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Unraveling the Effects of Tropical Cyclones on Economic Sectors Worldwide

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Abstract

This paper unravels the contemporaneous, lagged, and indirect effects of tropical cyclones on annual sectoral growth worldwide. The main explanatory variable is an area weighted measure for local tropical cyclone intensity based on meteorological data, which is included in a panel analysis for a maximum of 213 countries over the 1971-2015 period. I find a significantly negative influence of tropical cyclones on three sector aggregates including agriculture, infrastructure, as well as trade and tourism. In subsequent years, tropical cyclones negatively affect nearly all sectors. However, the Input-Output analysis shows that production processes are sticky and indirect economic costs are low.

JEL classification: E23, O11, O17, O44, Q51, Q54, Q56

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1 Introduction

Tropical cyclones are among the most destructive natural hazards. Together with floods they are responsible for 90% of weather-related damages worldwide (Kunreuther & Michel-Kerjan 2013). In 2004 and 2005 the cost of weather-related damages was very high, with the damage in the US alone amounting to an aggregate of 150 billion U.S. dollars (Pielke et al. 2008). Driven by climate change, at least in some ocean basins (Elsner et al. 2008; Mendelsohn et al. 2012), and a higher exposure of people in large urban agglomerations near an ocean (World Bank 2010), the overall damage as well as the number of people affected by tropical cyclones have been increasing since the 1970s (EM-DAT 2015). Thus, tropical cyclones are and will continue to be a serious threat to the life and assets of a large number of people worldwide.

The international community has also recognized this urgency. Coordinated by the United Nations Office for Disaster Risk Reduction (UNISDR) the Sendai Framework for Disaster Risk Reduction 2015-2030 should give international organizations, nation states, and non-governmental organizations an incentive to reduce disaster risk "at all levels as well as within and across all sectors" (UNISDR 2015). More specifically, priority area 4 calls for "build-back-better in recovery, rehabilitation and reconstruction" of the economy (UNISDR 2015). However, when looking at the empirical evidence, the results are disillusioning: The majority of current studies with reliable identification strategies do not find any evidence for a "build-back-better" of the economy, but rather only negative effects of tropical cyclones (Bertinelli & Strobl 2013; Deryugina 2017; Felbermayr & Gröschl 2014; Gröger & Zylberberg 2016; Hsiang & Jina 2014; Noy 2009; Strobl 2011, 2012). Older studies, which have found positive effects (Albala-Bertrand 1993; Cuaresma et al. 2008; Toya & Skidmore 2007) suffer to a large extent from endogeneity problems in their econometric analysis because their damage data are based on reports and insurance data, which are positively correlated with GDP (Felbermayr & Gröschl 2014) and prone to measurement errors (Kousky 2014).[2]

With this paper I contribute to a number of strands of the literature. First, I add to the literature on macroeconomic effects of disasters. The majority of studies focuses on average

[2] The empirical and theoretical literature discusses three different hypotheses of economic effects of natural disasters: build-back-better, recovery to trend, and no recovery. Klomp and Valckx (2014) provide a good overview of the different studies. Potential damages to the economy from tropical cyclones are summarized by Kousky (2014).

GDP effects. To better understand the post-disaster damages, however, it is necessary to open the black box and look at the damages on a more disaggregated level. Only a minority of papers explicitly investigate the disasters' influences on sectoral economic development. However, the existing evidence is far from being complete and satisfactory. Belasen & Polachek (2008) only focus on sectoral changes within Florida. In contrast, Loayza et al. (2012) cover a global sample of 94 countries but use report and insurance data on damages and therefore suffer from endogeneity problems. Hsiang (2010) provides the sole credible identification strategy within this literature by using meteorological wind data, but he focuses on the 26 Caribbean countries, which only account for 11% of total GDP in 2015 (United Nations Statistical Division 2015c). Additionally, all sectoral impact studies have in common to only analyze contemporaneous effects of natural disasters. This paper contributes to the literature by being the first study, which analyzes the whole world (213 countries) with a credible empirical identification strategy. Since some damages are only visible after a certain time lag (Felbermayr & Gröschl 2014; Hsiang & Jina 2014; Kousky 2014; Pelli & Tschopp 2017), it is therefore necessary to also look at the influence of past tropical cyclones. Thus, I include lags of up to five years to analyze the impact of tropical cyclones on economic sectors over time. This analysis will provide detailed insights about which sectors are most vulnerable to the exposure to tropical cyclones to better understand how to achieve a "build-back-better" situation in future.

Next, I contribute to the literature of Input-Output assessment of natural disasters. While there exists a lot of theoretical work on the importance of cross-sectional linkages in consequences of a shock (see e.g.: Acemoglu et al. 2012; Dupor 1999; Horvath 2000), recent empirical studies focus on the shock propagation in production networks within the US (Barrot & Sauvagnat 2016) or after the 2011 earthquake in Japan (Boehm et al. 2018; Carvalho et al. 2017). The empirical papers all share that they use firm-level data to draw conclusions on upstream and downstream production disruptions. However, little is known about the empirical Input-Output effects across sectors after a natural disaster shock. But since the response of the economy to a natural disaster is highly complex and many interactions between the individual sectors are taking place, it is highly relevant to understand how the sectors interact, whether there are any indirect effects of tropical cyclones, and whether any key sectors exist that link sectors. Within this paper I attempt to close this research gap by using an Input-Output panel dataset which allows me to analyze potential sector interactions after the occurrence of a tropical cyclone.

The main causal identification stems from the exogenous nature of tropical cyclones, whose intensity and position are difficult to predict even 24 hours before they strike (NHC 2016). To overcome existing endogeneity problems of report-based damage numbers, I make use of meteorological data to calculate an area weighted tropical cyclone intensity measure per country and year, consisting of a fine-gridded asymmetric wind field model.

Based on my empirical analysis, I find a contemporaneous negative growth effect of tropical cyclones for three sector aggregates including *agriculture, hunting, forestry, and fishing*, *wholesale, retail trade, restaurants, and hotels*, and *transport, storage, and communication*. The largest negative effect can be attributed to annual growth in the *agriculture, hunting, forestry, and fishing* sector aggregate, where a median tropical cyclone intensity is associated with a decrease of the average annual sectoral growth of 58.19 percent. This corresponds to a mean annual global loss of 28.5 million U.S. Dollars (measured in constant 2005 U.S. Dollars) for the sample average.

In subsequent years, tropical cyclones have a negative impact on almost all sectors which is undermined by a downward facing trend of the accumulated effects. The *agriculture, hunting, forestry, and fishing* sector aggregate forms an exception, since in the second year after a tropical cyclone my analysis reveals a positive effect. However, the positive growth effect is not enough to dampen the overall negative effect within this sectoral aggregate. Most surprisingly, the *construction* sector experiences the largest negative cumulative effect after five years. The Input-Output analysis reveals that the *utilities* sector suffers most from indirect effects of a tropical cyclone which are most likely compensated from a positive demand shock from the *wholesale, retail trade, restaurants, and hotels* sector aggregate. Overall, there are only a small number of significant sectoral shifts present in the data. This suggests that the production chains of the sectors are only slightly disrupted by tropical storms and, thus, indirect costs are negligible. In general, the results of this paper support the no recovery hypothesis discussed in the literature, which states that natural disasters have long-lasting negative effects from which the economy cannot recover.

The remainder of this paper is structured as follows: section 2 contains a description of the data source, the construction of the tropical cyclone intensity measure, and presents summary statistics. In section 3, the empirical approach is described. Section 4 presents the main results and extensions as well as the results of the robustness checks. Section 5 concludes with a discussion of the results and policy implications.

2 Data

2.1 Tropical Cyclone Intensity

Tropical cyclones are large cyclonically rotating wind systems which form over tropical or sub-tropical oceans and are mostly concentrated on months in summer or early autumn in the both hemispheres (Korty 2013). Their destructiveness has three sources: damaging winds, storm surges, and heavy rainfalls. The damaging winds are responsible for serious destruction of buildings and vegetation. In coastal areas storm surges can lead to flooding, destruction of infrastructures and buildings, erosion of shorelines and the salinization of the vegetation (Le Cozannet et al. 2013; Terry 2007). Torrential rainfall can cause serious in-land flooding, thereby augmenting the risk coming from storm surges (Terry 2007).

Since the commonly used report-based EMDAT dataset (Lazzaroni & van Bergeijk 2014) has been criticized for measurement errors (Kousky 2014), endogeneity, and reverse causality problems (Felbermayr & Gröschl 2014), I use meteorological data to generate a proxy for the destructive power of tropical cyclones. Consequently, I take advantage of the International Best Track Archive for Climate Stewardship (IBTrACS) provided by the National Oceanic and Atmospheric Administration (Knapp et al. 2010). It is a unification of all best track data on tropical cyclones collected by weather agencies worldwide. Best track data are a postseason reanalysis from different available data sources, including satellites, ships, aviation, and surface measurements to describe the position and intensity of tropical cyclones (Kruk et al. 2010).

