to the U.S. analysis, Mendelsohn et al. (2011b) conducted a parallel analysis using the Tropical Cyclone Integrated Assessment Model of the impact of climate change on tropical cyclone (including tropical cyclone, typhoon, and hurricane) damages around the globe. They estimate current global tropical cyclone damages to be $26 billion USD per year. They predict that in 2100, without climate change, tropical cyclones will cause an estimated $55 billion USD in real damages per year, with climate change adding an additional $54 billion USD per year in expected damages. The distribution of damages is likely to change, with North America facing $30 billion USD in damages per year and $21 billion USD per year in Asia. Caribbean islands will likely face the highest damages as a percentage of their total gross domestic product.

Both of these studies laid a solid theoretical and analytical foundation for many directions of future research. The current study adds to the research by differentiating marginal impacts on damages for developed and developing countries. New variables of global historical tropical cyclone characteristics were added to the model. This additional data allows calculation of the estimated parameters for global tropical cyclone characteristics, while past literature applied U.S. coefficients to the global analysis. These results were used to predict the impact of climate change on aggregated global tropical cyclone damages under four climate scenarios in the year 2000 and 2100. Further explanation of the current project can be found in Section 3 (*Methodology*). Directions for future work can be found in Section 4.4.

1.2 Review of the Relevant Literature

Modeling tropical cyclones, tropical cyclone damages, and the impacts of climate change have received complementary effort from both the natural and social sciences. Both areas have made advancements but much debate and future work remains, especially with regard to the social science side, as it necessarily follows new developments in the understanding of cyclones by the natural sciences.

Several points of academic debate in the natural sciences center on the relationship between hurricanes and climate change. While there is convincing evidence that rising sea surface temperature will increase the potential intensity and maximum wind speed of hurricanes, especially the most powerful hurricanes, it is still unclear by how much these factors will rise over time due to climate change (Emanuel, 2005; Montaigne 2010). With regard to the impact of climate change on hurricane frequency, some see evidence that climate change will increase hurricane frequency, while others contend that it is still too early to tell (Hallegate, 2007). Lastly, debate remains surrounding the evidence in the historical hurricane data, as some calculate climate impacts already on hurricane activity, while others claim the observed hurricane characteristics over past years to be within the range of historical trends and see no clear impact of climate change on hurricanes in recent decades (Pielke, 2005).

Among social scientists, various modeling efforts have been conducted to understand the relationship between hurricanes, hurricane damages, and climate change. In addition to the results by Mendelsohn, Emanuel, and Chonabayashi (2010) stated above in Section 1.1 (*Previous Results and the Current Research)*, the following results are noteworthy. Nordhaus (2009) estimated that climate change will result in $10 billion per year in additional U.S. hurricane damages in 2005 dollars, but this could be an underestimate, given current hurricane models. Further, warming temperatures will increase vulnerability of many coastal communities in the U.S., especially high valued areas near the Gulf of Mexico and in Florida. Narita et al. (2009) find that, by the year 2100, climate change will result in an expected $19 billion in additional damages per year globally, with the U.S. and China bearing the largest absolute damages and, similar to Mendelsohn et al. (2010), small island nations will suffer the largest percentage damages compared with their gross domestic product. Pielke (2007) observes that future hurricane damages will increase not only because of climate change, but also because additional population and assets will be located in the hurricane path, given population growth and economic development. Thus, he finds that increasing human adaptation to climate change will have a much great impact than climate mitigation in reducing future damages. Pielke contends that human adaptation will lead to a reduction in vulnerability not only from the impacts of climate change, but it will also better protect expanding population and capital in hurricane paths. All papers call for more research, especially with regard to decreasing vulnerability and increasing adaptation efforts, as well as gathering greater detail in hurricane, geographic, and socioeconomic data.

2. Theoretical Foundation

The theoretical foundation of the proposed project is based on the previous work of Mendelsohn et al. (2011). In their paper, they note that the economic damage from tropical cyclone (D) is equal to the total of all destruction caused by the tropical cyclone. In their analysis, damages were limited to buildings, infrastructure, and deaths. The expected value of damages from tropical cyclones can be calculated by:

$$E[D] = \sum_{j} \sum_{i} \pi\big(X_{ij}, C\big) D(X_i, Z_i)$$

where $\pi(X_{ij}, C)$ is the probability that tropical cyclone j will make landfall at location i, given tropical cyclone characteristics X and climate conditions C. $D(X_i, Z_i)$ represents the damages from tropical cyclone j at location i, given tropical cyclone characteristics X at i and local socioeconomic conditions Z at location i. Expected damages are a summation of the probability of a landfall at a given location multiplied by the damages from the tropical cyclones, summed across all landfalls and tropical cyclones. Atmospheric experts are key to estimating the probability function, while economists specialize in the damages portion (Mendelsohn et al., 2011).

The impact of climate change, or a change in atmospheric conditions from current climate CO to a new climate C1, on tropical cyclone damages can be calculated by:

$$W = E[D(C1)] - E[D(C0)]$$

which is the difference between the expected damages of each climate, holding all other factors constant. The frequency distribution of damages, or the probability of a range of damage magnitudes given a storm, can be calculated by:

$$Prob(D) = f(D(X))$$

which describes the hurricane risk distribution of a certain location. Finally, the return rate for storm damage (RR) can be found by:

$$RR = \frac{1}{Prob(D)} = \frac{1}{f(D(X))}$$

which is the expected length of time between events of a certain damage level (Mendelsohn, et al., 2010).

3. Methodology

The current project answers the following questions: (1) what are the marginal and interaction effects of development on tropical cyclone damages across the globe; (2) what are the marginal impacts of tropical cyclone storm characteristics, such as minimum sea level barometric pressure and maximum wind speed, in global damages from tropical cyclones; (3) given the results from (1) and (2), what are the estimated damages per country from tropical cyclones in 2100 using four potential climate change scenarios; and (4) what is the distribution of damages across the globe and which countries are most vulnerable to tropical cyclone impacts? The research is detailed in the following sections. The theoretical foundations are explained in Section 2, followed by a list of data sources in Section 3.1. Section 3.2 outlines the econometric methodologies of the research and Section 4 describes the results. Finally, Section 5 offers concluding remarks. References can be found in Section 6.

3.1 Data

The analysis utilizes data from multiple sources. The first part of the analysis relies on country-level historical tropical cyclone damages data, as well as affiliated historical country population and income data. Data on tropical cyclone damages are obtained from EM-DAT, the International Disaster Database managed by the Center for Research on the Epidemiology of Disasters. The EM-DAT database includes information on over 17,000 natural and technological disasters and is sponsored in part by the United Nations and United States Agency for International Development. Data on historical country population and income data are gathered from the U.S. Department of Agriculture's Economic Research Service International Macroeconomic Data Sets. The historical data includes various country-level macroeconomic variables including real gross domestic product and population from 1969 to 2010.

Historical tropical cyclone data are collected from several sources including the U.S. National Oceanic and Atmospheric Administration's International Best Track Archive for Climate Stewardship (IBTrACS) and the U.S. Navy's Joint Typhoon Warning Center's Tropical Cyclone Reports. These sources include variables such as location, wind speed, and minimum barometric pressure at 6-hour intervals for each hurricane since the mid-1800s (NOAA, 2010a). Affiliated tropical cyclone characteristics from these sources were matched by hand with the country level damages data to complete the historical data set. Currently, 611 hurricane characteristics at landfall have been matched with economic damages data, and the dataset includes tropical cyclones from the Atlantic, Eastern, Central, and Western Pacific, and Indian Oceans, as well as the Southern Hemisphere. Historically, maximum wind speeds were recorded more commonly than minimum sea level barometric pressure, and thus are found in all observations of this analysis' sample, while 355 observations contain both wind speed and barometric pressure characteristics.

The second half of the study utilizes simulation data for the year 2008 and 2100. Tropical cyclone tracks and characteristics are simulated by Professor Kerry Emanuel of the Massachusetts Institute of Technology. These data include 5,000 simulated hurricane tracks for the Atlantic basin and 3,000 simulated tropical cyclone tracks for each of the Western and Eastern Pacific, Indian Ocean, and Southern Hemisphere basins, for each of four climate models, for both current and future climate, resulting in a total of 136,000 storms. Each track contains tropical cyclone location and characteristics at six-hour intervals for the life of the storm. The climate models are: CNRM (Gueremy et al. 2005), ECHAM (Cubasch et al 1997), GFDL (Manabe et al. 1991), and MIROC (Hasumi and Emori 2004). The models are based on an A1B SRES climate scenario which assumes carbon dioxide concentrations stabilize at 720 ppm (IPCC, 2000). See Mendelsohn et al. (2011) for a more detailed description of the climate scenarios. Future economic data by country are projected by the World Bank and projections of population are compiled by the United Nations.

3.2 Methodology

The analysis takes place in three steps. First, a damage function is estimated using an ordinary least squares estimator on historical hurricane and socioeconomic data. Second, the estimated damage function is used to calculate the damages from tropical cyclone tracks simulated both for the current climate and for climate in the year 2100 under four climate scenarios. From these results, the impact of climate change on tropical cyclone damages is computed.

To estimate the historical tropical cyclone damages function, the regression equation is structured in the following form:

$$\begin{aligned} D_{ij} = \; & \beta_0 MSLP_{ij} * NonOECD_j + \beta_1 MSLP_{ij} * OECD_j + \beta_2 NonOECD_j + \beta_3 OECD_j \\ & + \beta_4 P_j * NonOECD_j + \beta_5 P_j * OECD_j + \beta_6 Y_j * NonOECD_j + \beta_7 Y_j * OECD_j \\ & + \varepsilon_{ij} \end{aligned}$$

where D_{ij} is a record of tropical cyclone damages from storm i in country j and $MSLP_{ij}$ is the minimum sea level barometric pressure at landfall[2] for tropical cyclone i in country j. P_j and Y_j are average country-level population density and per capita income terms, respectively. $OECD_j$ is an indicator variable for countries that are members of the Organization for Economic Cooperation and Development, a proxy for development. $NonOECD_j$ represent countries not in OECD and is an indicator variable equal to (1-OECD). Lastly, the NonOECD and OECD variables are interacted with the hurricane characteristic and socioeconomic variables to discover any variation in the impacts of these explanatory variables over levels of development. Note that, since OECD and NonOECD would together be perfectly collinear with a constant term, no constant is included in the regression, thus goodness of fit statistics, such as the F and R^2 statistics, are adjusted accordingly. With this, the first stage of the analysis is complete.

For the second stage, the estimated damage function was used to approximate the damages from the simulated tropical cyclone data. First, damages from tropical cyclones under current climate conditions using four climate models are calculated for current socioeconomic condition in the year 2008. These same current climate tropical cyclone damages are then re-calculated with socioeconomic projections for the year 2100. The difference between the future damages and present damages, given current climate, show the increase in damages from tropical cyclones due only to changes in population and economic growth. To calculate the impact of climate change on tropical cyclone damages, another set of tropical cyclones was simulated under year 2100 climate conditions based on the projections of the same four climate models. Damages were calculated using future climate and future socioeconomic projections. The impact

[2] If a tropical cyclone does not make landfall in a country and damages were observed in the historical evidence, characteristics were used from the storm when it was at its closest point to the given country.

of climate change is the difference between the expected damages from the future climate, future socioeconomic damages and the current climate, future socioeconomic damage projections.

Thus, the current project is carried out in three stages: first, historical damage is calculated using additional relevant variables and previously unused data; second, the results will be used to estimate future tropical cyclone damages under four climate scenarios; and lastly, the impact of both socioeconomic change and climate change on tropical cyclone damages is calculated at both the country and regional levels.