The unified data of the IBTrACS dataset identifies each storm uniquely by assigning an identification number, its geospatial position and its intensity given by maximum sustained wind speed and minimum sea level pressure. The data are reported at six-hour intervals. Data from IBTrACS are available from 1842 until today, but global coverage of the measurement has only been guaranteed since the start of satellite remote sensing in the late 1970s (Hsiang

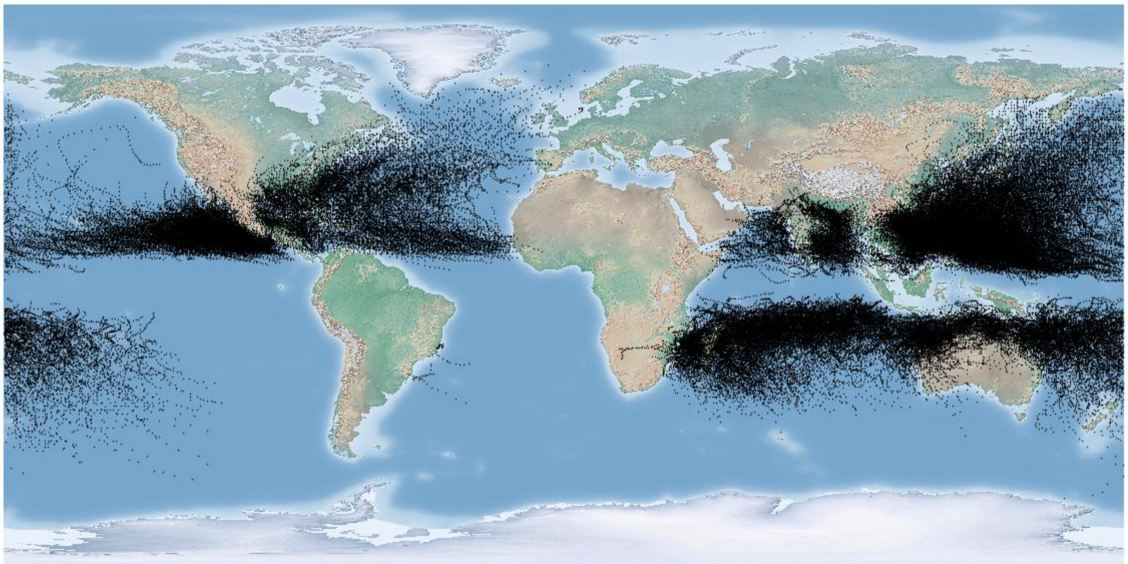

Figure 1: Tropical cyclone raw data, 1970-2015.

& Jina 2014). However, this restriction is for the most part only a concern for non-land-falling tropical cyclones as land-falling tropical cyclones were already covered by the other measurement methods (Hsiang & Jina 2014). For my analysis, I use the latest published version, the "IBTrACS-All data" version v03r09, for the 1970-2015 period.

One pitfall of the IBTrACS data is that the data of the maximum sustained wind speed of the different weather agencies are aggregated according to different rules. Weather agencies in the North Atlantic basin use the maximum sustained wind speed average over a one-minute period, agencies from China and Hong Kong use two-minute periods, agencies from India use three-minute periods, and the remaining agencies use ten-minute periods, which is the norm of the World Meteorological Organization (Kruk et al. 2010). As the conversion factor to consistent ten-minute averages is contested, the IBTrACS dataset stopped converging it since version 03 (Kruk et al. 2010). This inconsistent measurement introduces a measurement error in the data, where maximum sustained wind speed over a one-minute period is approximately 13% higher than over a ten-minute period (National Weather Service 2015). However, this bias can partly be attenuated by country fixed effects.

2.1.1 Calculation of the Tropical Cyclone Intensity Variable

One major effort of this paper is to calculate an aggregate and meaningful measure of tropical cyclone intensity on a country-year level, as the raw IBTrACS data have a six-hour frequency and no attribution to countries. Figure 1 shows a sketch of the raw data, consisting of several observation track points of all tropical cyclones in the period from 1970 until 2015. For this period, the dataset includes a total number of 7814 tropical cyclones.

As Figure 1 demonstrates, the measurement points give no indication of the size of the tropical cyclones. Further, the intensity of wind speed decreases with increased distance from the cyclone center. To simulate the size and intensity of the tropical cyclones, I make use of the climada model developed by Bresch (2014) at a resolution of 0.1°.[3] It employs the well-established Holland (1980) analytical wind field model, where for each track point a wind speed S is calculated, depending on the forward speed (T), the distance (D) from the storm center, and radius of the maximum wind (R):

$$S = \begin{cases} max\left(0, \left((M - abs(T)) * (\frac{R}{D})^{\frac{3}{2}} * e^{1-(\frac{R}{D})^{3/2}}\right) + T\right) & , D < 10 * R \text{ } from\ center\ to\ outer\ core \\ 0 & , D > 10 * R \text{ } out\ of\ radius \end{cases}$$

By doing so, the 6-hour raw data observations are interpolated to a 1-hour frequency and only wind fields above a raw data threshold of 15 m/s are calculated. Figure 2 illustrates the resulting modeled wind fields for Typhoon Haiyan in 2013 on its way to the South-East Asian coast.

In a next step, I spatially join the modeled tropical cyclone tracks to the affected countries on a 0.1° x 0.1° grid. Then I aggregate for each country and year the maximal occurring wind speed in a grid point weighted by the area of the exposed grid point relative to the overall size of each country. In more detail, I calculated for each country i at year t its tropical cyclone

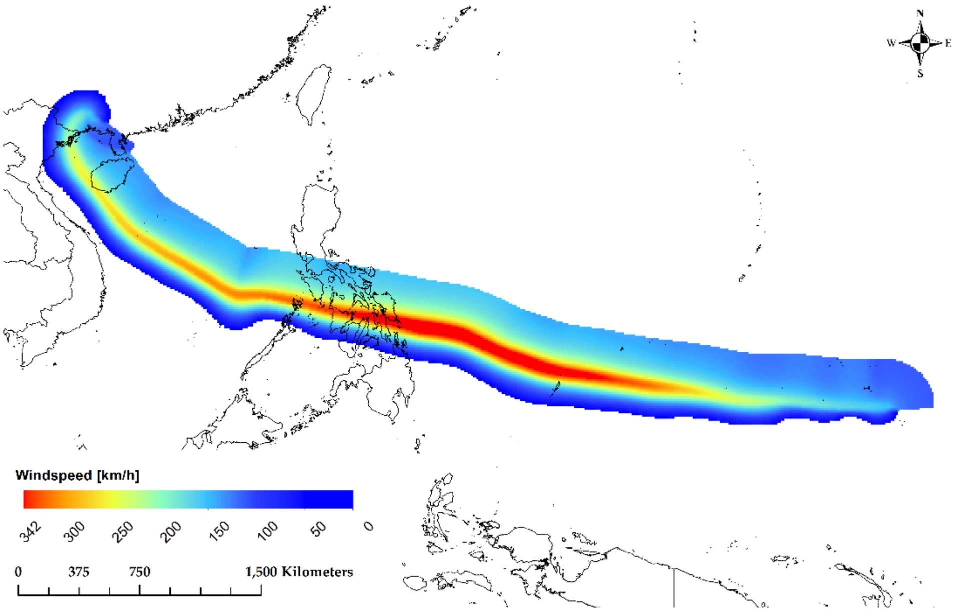

Figure 2: Wind field Model Typhoon Haiyan 2013.

[3] 0.1° corresponds to approximately 10 kilometers at the equator.

intensity *WIND* which consists of the sum of the maximum wind speed per year t and grid point g, $max\ wind_{g,t}$ multiplied by the size of its area, $area_{g,t}$, and divided by the total area of the respective country, $total\ area_i$, represented by the formula:

$$WIND_{i,t} = \frac{\sum_{g \epsilon i} max\ wind_{g,t} * \ area_{g,t}}{total\ area_i}$$

This measure follows the scale-free measure for wind intensity proposed by Hsiang and Jina (2014). Figure 3 gives an impression of how the calculation for the tropical cyclone intensity measure, *WIND*, was conducted. It shows again Typhoon Haiyan making landfall in the Philippines in 2013 with different colors representing different intensities and how they are attributed to the existing grid net.

There are three important points to note about this tropical cyclone intensity calculation. First, I use the maximum wind speed to derive the tropical cyclone intensity measure *WIND*, leaving out potential rainfall and storm surge damages. However, there exists a strong relationship between the maximum wind speed of a tropical cyclone and the total amount of precipitation (Cerveny & Newman 2000). In recognition of this I add precipitation as additional control variable in the sensitivity analysis.