4. Results

4.1 Historical Global Damages Function

Table 1 below contains the results from the estimation of the historical tropical cyclone damages function. Socioeconomic variables (P, population density; and Y, per capita income) and tropical cyclone intensity (MSLP, minimum barometric sea level pressure) are included. Level of development is interacted with each variable.

Table 1: Estimated Coefficients of the Historical Tropical Cyclone Damages Function

	NonOECD	OECD	P* NonOECD	P* OECD	Y* NonOECD	Y* OECD	MSLP* NonOECD	MSLP* OECD
Estimated Coefficient (Standard Error)	210.30 (45.08)	339.83 (81.91)	-0.29 (0.18)	-0.23 (0.22)	0.24 (0.15)	1.09 (0.40)	-28.16 (6.53)	-48.07 (11.85)

The estimated coefficients for variables in the historical global tropical cyclone damage function are shown in the table above. Standard errors are in the parentheses. The F statistic is 14.91 and the adjusted R^2 value is 0.23 with 355 observations. The F and R^2 statistics were adjusted for the fact that no constant was included in the regression (see a full explanation in Section 3.2 *Methodology*).

Recall from Section 3.2 (Methodology) that D_{ij} is a record of tropical cyclone damages from storm i in country j. P_j and Y_j are average country-level population density and per capita income terms, respectively. $OECD_j$ is an indicator variable for countries that are members of the Organization for Economic Cooperation and Development, a proxy for development. *NonOECD* represent countries not in the OECD and is an indicator variable equal to (1-OECD).

The above regression was estimated using Ordinary Least Squares with logged variables. Thus, the resulting estimated coefficients can be viewed as elasticities between the respective independent and dependent variables. The results shed new light on the structure of tropical cyclone damages, as well as the distribution of vulnerability. The estimated coefficient of 339.83

for OECD countries versus 210.30 for non-OECD countries implies that, holding everything else constant, developed countries are more vulnerable to damages from tropical cyclones than developing countries.

Turning to the interaction coefficients, a one percent increase in population density will decrease damages slightly by 0.29 percent for NonOECD countries and 0.23 percent for OECD countries. This elasticity implies that as countries transitioning from more rural to more urban living will have a modest reduction in vulnerability from tropical cyclone damages. Although both estimated coefficients are similar in magnitude and not statistically different than an estimated zero, it is also important to note that these results show evidence that there is not a positive relationship between population density and tropical cyclone damages. This is an important distinction because it is often assumed in the literature that increasing population density will lead to increased damages from tropical cyclones, often with an elasticity of one (Nordhaus, 2010; Pielke et al, 2008).

Turning to income, a one percent increase in income in a non-OECD country will increase damages by an estimated 0.24 percent. This implies developing countries, although still vulnerable to damages, are taking steps to protect their assets through growth. More analysis should be directed into this area to find out what strategies are undertaken by these countries to reduce vulnerability. However, one should not assume that development will necessarily result in low damages in non-OECD countries, because OECD countries have a strikingly different result. The estimated interaction coefficient for income and OECD country status robustly implies that a one percent increase in income in a developed country will increase damages by 1.09 percent. Two theories could be at play, and further investigation is needed to determine what hypothesis is supported empirically. First, there could be limits on available strategies to reduce vulnerability from tropical cyclone damages. Low hanging fruits, based on inexpensive technological and structural protection, could be implemented during earlier stages of development at relatively low cost. But once a country reaches a certain level of development, these methods may no longer be sufficient. Second, it is possible that developed countries may have maladaptive policies in place. For example, government policies and insurance contracts could be encouraging development of expensive assets situated in harm’s way. Careful study is needed to determine precisely what is the causal factor and what measures can be taken to decrease vulnerability of developed countries and ensure that developing countries can continue to reap the benefits of reduced vulnerability through development.

Turning lastly to the hurricane intensity coefficient, we find damages are highly and significantly influenced by hurricane intensity. Note too, that minimum sea level barometric pressure is inversely related to maximum wind speed and also damages. A lower pressure is indicative of a more powerful storm. Thus, a one percent decrease in minimum sea level barometric pressure will increase damages by 28.16 percent in non-OECD countries and 48.07 percent in OECD countries. Although these are lower numbers that that of Mendelsohn et al. (2011) who estimated a damages elasticity from minimum sea level barometric pressure of 86, they reinforce the importance of storm intensity in damages. Also, they show that OECD countries are more vulnerable to damages than are non-OECD countries. Further work is needed to explain the underlying relationship between hurricane pressure and damages, and their interaction with level of development. Heterogeneity in the potential range of adaptation strategies to reduce vulnerability may occur. It may be easier to more fully protect against damages from lower category storms yet difficult, based on available technology and cost constraints, to protect against damages from very large (low minimum pressure) and low probability storms.