Second, only the maximum wind speed per grid cell and year is used for the calculation of the tropical cyclone intensity measure. This means that if a grid cell of a country was exposed

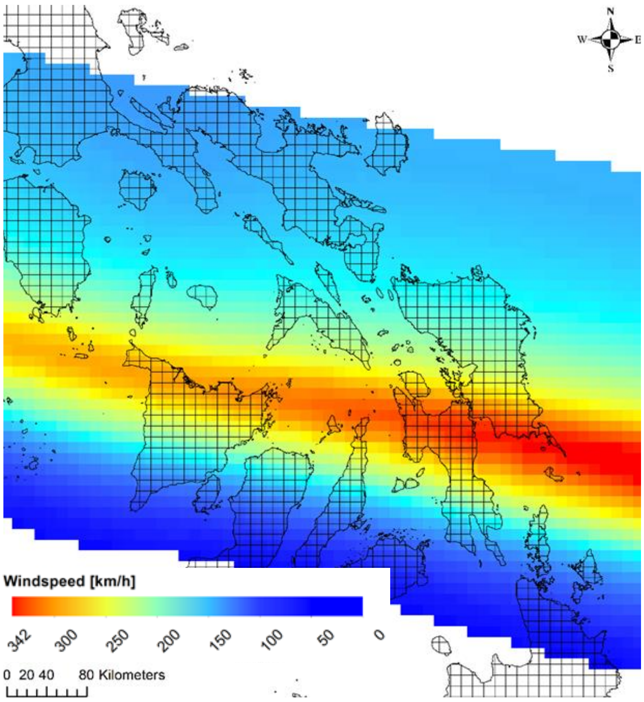

Figure 3: Schematic illustration of the calculation of the tropical cyclone intensity variable WIND.

to two storms in one year, only the physically more intense storm is considered. In the used sample, 70% of all grid-points are hit once by a tropical cyclone per year, whereas 20% are hit twice, and 10% more than twice. As discussed by Hsiang and Jina (2014) and Nordhaus (2010), it is appropriate to only use the maximum wind speed per year as a measure for extensive capital destruction from tropical cyclones, as catastrophic damages of materials will only appear above a certain threshold. Moreover, most (natural or physical) assets are not rebuilt very quickly (within one year), and therefore, repeated less severe storms within one year only cause a limited extent of further damage.

Third, the measure has an area weight, which has a two-fold impact. On the one hand, it guarantees that the results are not driven by large countries, which have a higher probability of being hit by a tropical cyclone due to their larger area. On the other hand, it ensures that there will be a larger coefficient for smaller countries compared to larger countries if a physically identical storm strikes them. I assume that an identical tropical cyclone will generate relatively more damage to a smaller country than to a larger country because the relative size of the tropical cyclone is larger compared to the country's overall area. A disadvantage of using an area weight is that it introduces a measurement error, because large unpopulated areas like deserts or rain forests bias the tropical cyclone intensity average of large countries like Australia, Brazil or Russia (Dell et al. 2014). However, employing a population weight instead generates an endogeneity problem for the statistical analysis. In particular, population can resettle as a response to tropical cyclones. If different parts of the population have different abilities to resettle, which may be correlated with economic output, a population-weighted tropical cyclone measure is no longer exogenous to economic output (Hsiang & Narita 2012).

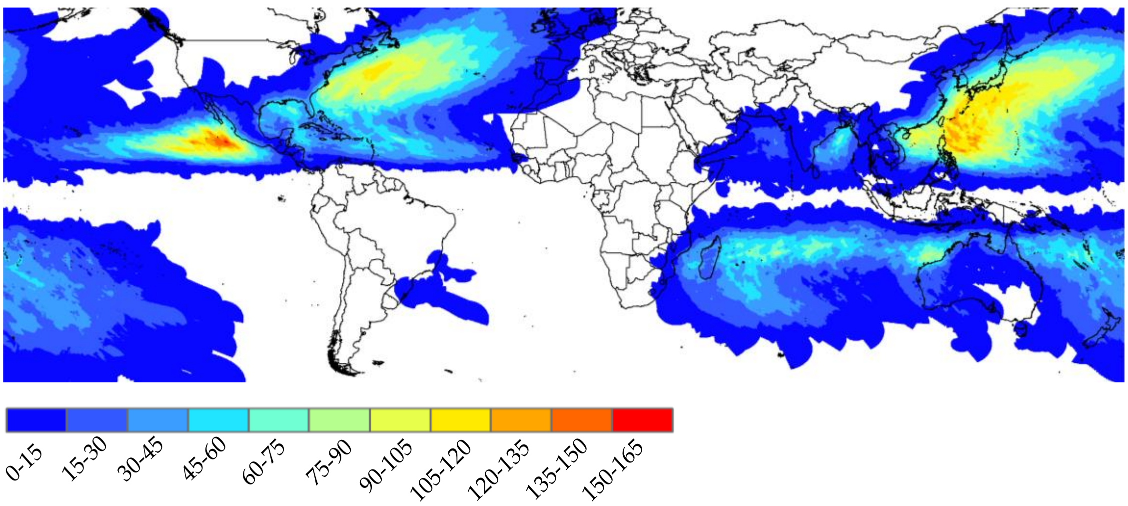

Figure 4: Average of the maximum wind speed of tropical cyclones [km/h], 1970-2015.

The same problem arises when using a GDP weight. In favor of having "true" exogenous variation, I decided to apply an area weight.

2.1.2 Descriptive Statistics

Figure 4 represents the yearly maximum wind speed of tropical cyclones averaged over the 1970-2015 period. The figure clearly shows that the wind speed intensities of tropical cyclones are unequally distributed around the world with regions such as East Asia experiencing relatively high intensities and others as South America suffering less from tropical cyclones, on average. In the South Atlantic basin there are only two tropical cyclones in the sample period due to climatic reasons: usually the water surface temperature is too low, as tropical cyclones need at least 27° Celsius (Kerry 2003).

Figure 5 includes a line graph representation of the distribution of the area weighted tropical cyclone intensity variable *(WIND)* for the 20 countries with the highest mean values over

Figure 5: Variation of the tropical cyclone intensity variable (WIND) for the 20 most exposed countries over the years 1970-2015. The countries are listed according to their mean exposure. It ranges from Bermuda (mean WIND = 91 km/h) to Cayman Islands (mean WIND = 35 km/h).

the sample period from 1970 to 2015. Bermuda has the highest mean tropical cyclone intensity value in the sample, which is plausible since it is situated in a very exposed region for tropical cyclones and is comparatively small. With 640 and 610 tropical cyclones over the sample period, Japan and the Philippines are the two countries with the highest number of tropical cyclones in the sample.[4] This high exposure translates to a relatively small variance of their wind intensity variable. However, for the other countries in Figure 5 *WIND* intensity varies considerably which points to sufficient exogenous variation of the main explanatory variable. In general, out of the 20 most exposed countries, 15 are small islands.[5]

Recapitulating the characteristics of the main explanatory variable, *WIND*, it can be concluded that it is plausibly exogenous to economic output, because the occurrence and intensity of a tropical cyclone cannot be influenced by economic factors. In addition, the variable takes the spatial dimension of the tropical cyclone into account by weighting the intensity with the

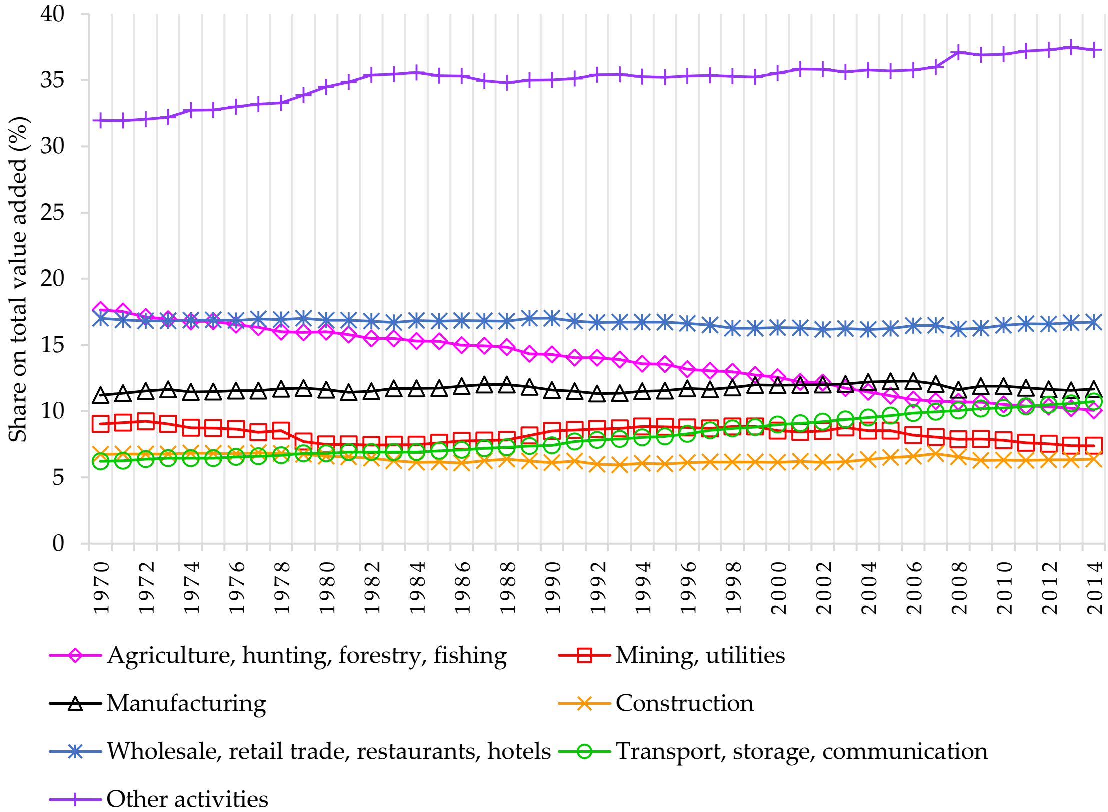

Figure 6: Share of sectors in total value added (in %), 1970-2015.