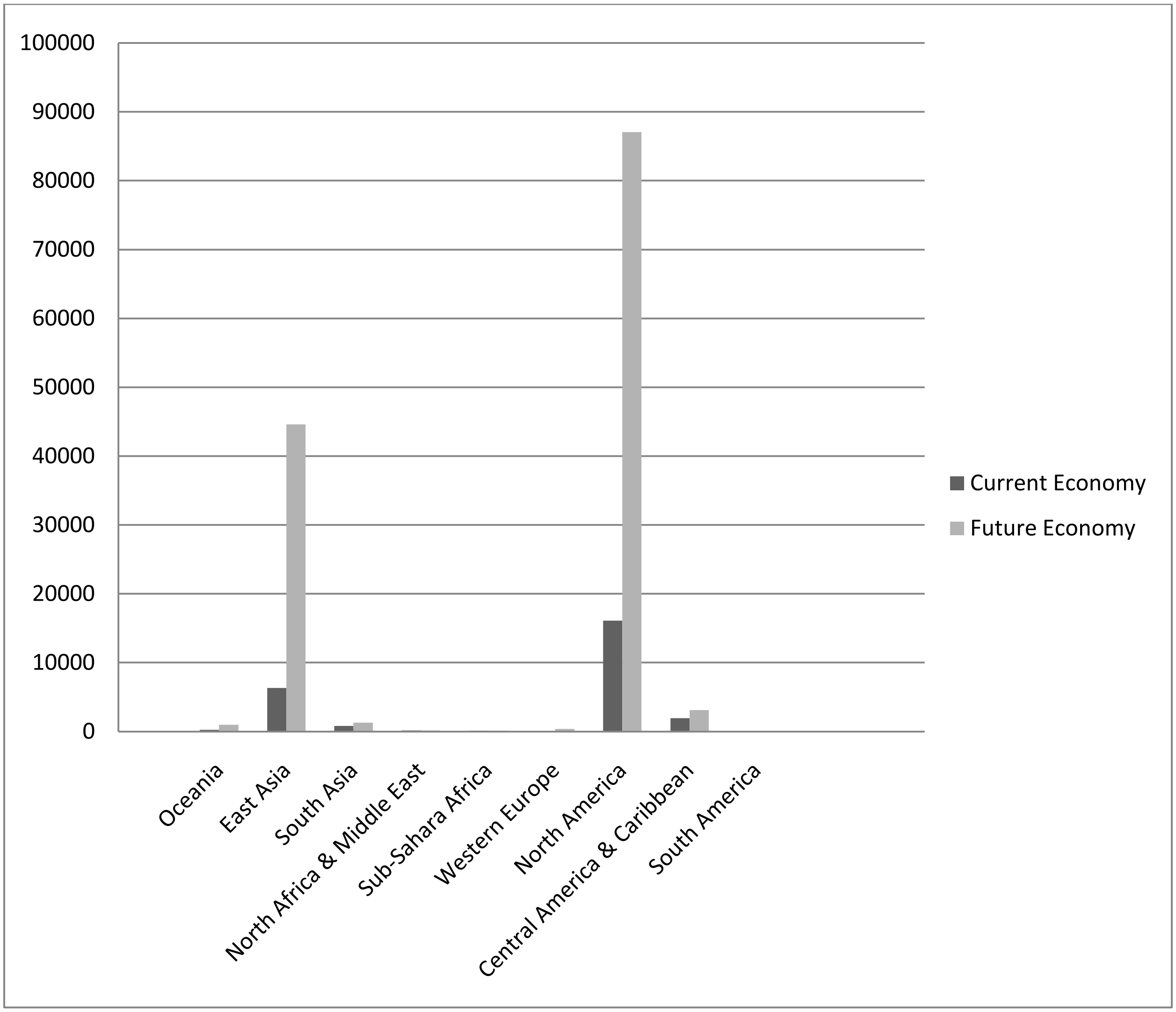
4.2 Socioeconomic Change Impact on Tropical Cyclone Damages

The first part of the analysis calculats the impact of socioeconomic change on tropical cyclone damages, from the present global levels of development to the world in 2100, holding climate constant. Currently, average annual global tropical cyclone real damages are approximately U.S. $25 billion per year, and socioeconomic change is expected to increase this number by about $112 billion in the year 2100. In Table 2 and Figure 1 below, regional total expected damages are compared, given current and future socioeconomic conditions, holding climate conditions constant at the present-day.

Table 2: Annual Expected Regional Damages for Current and Future Socioeconomic Conditions, Given Current Climate Conditions

Region	Current Economy Damages ($ millions)	Future Economy Damages ($ millions)
Oceania	255	998
East Asia	6,343	44,591
South Asia	814	1,303
North Africa & Middle East	174	176
Sub-Sahara Africa	94	115
Western Europe	32	383
North America	16,103	87,072
Central America & Caribbean	1,918	3,117
South America	1	2
World	25,734	137,757

Figure 1: Annual Expected Regional Damages for Current and Future Socioeconomic Conditions, Given Current Climate Conditions, in millions of U.S. dollars



As seen in the results, damages and vulnerability due to tropical cyclones are extremely regional in nature. East Asia and North America bear the vast majority of global damages, both currently and in the future. Of the approximately $112 billion expected increase in tropical cyclone damages due to socioeconomic change, North America is expected to bear about 63 percent of the increase, followed by East Asia sustaining approximately 34 percent of the damages increase. Although continued development will no doubt put more infrastructure and assets in harm's way, these results should not be interpreted as an argument against future development. Rather they serve as a reminder that smart strategies in adaptation and development are essential in order to reduce or mitigate future tropical cyclone damages and vulnerability.

Recall from Section 4.1 that the estimated population density coefficients for OECD and non-OECD countries are of similar magnitude, so changes in population density from present to future socioeconomic conditions will impact countries similarly. Growth in per capita income, however, was found to increase damages much more quickly in OECD countries than in non-OECD countries. This greatly impacts expected damages due to socioeconomic change, as OECD country damages are predicted to increase sharply over the next century due to development alone. Caution should be exercised with these numbers, as the analysis assumes no countries will change OECD status over the next one hundred years, an unlikely outcome. It is possible that, with continued development, income elasticities for developing countries may increase, leading to greater damages than predicted above. Further research is needed to understand and better model the transition in damage elasticity across levels of development.

4.3 Climate Change Impact on Global Tropical Cyclone Damages

The results from the impact of climate change on tropical cyclone damages are presented below. Holding future socioeconomic conditions fixed, climate change is expected to increase tropical cyclone damages by approximately $110 billion per year. Impacts will be highly regionalized, as North America will be hit hardest by climate change impacts, followed by the Caribbean region and Central America. Results below are summarized on a regional basis. Country-level results can be found in Appendix A. Below in Table 3 are annual expected regional damages associated with climate change.