[4] A detailed descriptive statistic of the *WIND* variable for all exposed countries is given in Appendix B1 in Table 7.

[5] One may argue that the high exposure of small island states is due to construction of the WIND variable since it compromises an area weight. However, if one takes just the mean wind speed per country instead of an area-weighted maximum wind speed (*WIND*) the sample of the 20 most exposed countries is more or less similar but with a different ranking of the countries.

exposed area relative to the whole area of an exposed country. Furthermore, the descriptive statistics show a substantial range of variation of the *WIND* variable within and between countries.

2.2 Sectoral GDP Data

The sectoral GDP data originates from the United Nations Statistical Division (UNSD) (United Nations Statistical Division 2015c). Sectoral GDP is defined as gross value added per sector aggregate and is collected for different economic activities following the International Standard Industrial Classification (ISIC) revision number 3.1. Gross value added is defined by the UNSD as "the value of output less the value of intermediate consumption" (United Nations Statistical Division 2015a). The variables are measured in constant 2005 U.S. dollars. The different economic activities are classified as follows with the respective ISIC codes given in parentheses: *agriculture, hunting, forestry, and fishing (A&B); mining, and utilities (C&E); manufacturing (D); construction (F); wholesale, retail trade, restaurants, and hotels (G-H); transport, storage, and communication (I); other activities (J-P),* which includes inter alia the financial and government sector. Appendix A2 provides a more detailed description of the composition of the individual ISIC categories. The data are collected every year for as many countries and regions as possible. If the official data of the countries or regions are not available, the UNSD consults additional data sources. The procedure is hierarchical and reaches from other official governmental publications over publications from other international organizations to the usage of data from commercial providers (United Nations Statistical Division 2015b). The sample used in my analysis covers the period 1970 through 2015 and includes a maximum of 213 countries.[6]

Figure 6 presents the development of the share each sector aggregate has in the total value added. The aggregate *other activities* has the major share in the composition of the total value added, which is quite intuitive as it covers among others the financial and the government sector. In 1970 the *agriculture, hunting, forestry, and fishing* sector aggregate constitutes the second highest share in total value added, which then diminishes over time. The sector *transport,*

[6] The sample is larger than the maximum size of recognized sovereign states as it also includes quasi-autonomous countries such as the Marshall Islands, if data are provided for them by the UNSD. A complete list of countries in the sample can be found in Appendix A1.

storage, and communication gains relative importance over time, whereas the remaining sectors' shares remain relatively constant over the sample period.

3 Empirical Approach

In order to examine tropical cyclones as exogenous weather shocks, I pursue a panel data approach in a simple growth equation framework (Hsiang 2016; Strobl 2012). The level of analysis is country-year observations. To identify the causal effects of tropical cyclone intensity on sectoral per capita growth, I use the following regression equation, which constitutes my main specification:

$$\text{(I)} \qquad GROWTH^{j}_{i,t-1\to t} = \alpha^{j} + \beta^{j} WIND_{i,t} + \gamma^{j}\boldsymbol{Z}_{i,t} + \delta^{j}_{t} + \theta^{j}_{i} + \varepsilon^{j}_{i,t},$$

where the dependent variable, $GROWTH^{j}_{i,t-1\to t}$ is the annual value added per capita growth rate of sector j in country i. The main specification is estimated for each of the j sectors separately. $WIND_{i,t}$ is the area weighted tropical cyclone intensity measure for country i at year t and is measured in kilometers per hour. Consequently, β^{j} is the coefficient of main interest in this specification. By calculating the annual sectoral GDP per capita growth rate, I lose the first year of observation of the panel. Hence, the sample period reduces to 1971-2015. I include time fixed effects δ_t to account for time trends and other events common to all countries in the sample. The country fixed effects θ_i control for unobservable time-invariant country-specific effects such as culture, institutional background, and geographic location. The error term $\varepsilon_{i,t}$ is clustered at the country level.

The main causal identification stems from the occurrence of tropical cyclones which are unpredictable in time and location (NHC 2016) and vary randomly within geographic regions (Dell et al. 2014). As demonstrated in the previous section, their intensity and frequency spreads sufficiently between years and countries. Additionally, tropical cyclone intensity is measured by remote sensing methods and other meteorological measurements. Especially, remote sensing methods like satellite analyses are uncorrelated with political and economic factors. To underpin this argument I conduct a falsification test, where I introduce leads instead of lags of the *WIND* variable in the main specification (I). One could also argue, that the estimation results are biased by the fact that certain regions have a higher exposure to tropical cyclones than others. However, the country fixed effects will partly control for this concern.

Additionally, in one specification of model (I) I will cluster the standard errors at the regional level.

As tropical cyclones are plausibly exogenous to sectoral economic growth, the greatest threat to causal identification could arise by leaving out important climatic variables which are correlated with tropical cyclones (Hsiang 2016). Therefore I include the mean level of temperature and precipitation as additional climate controls in a further specification of model (I). Both variables are associated with the occurrence of tropical cyclones, since they only form when water temperatures exceed 26 °C and torrential rainfalls are usually a part of them.

To be in line with the related growth literature I estimate a further specification of model (I) where I add a set of socioeconomic control variables (Felbermayr & Gröschl 2014; Islam 1995; Strobl 2012). It comprises the logged per capita value added of the respective sector j to simulate a dynamic panel model, the population growth rate, a variable for openness (imports plus exports divided by GDP), and the growth rate of gross capital formation. Including socioeconomic control variables introduces some threats to causal inference. First, as shown by Nickell (1981), there is a systematic bias of panel regressions with a lagged dependent variable and fixed effects. However, it has been demonstrated that this bias can be neglected if the panel is longer than 15 time periods (Dell et al. 2014). As my panel has a length of 45 years, I assume this bias will not influence my analysis. Second, all control variables are measured in t-1 to reduce potential endogeneity problems stemming from the fact that control variables in t can also be influenced by tropical cyclone intensities in t (Dell et al. 2014). Admittedly, it will not fully solve potential endogeneity problems, and concerns about bad controls (Angrist & Pischke 2009) and "over-controlling" (Dell et al. 2014) remain.

Finally, the standard errors $\varepsilon_{i,t}$ could be biased by the autocorrelation of unobservable omitted variables (Hsiang 2016). To deal with this problem I will re-estimate model (I) with Newey-West (Newey & West 1987) as well as spatial HAC standard errors (Fetzer 2014; Hsiang 2010), which allow for a temporal correlation of 10 years and a spatial correlation of 1000 kilometer radius.

Generally speaking, the model proposed in equation (I) offers a simple but strong way for causative interpretation of the impact of tropical cyclones on sectoral growth. The area weighted tropical cyclone variable is orthogonal to economic growth and the panel approach allows me to identify the causal effect.[7]

4 Results

4.1 Main Results

Table 1 presents the results of the main specification for each of the seven annual sectoral GDP per capita growth rates.[8] Column 1 shows a negative influence of tropical cyclones on annual per capita growth of total output. Although I have used a different wind field model, as Hsiang and Jina (2014) or Strobl (2012), I can replicate their main finding of a negative influence of tropical cyclones on GDP growth. This negative GDP growth effect can be attributed to three sectoral aggregates, including *agriculture, hunting, forestry, and fishing; wholesale, retail trade, restaurants, and hotels;* and *transport, storage, and communication*, where tropical cyclones have a significantly negative effect.

Table 1: Regression results of the main specification

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manu-facturing	Construc-tion	Wholesale, retail trade, restaurants, hotels	Transport, storage, communi-cation	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0067	-0.0304	-0.0093	-0.0090	0.0102	-0.0105	-0.0075	-0.0031
	(0.0030)	(0.0062)	(0.0152)	(0.0069)	(0.0127)	(0.0045)	(0.0042)	(0.0027)
	[0.0262]	[0.0000]	[0.5429]	[0.1936]	[0.4212]	[0.0214]	[0.0727]	[0.2472]
Observations	8,907	8,865	8,739	8,868	8,911	8,861	8,865	8,905
# of countries	213	212	210	213	213	212	212	213
Adj. R^2	0.0434	0.0102	0.0024	0.0146	0.0178	0.0256	0.0153	0.0181
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

[7] All variables used in the regressions are summarized in Appendix A3, including definitions and data sources.

[8] For all regressions I excluded potential outliers as described in Appendix C. However, Table 32 demonstrates that the results of the main specification are not sensitive to the inclusion of potential outliers.