Table 3: Annual Expected Regional Damages for Climate Change, Given Future Socioeconomic Conditions, in millions of U.S. dollars

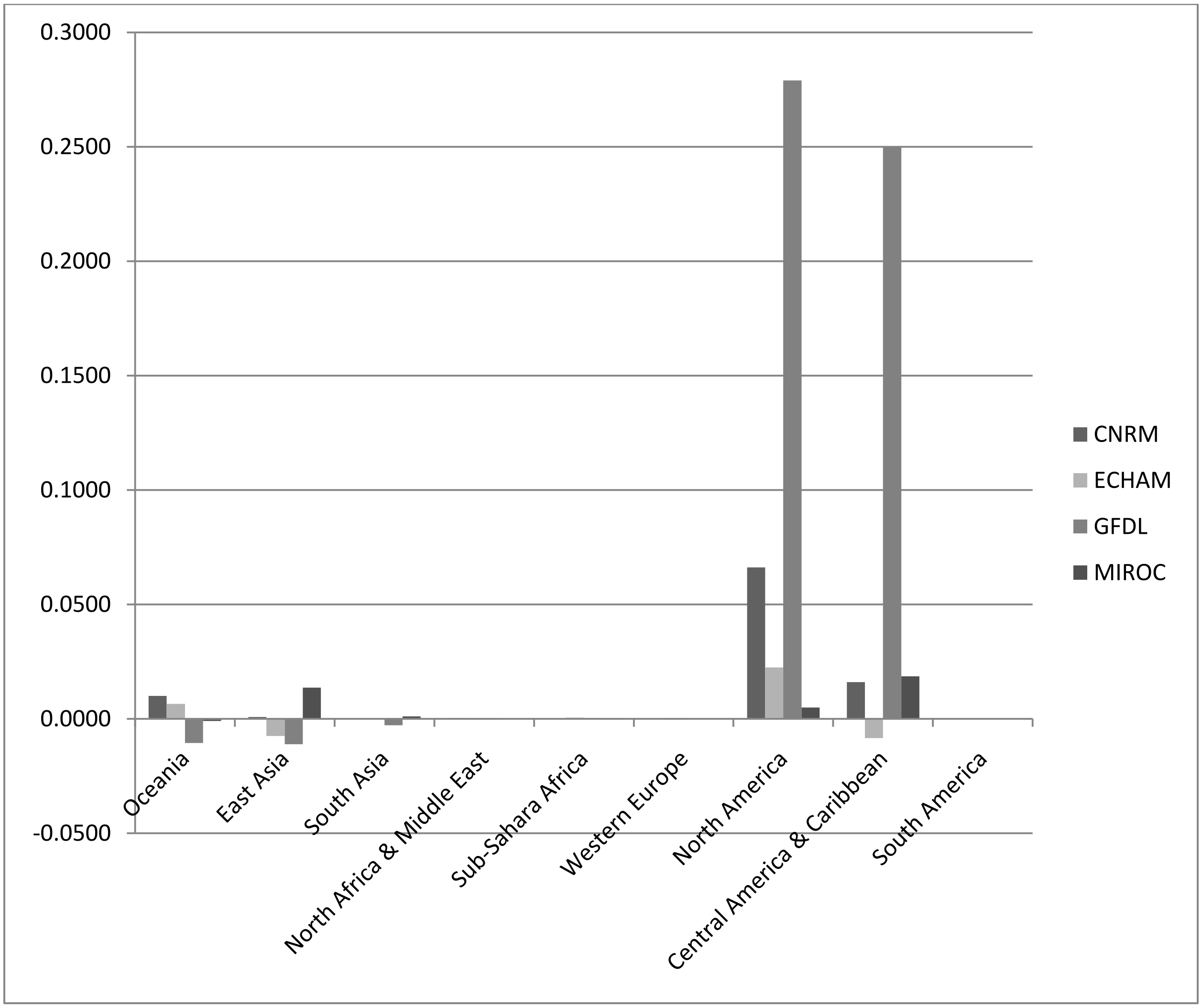
Region	Current Climate, Future Economy Baseline	CNRM Climate Change Impact	ECHAM Climate Change Impact	GFDLCM Climate Change Impact	MIROC Climate Change Impact	Average Climate Change Impact
Central America & Caribbean	3,117	643	-337	3,855	744	1,226
East Asia	44,591	1,316	-11,821	-17,551	21,501	-1,639
North Africa & Middle East	176	105	63	55	43	67
North America	87,072	78,119	26,492	329,264	5,824	109,925
Oceania	998	736	484	-781	-74	91
South America	2	1	0	-1	0	0
South Asia	1,303	-33	-7	-782	317	-126
Sub-Sahara Africa	115	-13	168	124	103	96
Western Europe	383	-100	377	-54	165	97
World	137,757	80,773	15,420	314,130	28,623	109,736

As seen above, climate change impacts on tropical cyclone damages are highly regional in nature. Damages in North America are expected to double, on average, and are predicted to rise in all four climate scenarios. Damages from the Caribbean region and Central America will increase, on average, by almost fifty percent. It is important to note the large variability in climate model predictions in regional averages. For Central America and the Caribbean region, all models except for ECHAM model predict increases from the future baseline. East Asia, another region facing large increases in expected future damages due to socioeconomic change, has higher variability in expected future climate damages, with MIROC predicting an approximately 50 percent increase in damages due to the changed climate, while ECHAM and GFDL predict decreased damages by 25 to 40 percent. Somewhat masked by the average value over the four climate models, Oceania also shows high variability in the estimated climate change impacts. ECHAM and CNRM predict average increase in future baseline damages of approximately 48 to 74 percent, respectively. Sub-Sahara Africa shows more consistency in the approximation, as three of the four models predict at least an approximately 90 percent increase in damages, similar to the calculated average.