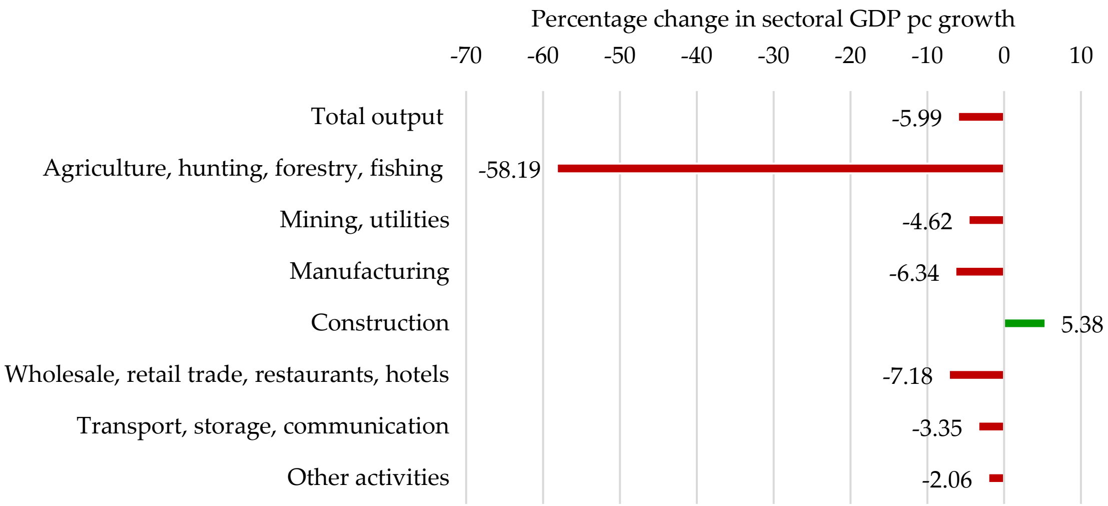

Figure 7: Effect of a median tropical cyclone intensity (15.4 km/h) on average p.c. sectoral GDP growth [%].

Tropical cyclones have the largest negative effect on the *agriculture, hunting, forestry, and fishing* sector aggregate compared to other sector aggregates. The absolute size of this effect is approximately more than 2.5 times the size of the coefficient in the *wholesale, retail trade, restaurants, and hotels* sector aggregate and 4 times as large as the respective coefficient for the *transport, storage, and communication* sector aggregate. In general, an increase in the area weighted wind speed by a median tropical cyclone intensity is associated with a decrease of the annual growth rate in the sector aggregate *agriculture, hunting, forestry, and fishing* of 0.47 percentage points. For the sample average (0.804) of the regression of column (2) this effect can be translated into a decrease of 58.19 percent, as displayed in Figure 7. In terms of total losses, an increase of a median tropical cyclone intensity results in a loss of 28.5 million U.S. Dollars (measured in constant 2005 U.S. Dollars) for the sample average.

This strong negative effect is not surprising. The agricultural sector heavily relies on environmental conditions as most of its production facilities lie outside of buildings, and hence are more vulnerable to the destructiveness of tropical cyclones. In addition to damaging wind speed, salty sea spread and storm surge can cause a salinization of the soil, leaving it useless for cultivation.

For the sector aggregate *wholesale, retail trade, restaurants, and hotels*, a median tropical cyclone causes a decrease of 7.18 percentage in comparison to the sample average. The reasons for this downturn can stem from different sources. First, affected people could shift their spending from general products to products related to the construction sector. Second, if the landscape is devastated after a tropical cyclone, the restaurant and hotel industry will suffer heavily, as people prefer regions with an intact landscape.

In the *transport, storage, and communication* sector aggregate, a median tropical cyclone leads to a reduction of 3.35 percentage. An intuitive explanation could be that if infrastructure (e.g., roads, railways) is destroyed, the transport and storage sector experiences a downturn. For the remaining sectors, including *mining, utilities, manufacturing, construction, and other activities* tropical cyclones have no contemporaneous effects.[9]

4.2 Past Influence of Tropical Cyclones

The growth literature predicts that some potential positive or negative impacts of natural disasters only emerge after a few years, it is therefore important to look at the effect over time. To analyze the effect of tropical cyclones in the longer run, I follow Felbermayr & Gröschl (2014) by introducing five lags of the tropical cyclone intensity variable into the main specification. This allows me to identify which of the competing hypotheses – build-back-better, recovery to trend, or no recovery – is appropriate for which sector.[10] In detail, this model can be described by the following regression equation:

$$\text{(II)} \quad GROWTH^{j}_{i,t-1\rightarrow t} = \alpha^{j} + \sum_{L=0}^{5}(\beta^{j}_{L} * WIND_{i,t-L}) + \delta^{j}_{t} + \theta^{j}_{i} + \varepsilon^{j}_{i,t} \, ,$$

where all variables are defined as in regression equation (I).

Figure 8 illustrates the individual point estimates of the past influence of tropical cyclone intensity on the different sectoral growth variables. Since it is also important to discuss the magnitude and statistical significance of the cumulative effects, I estimate cumulative significance of the different lags up to 5 years. Figure 9 shows the result of the cumulative β coefficients for the different sectors. For both Figures the x-axis represents the lags of the *WIND* variable, whereas the y-axis indicates the size of the (cumulative) coefficient β. The grey

[9] Appendix D shows additional results for different sample groups.

[10] The build-back-better hypothesis describes a situation where natural disasters first trigger a downturn of the economy, which is then followed by a positive stimulus, leading to a higher growth path than in the pre-disaster period. The recovery to trend hypothesis characterizes a pattern where after a negative effect in the short run, the economy recovers after some time to the previous growth path. In contrast, the no recovery hypothesis states that natural disasters lead to a permanent decrease of the income level without the prospect of reaching the pre-disaster growth path.

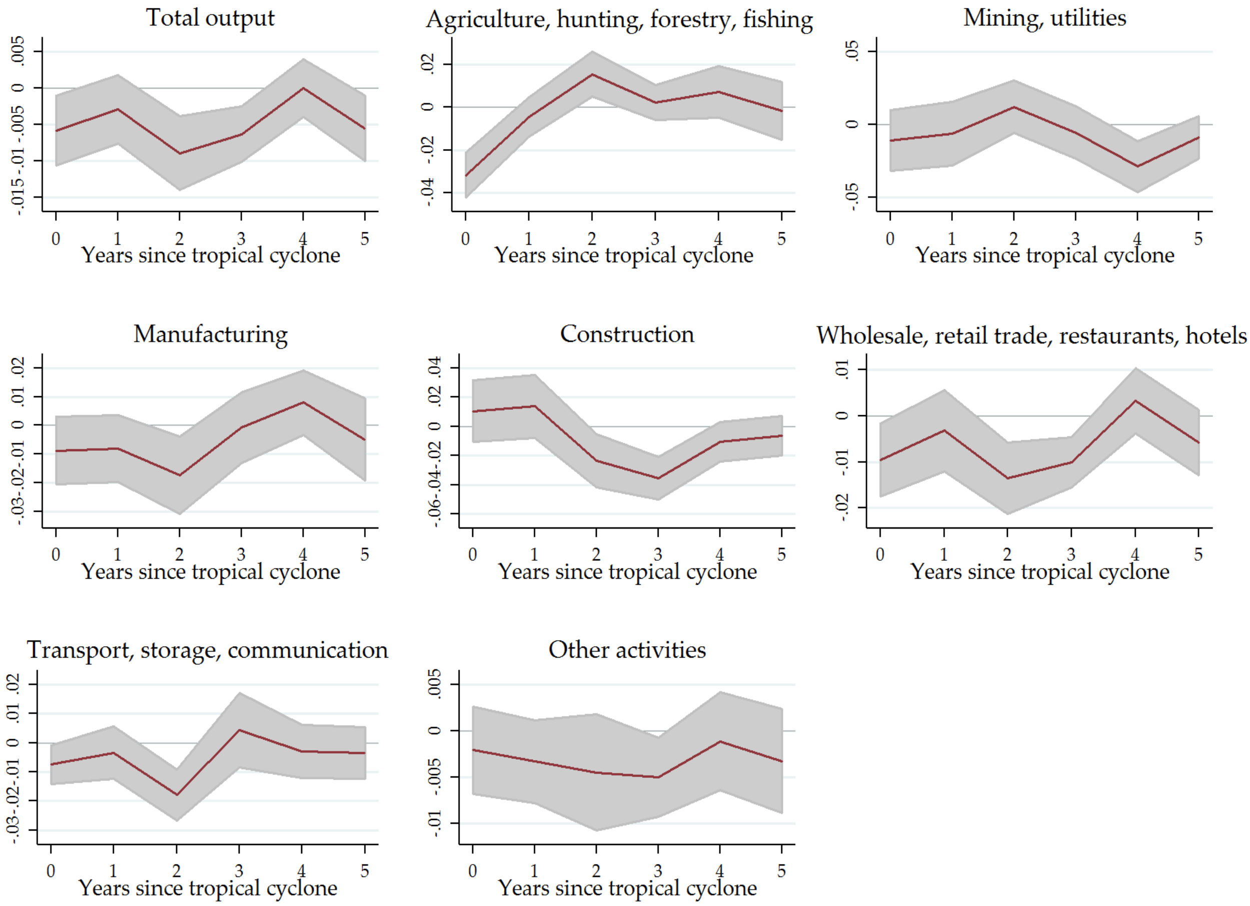

Figure 8: Point estimates of past influence of tropical cyclone intensity up to 5 years on the respective per capita growth rates. The x-axis displays the coefficient of tropical cyclone intensity (WIND) and the y-axis shows the years since the tropical cyclone passed. The grey areas represent the respective 90% confidence interval and the red line to respective point estimates. The underlying estimation can be found in Appendix B.

shaded area specifies the respective 90% confidence bands and the red line depicts the connected estimates. The underlying estimation results of the Figures can be seen in Appendix B in Tables 24-26.

Figure 8 shows that nearly all sectors suffer from delayed negative impacts of tropical cyclones.[11] The *agriculture, hunting, forestry, and fishing* sector aggregate forms an exception, where only the current tropical cyclone intensity has a significantly negative impact. After two years the coefficient displays a significantly positive effect, indicating that some recovery is taking place in this sector. However, after three years as shown in Figure 9 the sum of coef-

[11] As the lag structure decreases the sample size, I also re-estimate the main model (I) with the reduced sample, to verify whether the results of my main specification still hold. The results of this specification are presented in column 2 for each dependent variable in Tables 24-26 in Appendix B. They show that, despite of the reduced sample size, the results of the main estimation can be replicated.

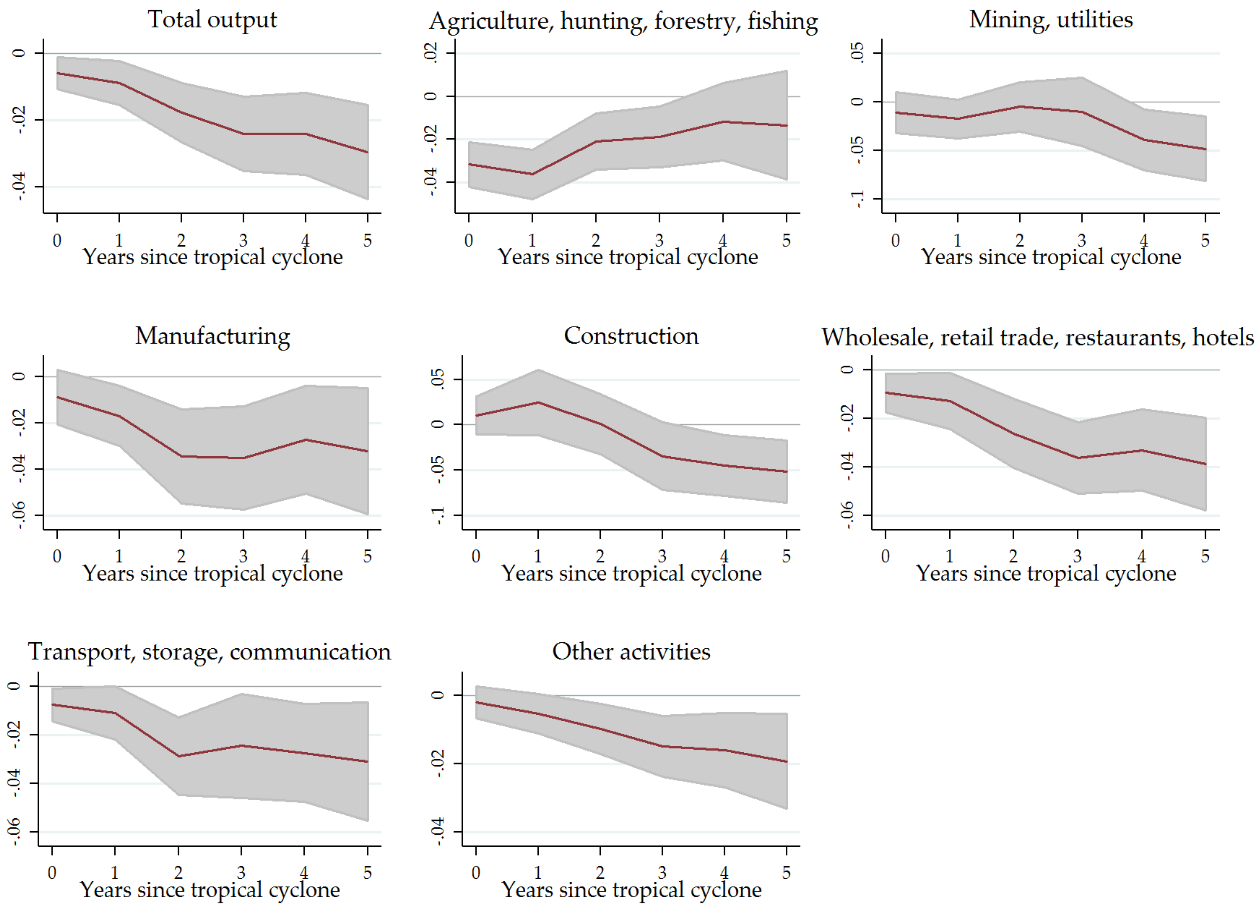

Figure 9: Additive estimates of the past influence of tropical cyclone intensity up to 5 years on the respective per capita growth rates. The x-axis displays the cumulative coefficient of tropical cyclone intensity (WIND) and the y-axis shows the years since the tropical cyclone passed. The grey areas represent the respective 90% confidence interval and the red line to respective point estimates. The underlying estimation can be found in Table 27 in Appendix B.

ficients is still negative (-0.0188) and statistically different from zero indicating that the *agriculture, hunting, forestry, and fishing* sector aggregate cannot fully recover.

An interesting pattern can be discovered for the influence of past tropical cyclone intensity on the *construction* sector. In t and t-1, the coefficient is positive, albeit not statistically different from zero. Then it turns negative and becomes significant from the second until the third lag. After 5 years the cumulative effect reaches a size of -0.052 at a p-value<0.05, which is larger in absolute terms than any other cumulative effect of the other sectors. This observation corresponds to the hypothesis of Kousky (2014) which states that after a short boom with exceptionally many orders in the construction sector, a recession with few orders will follow. However, clear evidence for a boom in the construction sector cannot be found. One reason for the lack of a positive effect could be that the destruction of productive capital outweighs the higher number of orders. Furthermore, for the *wholesale, retail trade, restaurants, and hotels* sector aggregate, the individual past effects of tropical cyclone intensity on the annual sectoral growth is significantly negative, except for the first, fourth, and fifth lag. This undermines the finding of the main specification that people shift their consumption away from this sector aggregate and avoid restaurants and hotels in devastated areas, even several years after the occurrence of a tropical cyclone. Figure 9 shows the same pattern for the *wholesale, retail trade, restaurants, and hotels* sector aggregate, where one can see a decreasing and highly significant effect of past tropical cyclones.

In total, delayed negative effects are present in six out of seven sectoral aggregates. More worryingly, Figure 9 demonstrates a downward trend for all sectors, expect for the *agriculture, hunting, forestry and fishing* sector aggregate. This finding clearly opposes the build-back-better hypothesis as well as the recovery to trend hypothesis. It rather points to the presence of (delayed) negative effects of tropical cyclones in all sectors, from which they cannot recover and which worsens over time. The result offers a better understanding of the finding of Hsiang and Jina (2014), who show that tropical cyclones have long lasting negative impacts on GDP growth, by demonstrating which sectors are responsible for the long-lasting GDP downturn that they identify.

4.3 Sectoral Shifts

The analysis of the temporal growth effects demonstrates that the sectoral growth response following a tropical cyclone is a complex undertaking. It remains unclear if there exists some key sector, which, if damaged, results in a negative shock for the other sectors. Additionally, it is unexplained how the sectors are interconnected and if their structural dependence changes. Therefore, in this section I investigate by the means of Input-Output data, how the sectors interact after a tropical cyclone has hit a country. This will give further insights into whether production processes are seriously distorted by tropical cyclones. To my best knowledge, this is the first paper which analyzes sectoral interactions after the occurrence of a tropical cyclone.

To analyze potential sectoral shifts within the economy after the occurrence of a tropical cyclone I take advantage of the Input-Output data of EORA26 (Lenzen et al. 2012; Lenzen et al. 2013). It provides data on 26 homogenous sectors for 189 countries from 1990 until 2015 and is the only Input-Output panel dataset with (nearly) global coverage available. One disadvantage of the EORA26 dataset is that parts of the data are estimated and not measured. On the other hand, EORA knows about this critic and works continuously on quality check reports and verifies its result to other IO databases such as GTAP or WIOD. As the new results could be driven by the reduced sample size I have re-estimated the regression model of the main specification (I) for the reduced sample of model (IV). Table 2 reveals that the results remain robust. Even with the smaller sample, all previously found effects can be identified again. But the coefficients for the *manufacturing* and the *construction* sector turn significant at the 5% level and 10% level, respectively.