Although future tropical cyclone damages from socioeconomic and climate changes seem large compared with current damages, the future global economy will also be much larger in the year 2100. Thus, contextualizing damages, as a percentage of future Gross Domestic Product (GDP), is vital for balanced analysis. In Figure 2 below, regional annual damages from climate change are given as a percentage of total regional Gross Domestic Product[3]. Table 4 below shows the top ten countries expected to lose the greatest amount of their annual gross domestic product due to total expected tropical cyclone damages, given future socioeconomic and climate conditions.

[3] Regional gross domestic product is defined in this paper as the sum gross domestic product across all countries in the region, regardless if the country is at risk for tropical cyclones or not.

Figure 2: Expected Regional Annual Damages from Climate Change, as a percentage of Regional Gross Domestic Product



Rescaling damages by projections for the future economy, Atlantic basin storms will lead to the largest percentage of loss in regional Gross Domestic Product, with North America and the Caribbean region and Central America losing up to approximately 0.25 percent of their GDP per year due to climate change. Note that the above graph only represents the impact of climate change, and not total expected tropical cyclone damages in the year 2100, a still larger percent of regional GDP. Also note that regional GDP was calculated by including the GDP of all countries within the region, regardless of whether they are at risk for tropical cyclones. Thus, heterogeneity in country impacts within regions is present. For details about country impacts, see Appendix A.

Table 4: Annual Expected Damages, as a percent of Country GDP

Cayman Is.	1.93
British Virgin Is.	1.47
St. Kitts & Nevis	1.47
Virgin Is.	1.20
Turks & Caicos Is.	1.18
Samoa	0.75
Grenada	0.68
Antigua & Barbuda	0.64
The Bahamas	0.61
Dominica	0.50

Table 4 above shows the ten countries with greatest annual expected losses, as a percentage of future GDP, due to tropical cyclone damages in the year 2100. Small island nations are at greatest risk, including islands in the Caribbean region, as well as some in Oceania and Sub-Saharan Africa around Madagascar. Small island nations are at particular risk, not only due to the large expected damages as a percent of their GDP, but also because they may have more limited adaptation ability compared with larger countries, given smaller land area for evacuation and development retreat from coastal communities.

With all of the above analysis, it is vital to keep in mind that tropical cyclones are low probability events and past studies have shown that damages are skewed, with low frequency, large storms causing a large fraction of total damages (Mendelsohn et. al, 2011). Thus, the above annual average values will vary greatly from year to year, so strategies for adaptation and reduced vulnerability must take this into account.

4.3 Limitations of the Study

As with any empirical analysis, honest reflection on the limitations of a study must be conducted. Several points are noteworthy in this project. First, it must be acknowledged that the precision and accuracy of the economic analysis is limited necessarily by the correctness of the present state of natural science knowledge. Although much advancement has occurred in understanding tropical cyclones and the impacts of climate change on these meteorological events, debate remains in several areas (see Section 1.2 – Review of the Relevant Literature) that translates into increased uncertainty in the economic analysis. Second, underlying assumptions of the model could be incorrect. For example, endogeneity could be an issue if the independent variables are not independent of the error terms. This could be due to omitted variable bias such as human adaptation to hurricane damages. Tests with instrumental variables could provide evidence of the completeness of the explanatory variables. Third, the current study calculated damages based on building and infrastructure loss. While this assumption is reasonable at this time and is consistent with past literature, it does not provide a number inclusive of all hurricane damages, and therefore will underestimate expected damages. Lastly, while the data are technically cross-sectional in nature, the individual historical hurricanes were compiled over decades of records. Although care is taken to track and record hurricane activity, no doubt technological innovation and scientific advancements occurred during this time span, leading to better quality data in the later years. Care must be taken when using older data to ensure no bias is introduced due to heterogeneous measurement error. Although there are several limitations to the study, as previously noted, there are also many positive contributions of the current work.

4.4 Directions for Future Research

Although these results are important, they are only the first step. Many questions are raised by the analysis and provide rich fodder for future improvement. Below are directions to be taken for future work on this area of research.

First, in order to test the robustness of the specification and analysis, a spline regression can be performed on the historical data. The independent variable data can be subdivided into nine categories: three categories for each independent variable including low, medium, and high population; low, medium, and high income per capita; and low, medium, and high minimum barometric hurricane pressure[4]. These nine categories can be regressed on the damages using a spline regression, which allows the coefficients to be estimated with no functional form assumptions other than continuity between categories. Thus, the estimated coefficients are allowed to vary between population, income, and minimum barometric pressure categories. Results can be compared to see if the estimated coefficients are statistically similar. If so, this is probative evidence supporting the use of a linear regression to estimate the climate change impacts in 2100. If the resulting estimated coefficients are not statistically significant, one must be cautious when extrapolating too far into the future.

Improving the global damages function by adding levels of development and tropical cyclone characteristics is just a second step in a large area of potential research. Geographic improvements are a further logical step. An ocean-basin level analysis could be used to calculate the impacts of climate change on the distribution and magnitude of regional damages. Also, a finer scale in the global socioeconomic data, as well as additional hurricane characteristics such as rainfall, storm surge and tide, and movement of the storm, would provide improvements in the analysis. Lastly, disaggregating damages into damages from storm surge, inland flooding, and tropical cyclone winds would greatly advance the literature, as vulnerability around the world likely varies heterogeneously across these dimensions.

Further, given that the distribution of historical tropical cyclones damages is skewed as a large percent of the damages result from a small number of highly destructive storms, additional

[4] Note that a hurricane with high minimum barometric pressure implies that it is a weaker storm; minimum pressure is inversely related to hurricane strength and wind speed.

analysis on the distribution of storms and how the distribution changes due to climate change is needed. This will also help inform effective adaptation strategies.

In addition to these directions, additional relevant policy questions can be addressed, such as the efficient methods for public and private adaptation to tropical cyclone winds, storm surge, and inland flooding; optimal levels of insurance for each type of damage; and also policy questions for disaster relief programs, public insurance, and land use regulation. All these topics are rich grounds for future inquiry.

5. Conclusion

The current project answers the following questions: (1) what are the marginal and interaction effects of development on tropical cyclone damages across the globe; (2) what are the marginal impacts of tropical cyclone storm characteristics, such as minimum sea level barometric pressure, in global damages from tropical cyclones; (3) given the results from (1) and (2), what are the estimated damages per country from tropical cyclones in 2100 using four potential climate change scenarios; and (4) what is the distribution of damages across the globe and which countries are most vulnerable to tropical cyclone impacts? The study analyzes these questions through estimation of a refined global damages function and then applies the estimated relationships to simulation data of hurricane tracks in the year 2100 under four different climate scenarios. The results show that, from a base of approximately $25 billion per year in damages from tropical cyclones, socioeconomic change will increase the global total by approximately $112 billion, and climate change will result in additional losses of $110 billion. Damages will be heterogeneous across the globe, with the United States and small island nations being hit disproportionately more. Although tropical cyclone damages will never be entirely eliminated, further research efforts in this area including efficient adaptation, insurance, and public policy choices can help to reduce vulnerability and hopefully decrease future damages and deaths from tropical cyclones.

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Appendix A: Climate Change Impact by Country

Table 5 below shows the expected impact of climate change on country-level tropical cyclone damages. The Future Baseline represents expected annual tropical cyclone damages, given current climate conditions and future socioeconomic conditions for the year 2100. The next four columns show the expected impact of climate change, isolated from total climate damages.

Table 5: Climate Change Impact on Annual Expected Damages by Country, in millions of U.S. Dollars

Country	Future Baseline	CNRM	ECHAM	GFDL	MIROC	AVERAGE	Climate Damage Percent of GDP
Afghanistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Algeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
American Samoa	10.6	5.9	-2.0	-7.4	-9.1	-3.2	-0.0594
Andorra	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Angola	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Anguilla	0.0	0.0	0.0	0.0	0.0	0.0	0.0003
Antigua & Barbuda	41.7	25.7	0.7	130.3	27.2	46.0	0.3359
Argentina	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Armenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Aruba	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Australia	801.0	599.0	479.0	-763.5	-50.0	66.1	0.0011
Austria	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Azerbaijan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Bahrain	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Bangladesh	304.0	-76.0	-44.0	-220.4	6.0	-83.6	-0.0091
Barbados	0.5	0.8	-0.2	1.1	-0.1	0.4	0.0010
Belarus	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Belgium	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Belize	42.7	-18.2	-18.1	20.1	12.7	-0.9	-0.0055
Benin	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Bermuda	18.9	-7.7	9.5	7.3	0.8	2.5	0.0068
Bhutan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000

Bolivia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Bosnia & Herzegovina	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Botswana	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Brazil	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
British Virgin Is.	44.7	19.5	-3.8	84.3	29.9	32.5	0.6201
Brunei	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Burundi	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Cambodia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Cameroon	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Canada	72.0	18.1	-9.0	63.0	24.1	24.1	0.0003
Cape Verde	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Cayman Is.	213.0	-5.0	-55.0	323.0	44.0	76.8	0.5125
Central African Republic	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Chad	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Chile	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
China	4700.0	820.0	60.0	-2230.0	220.0	-282.5	-0.0003
Colombia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Comoros	21.3	3.6	2.5	17.5	7.4	7.8	0.1261
Congo	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Congo, DRC	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Cook Is.	4.1	3.0	-2.1	-4.1	-4.1	-1.9	-0.0874
Costa Rica	26.6	20.1	-5.1	2.2	12.8	7.5	0.0022
Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Cuba	961.0	189.0	-174.0	1589.0	5.0	402.3	0.0628
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Czech Republic	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Djibouti	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Dominica	17.8	-4.8	-2.2	20.8	2.4	4.1	0.0924
Dominican Republic	224.0	91.0	-25.0	463.0	77.0	151.5	0.0285

Ecuador	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Egypt	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
El Salvador	53.1	22.6	47.9	-36.8	20.6	13.6	0.0053
Equatorial Guinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Eritrea	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Ethiopia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Faroe Is.	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Fiji	45.1	43.2	8.0	-2.5	-17.9	7.7	0.0188
Finland	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
France	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
French Guiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
French Polynesia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Gabon	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Gaza Strip	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Georgia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Germany	0.2	-0.2	1.4	0.9	0.2	0.6	0.0000
Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Gibraltar	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Greece	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Greenland	0.2	0.2	0.4	-0.1	0.5	0.2	0.0036
Grenada	63.7	23.1	-47.0	-13.8	-1.5	-9.8	-0.1237
Guadeloupe	26.9	5.7	7.7	52.2	19.6	21.3	0.0344
Guam	53.6	8.2	-8.0	30.1	43.4	18.4	0.0573
Guatemala	104.0	60.0	41.0	-96.8	116.0	30.1	0.0066
Guernsey	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Guinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Guinea-Bissau	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Guyana	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Haiti	27.5	9.3	-4.4	44.3	8.0	14.3	0.0177
Honduras	284.0	-14.0	-65.0	-69.0	-15.0	-40.8	-0.0250
Hungary	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
India	616.0	-13.0	15.0	-338.0	177.0	-39.8	-0.0002
Indonesia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000