To be consistent with the remaining analysis, I aggregate the given 26 sectors to the previously used 7 sectoral aggregates. For the analysis, I first calculate the Input-Output coefficients by dividing the specific input of each sector by the total input of each sector, given in the transaction matrix of the data:

$$\text{(III)} \qquad IO^{jk} = \frac{Input^{jk}}{Total\ Input^{k}}$$

The resulting Input-Output coefficients (IO^{jk}) indicate how much input from sector k is needed to produce one unit of output of sector *j*. Consequently, they give an idea of the structural interaction of sectors within an economy. A complete list of all Input- Output coefficient

Table 2: Regression results of the main specification for sectoral shift sample

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manu-facturing	Con-struction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communi-cation	Other activities
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$WIND_t$	-0.0075	-0.0330	-0.0106	-0.0165	-0.0221	-0.0116	-0.0112	-0.0001
	(0.0036)	(0.0063)	(0.0111)	(0.0079)	(0.0114)	(0.0056)	(0.0059)	(0.0040)
	[0.0384]	[0.0000]	[0.3381]	[0.0396]	[0.0533]	[0.0399]	[0.0576]	[0.9713]
Observations	4,658	4,632	4,565	4,642	4,658	4,632	4,632	4,658
#. of countries	184	183	180	183	184	183	183	184
Adj. R^2	0.0678	0.0077	0.0016	0.0405	0.0257	0.0415	0.0531	0.0272
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1990 through 2015. WIND is the area-weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

can be found in Appendix B in Table 28. In contrast to equation (I), I will introduce a lagged dependent variable, since I suspect a strong path dependence of the Input-Output coefficient, e.g. most sectors plan their inputs at least one period ahead. Following equation (I), I estimate the following regression model:

$$\text{(IV)} \qquad IO_{i,t}^{jk} = \alpha^{jk} + \beta^{jk} WIND_{i,t} + IO_{i,t-1}^{jk} + \delta_t^{jk} + \theta_i^{jk} + \varepsilon_{i,t}^{jk},$$

where $IO_{i,t}^{jk}$ indicates the Input-Output coefficient of sectors j and k in year t. The remaining variables are defined as in equation (I). Using the lag dependent variable ($IO_{i,t-1}^{jk}$) as a further control variable in a panel regression with fixed effcts introduces the possible threat of Nickell bias (1981). However, it can be neglected if the panel is longer than 15 time periods (Dell et al. 2014). As the used panel still has a length of 26 years, I assume this bias will not influence my analysis.

Figure 10 illustrates the connections of significant effects resulting from the estimation of equation (IV). The coefficients are the effect of a median increase in tropical cyclone intensity

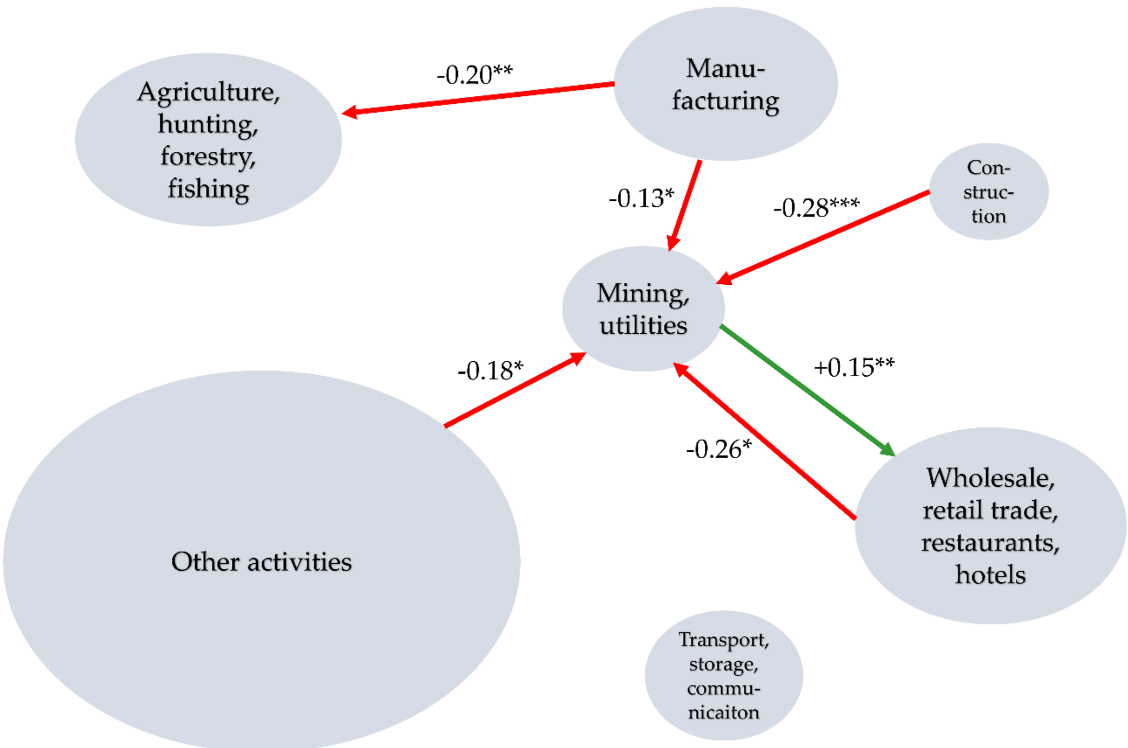

Figure 10: Effect of a median increase in tropical cyclone intensity (15.4 km/h) on the average Input-Output coefficient of the respective sector aggregate (%). Circle size is proportional to the average sectoral share on total GDP. The arrows depict all significant coefficients between the sector aggregates, with negative coefficients in red and positive in green. Asterisks indicate p-values according to: *** p<0.01, ** p<0.05, * p<<0.1. Table 29 in Appendix B shows the underlying regression results.

(15.4 km/h) on the average Input-Output coefficient of the respective sector aggregates.[12] For example, due an increase of tropical cyclone damages by median storm, the *manufacturing* sector uses 0.2% less input from the *agriculture, hunting, forestry and fishing* sector aggregate relative to the average Input-Output coefficient (0.06) to produce one unit of output. Circle sizes represent the average proportional share on total GDP ranging from 32% (*other activities*), over 12% (*manufacturing*) to 6% (*construction*).[13]

Tropical cyclones only lead to a small number of sectoral shifts with coefficients being relatively small. Out of 49 parameter estimates only 6 are significantly different from zero. The *mining and utilities* sector aggregate suffer the most from sectoral shifts after the occurrence of a tropical cyclone. Most probably it is the *utilities* sector, which includes the electricity, gas and water supply that drives the results. As the sector aggregates *manufacturing*, *construction* and *wholesale, retail trade, restaurants, and hotels* experience a monetary downturn, they demand less from the *utilities* sector as they produce less. However, it is puzzling why we cannot see a downturn in the *utilities* sector. One explanation could be that the downturn is most likely offset by more demand from the *wholesale, retail trade, restaurants, and hotels* sector, which has on average a 50% higher quantitative importance on total GDP. The *agriculture, hunting, forestry and fishing* sector aggregate experiences the largest downturns in absolute numbers but which only has limited consequences for the other sectors: It only demands less input from the *manufacturing* sector. The transport, storage and communication sector aggregate seems to be isolated as it has no significant connections to other sectors after a tropical cyclone has hit a country.

This analysis shows that only few changes within the production portfolio of the individual sectors exist. Thus, production processes are rather sticky and only limited indirect costs of tropical cyclones on economic sectors emerge. But, as in models (I) and (II) negative effects of tropical cyclones prevail.

[12] Detailed regression tables are shown in Appendix B in Table 29.

[13] The other proportional shares on total GDP are: *Wholesale, retail trade, restaurants, hotels* (15%); *agriculture, hunting, forestry, fishing* (14%); *mining and utilities* (10%); *transport, storage, communication* (8%).

Table 3: Regression results of the main specification (Placebo-Test)

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufac-turing	Construc-tion	Wholesale, retail trade, restaurants, hotels	Transport, storage, communi-cation	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_{t+1}$	0.0022	-0.0033	-0.0126	0.0093	0.0099	-0.0017	-0.0021	0.0010
	(0.0028)	(0.0053)	(0.0095)	(0.0069)	(0.0078)	(0.0038)	(0.0060)	(0.0027)
	[0.4259]	[0.5381]	[0.1862]	[0.1777]	[0.2021]	[0.6558]	[0.7341]	[0.7114]
Observations	8,694	8,653	8,529	8,655	8,698	8,649	8,653	8,692
# of countries	213	212	210	213	213	212	212	213
Adj. R^2	0.0432	0.0068	0.0021	0.0145	0.0179	0.0253	0.0150	0.0178
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results of the Placebo-Test with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity, forwarded by one period, and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

4.4 Sensitivity Analysis

To underline the credibility of my main regression model (I) I run a Placebo-Test by using leads instead of the contemporaneous measure of the *WIND* variable. As expected, Table 3 shows that no coefficient estimate is significant, underpinning the causal identification of the chosen regression model and ruling out possible concerns over reverse causality.

As argued above, one further concern when analyzing the sectoral growth effects of tropical cyclones is that the result can be driven by precipitation and temperature, leading to an omitted variable bias. Therefore, in Table 4 I add variables for precipitation and temperature for each country to the main specification (I). For the precipitation data I calculate yearly averages per country from the CMAP dataset provided by NOAA (Xie & Arkin 1997), which is available at a global scale since 1979 with a resolution of 2.5x2.5 degrees. The temperature is derived from the NCEP Reanalysis data, also made available from NOAA (Kalnay et al. 1996). It covers the entire world from 1948 to present at a 2.5x2.5 degrees grid, from which I calculate yearly means per country. Due to the limited availability of the precipitation data the sample period reduces to 1979-2015.[14] For the sake of convenience, I only show the coefficient for tropical cyclone intensity in Table 4, but the respective climate control variables as well as country and year fixed effects are included in the corresponding regressions. Tables 8-10 in Appendix B show the results in more detail.