Iran	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Iraq	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Ireland	0.4	-0.3	0.8	3.3	0.0	0.9	0.0001
Isle of Man	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Israel	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Jamaica	100.0	26.0	-18.2	173.0	35.0	54.0	0.0309
Japan	33500.0	-500.0	-10200.0	-13700.0	16600.0	-1950.0	-0.0064
Jersey	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Jordan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Kazakhstan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Kenya	6.5	9.2	1.1	9.0	38.9	14.5	0.0036
Kiribati	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Kyrgyzstan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Laos	22.3	1.4	0.4	-6.8	-2.0	-1.8	-0.0028
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Lebanon	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Lesotho	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Liberia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Libya	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Macedonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Madagascar	28.0	-3.5	10.9	-5.0	21.8	6.1	0.0058
Malawi	0.4	0.0	0.1	0.0	0.2	0.1	0.0002
Malaysia	4.4	-1.6	0.4	-0.2	-1.2	-0.6	0.0000
Maldives	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Mali	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Marshall Is.	0.0	0.0	0.0	0.1	0.0	0.0	0.0013
Martinique	35.7	23.1	-10.2	99.3	16.7	32.2	0.0521
Mauritania	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Mauritius	18.2	-1.0	5.2	-4.2	0.8	0.2	0.0002

Mayotte	2.2	-0.3	-1.1	1.1	2.7	0.6	0.0106
Mexico	16300.0	800.0	100.0	12900.0	700.0	3625.0	0.0168
Micronesia	0.0	0.0	0.1	0.0	0.0	0.0	0.0007
Moldova	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Monaco	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Mongolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Montenegro	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Montserrat	1.7	0.6	0.4	4.3	1.6	1.7	0.1521
Morocco	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Mozambique	5.1	0.4	1.4	0.6	2.1	1.1	0.0010
Myanmar	280.0	15.0	-7.0	-192.8	41.0	-36.0	-0.0114
Namibia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Nauru	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Nepal	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Netherlands	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Netherlands Antilles	94.7	39.3	-80.0	-58.7	-26.6	-31.5	-0.1108
New Caledonia	2.9	0.0	-0.3	-0.6	-1.3	-0.5	-0.0014
New Zealand	21.8	-9.4	-2.6	-6.2	-5.4	-5.9	-0.0007
Nicaragua	65.8	-13.0	-7.3	-4.2	100.2	18.9	0.0247
Niger	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
North Korea	595.0	-33.0	-317.0	140.0	42.0	-42.0	-0.0138
Northern Mariana Is.	12.0	6.5	2.9	-1.4	-0.7	1.8	0.0249
Norway	1.4	-1.1	8.0	5.4	1.4	3.4	0.0001
Oman	176.0	105.0	63.0	55.0	43.0	66.5	0.0160
Pakistan	82.7	40.3	24.3	-15.8	71.3	30.0	0.0015
Palau	0.0	0.1	0.0	0.0	0.0	0.0	0.0007
Panama	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Papua New Guinea	0.1	0.0	0.0	0.0	0.0	0.0	0.0000
Paraguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Peru	1.1	0.9	0.6	-0.3	0.0	0.3	0.0000
Philippines	264.0	-1.0	5.0	-53.0	10.0	-9.8	-0.0003
Poland	0.0	0.0	0.0	0.0	0.0	0.0	0.0000

Portugal	161.0	-42.0	135.0	103.0	163.0	89.8	0.0060
Puerto Rico	271.0	38.0	14.0	454.0	134.0	160.0	0.0334
Qatar	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Reunion	3.5	-1.3	0.5	1.1	2.2	0.6	0.0005
Romania	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Russia	14.4	1.9	-4.6	1.4	0.2	-0.3	0.0000
Rwanda	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Samoa	41.6	74.4	7.4	-33.9	-31.4	4.1	0.0682
San Marino	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Sao Tome & Principe	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Saudi Arabia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Serbia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Seychelles	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Sierra Leone	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Slovakia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Solomon Is.	0.3	0.1	0.4	0.0	0.1	0.1	0.0018
Somalia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
South Korea	5140.0	1020.0	-1370.0	-1600.0	4660.0	677.5	0.0118
Spain	220.0	-57.0	231.0	-166.4	0.0	1.9	0.0000
Sri Lanka	20.4	0.5	5.2	-14.7	22.1	3.3	0.0007
St. Helena	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
St. Kitts & Nevis	52.0	4.7	4.7	127.0	28.3	41.2	0.6489
St. Lucia	3.4	5.4	-0.2	7.5	0.1	3.2	0.0274
St. Pierre & Miquelon	0.4	0.5	1.1	0.7	0.3	0.7	0.1228
St. Vincent & the Grenadines	1.4	4.4	-0.1	6.6	-0.2	2.7	0.0387
Sudan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Suriname	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Swaziland	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Sweden	0.0	0.0	0.0	0.0	0.0	0.0	0.0000

Switzerland	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Syria	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Tajikistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Tanzania	4.4	0.3	1.7	6.4	2.5	2.7	0.0011
Thailand	43.0	-11.5	-0.4	-8.8	-0.4	-5.3	-0.0002
The Bahamas	192.0	63.0	35.0	199.0	-18.0	69.8	0.1627
The Gambia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Timor-Leste	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Togo	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Tonga	4.6	4.6	1.6	8.6	2.5	4.3	0.1407
Trinidad & Tobago	0.1	0.0	0.0	0.0	0.0	0.0	0.0000
Tunisia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Turkmenistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Turks & Caicos Is.	31.7	7.5	10.0	49.3	12.3	19.8	0.4522
Tuvalu	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Uganda	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Ukraine	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
United Kingdom	25.3	-20.5	145.7	97.7	24.6	61.9	0.0004
United States	70700.0	77300.0	26400.0	316300.0	5100.0	106275.0	0.1210
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Uzbekistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Vanuatu	0.4	0.0	0.0	-0.2	-0.3	-0.1	-0.0014
Venezuela	0.4	0.2	-0.2	-0.2	-0.2	-0.1	0.0000
Vietnam	308.0	20.0	5.0	-94.0	-28.0	-24.3	-0.0023
Virgin Is.	117.0	27.0	8.0	277.0	101.0	103.3	0.5605
Wallis & Futuna	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Western Sahara	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Yemen	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Zambia	0.0	0.0	0.0	0.0	0.0	0.0	0.0000
Zimbabwe	0.1	0.0	0.0	0.0	0.0	0.0	0.0001