Adding temperature and precipitation as additional control variables does not significantly change the original effect sizes and probability values. An exception is the sector aggregate *transport, storage, and communication*. Despite being marginally significant when temperature alone is added, the coefficient turns insignificant for the remaining regressions in Table 4. When looking at the detailed results in Tables 9 and 10, it seems that the precipitation variables pick up the significance for *transport, storage, and communication.*

Table 4: Regression results of the main specification with climate controls

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manu-facturing	Construc-tion	Wholesale, retail trade, restaurants, hotels	Transport, storage, communi-cation	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Controlled for Temperature								
$WIND_t$	-0.0067	-0.0301	-0.0109	-0.0089	0.0114	-0.0111	-0.0073	-0.0029
	(0.0032)	(0.0063)	(0.0155)	(0.0071)	(0.0135)	(0.0048)	(0.0044)	(0.0028)
	[0.0364]	[0.0000]	[0.4838]	[0.2131]	[0.3989]	[0.0228]	[0.0961]	[0.3137]
Panel B: Controlled for Precipitation								
$WIND_t$	-0.0061	-0.0323	-0.0132	-0.0109	0.0074	-0.0102	-0.0065	-0.0022
	(0.0030)	(0.0063)	(0.0134)	(0.0070)	(0.0133)	(0.0050)	(0.0046)	(0.0026)
	[0.0438]	[0.0000]	[0.3254]	[0.1177]	[0.5785]	[0.0446]	[0.1569]	[0.4056]
Panel C: Controlled for Precipitation and Temperature								
$WIND_t$	-0.0060	-0.0319	-0.0155	-0.0106	0.0088	-0.0107	-0.0063	-0.0019
	(0.0032)	(0.0065)	(0.0135)	(0.0072)	(0.0142)	(0.0054)	(0.0048)	(0.0027)
	[0.0636]	[0.0000]	[0.2509]	[0.1467]	[0.5367]	[0.0469]	[0.1924]	[0.4988]
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1979 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C. The full regression tables can be found in Appendix B.

[14] There are also datasets available which cover longer time periods, e.g. the CRU dataset offers climate data from 1901 until 2016 (Harris et al. 2014). However, many small island states are missing in their data. But since they are highly exposed to tropical cyclones, I decide to use the CMAP dataset.

To further test the robustness of my regression model, I examine the influence of a set of socioeconomic control variables, which are typically included in economic growth regression (see for example Islam (1995) or Strobl (2012)). It covers the logged per capita value added of the respective sector, the population growth rate, economic openness, and the growth rate of gross capital formation, all lagged by one year. Table 11 in Appendix B shows similar results to those when climate controls were added: Except for the sector aggregate *transport, storage, and communication* the results are robust to the addition of socioeconomic control variables.

To take care of concerns on biased uncertainty measures (Hsiang 2016), I calculate different standard errors: Newey-West standard errors with a lag length of 10 years, and Conley- HAC standard errors, allowing for dependence of the standard errors within a radius of 1000 kilometers and within a time span of 10 years. Table 20 and Table 21 in Appendix B replicates the previously found results, however, for the Conley-HAC estimator *transport, storage, and communication* gets marginally insignificant.

Table 22 and Table 23 in Appendix B include two final robustness tests – regional clustering of the standard errors, and an alternative tropical cyclone intensity measure, where I use the mean instead of maximum wind speed per grid cell in country i at time t to calculate the *WIND* intensity variable. In any manner, the levels of significance of the coefficient are relatively robust to these additional tests, underpinning the causal identification of the chosen regression model.

5 Conclusion

Although there are opposing hypotheses on the influence of natural disasters on economic output, no study has yet estimated the effect of tropical cyclones on sectoral growth worldwide using meteorological data. This paper unravels post-disaster economic damages of tropical cyclones worldwide, by looking at their immediate, delayed, as well as indirect influence on economic sector per capita growth. To quantify the destructiveness of tropical cyclones, I construct an intensity measure based on a spatially weighted wind field model. The influence on sectoral growth rates is then estimated by a panel regression for up to 213 countries for the 1971-2013 period.

This study gives an explanation which sectors contribute to an overall negative GDP effect identified by previous studies (Felbermayr & Gröschl 2014; Hsiang & Jina 2014). I show that tropical cyclones have a significantly negative effect on the annual growth rate of the *agriculture, hunting, forestry, and fishing*; the *wholesale, retail trade, restaurants, and hotels;* and the *transport, storage, and communication* sector aggregate. With the exception of the *transport, storage, and communication* sector aggregate, the findings can be replicated in various modifications. The dynamic analysis reveals that past tropical cyclones have a significant negative influence on nearly all sectors, whereas the cumulative effects after five years remain negative for all sectors. Most surprisingly, the cumulative effect is smallest for the *construction* sector. The Input-Output analysis shows that production processes are only slightly disturbed by tropical cyclones.

The outcomes of this study can serve as a guide for local governments as well as international organizations to revise and refine their adaptation and mitigation strategies. Further, the findings can help them to identify the sectors for which they need to reduce disaster risk. The results indicate that the policies should focus on the direct costs of tropical cyclones. Immediately after the disaster the policy should concentrate on the *agriculture, hunting, forestry, and fishing*; the *wholesale, retail trade, restaurants, and hotels;* and the *transport, storage, and communication* sector aggregate, as they are most vulnerable, and/or recovery measures were not conducted efficiently in these sectors. Likewise, the contemporaneous non-significant effect for the remaining sectors can be a result of lower vulnerability, and/or efficient recovery measures, which attenuate the potentially negative effect of tropical cyclones. In the five years following the tropical cyclone, the efforts should be broadened, as, except for the agricultural sector, all sectors show delayed negative growth effects. Most worryingly, the cumulative effects for nearly all sectors are still negative five years after the occurrence of a tropical cyclone underpinning how far away the international community still is from a "building-back better" situation for tropical cyclone-affected economies. As the *construction* sector constitutes the largest negative per capita growth effect after five years, it should receive more attention by the policy makers.

Better post-disaster assistance is not the only required improvement; policy makers should also find ways to better prepare the affected sectors of their economy to possible effects of tropical cyclones before they strike. However, the presented results are generalized for at most

213 countries, and every specific country should make an analysis of their specific vulnerability and individual exposure. Nonetheless, the results can provide general guidance for international disaster relief organizations, which are active in various countries, on how to direct their long-run disaster relief programs. The results are particularly pressing, as tropical cyclones will intensify due to global warming and simultaneously more people will be exposed to tropical cyclones. In this respect, the results can also be used to calculate the future costs of climate change.

The physical measure I use as the main explanatory variable seems an appropriate way to circumvent past problems of endogeneity and reverse causality associated with the use of datasets based on governmental and non-governmental reports. Nonetheless, the use of the IBTrACS dataset has some potential drawbacks that should be considered when interpreting the results as well as for future research. As already mentioned above, depending on the local weather agency, maximum sustained wind speed is either measured over a one-, two-, three-, or ten-minute average. This leads to inconsistencies across agencies which cannot be easily revised. As indicated by Bakkensen and Mendelsohn (2016) one possible solution for future research is the use of pressure instead of maximum sustained wind speed which is measured consistently across time and agencies. Furthermore, the chosen tropical cyclone measure only uses wind speed as a proxy for the damages caused by tropical cyclones. Although wind speed is a good proxy for rainfall damages, it leaves out storm surge damages, which are particularly destructive but hard to model.

6 References

Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi, "The Network Origins of Aggregate Fluctuations," *Econometrica* 80 (2012), 1977–2016.

Albala-Bertrand, Jose-Miguel, "Natural disaster situations and growth: A macro-economic model for sudden disaster impacts," *World Development* 21 (1993), 1417–1434.

Angrist, Joshua D., and Jörn-Steffen Pischke, *Mostly harmless econometrics: An empiricist's companion* (Princeton: Princeton University Press, 2009).

Bakkensen, Laura A., and Robert O. Mendelsohn, "Risk and Adaptation: Evidence from Global Hurricane Damages and Fatalities," *Journal of the Association of Environmental and Resource Economists* 3 (2016), 555–587.

Barrot, Jean-Noël, and Julien Sauvagnat, "Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks," *The Quarterly Journal of Economics* 131 (2016), 1543–1592.

Belasen, Ariel R., and Solomon W. Polachek, "How Hurricanes Affect Wages and Employment in Local Labor Markets," *American Economic Review* 98 (2008), 49–53.

Bertinelli, Luisito, and Eric Strobl, "Quantifying the Local Economic Growth Impact of Hurricane Strikes: An Analysis from Outer Space for the Caribbean," *Journal of Applied Meteorology and Climatology* 52 (2013), 1688–1697.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar, "Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tohoku Earthquake," *Review of Economics and Statistics* (2018).

Bresch, David N., *climada – the open-source Economics of Climate Adaptation (ECA) tool, implemented in MATLAB/Octave.* (2014), https://github.com/davidnbresch/climada.

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi, "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake," *Becker Friedman Institute for Research Economics Working Paper Series* 01 (2017).

Cerveny, Randall S., and Lynn E. Newman, "Climatological Relationships between Tropical Cyclones and Rainfall," *Monthly Weather Review* 128 (2000), 3329–3336.

Cuaresma, Jesús Crespo, J. Hlouskova, and M. Obersteiner, "Natural Disasters as Creative Destruction? Evidence from Developing Countries," *Economic Inquiry* 46 (2008), 214–226.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken, "What Do We Learn from the Weather? The New Climate-Economy Literature," *Journal of Economic Literature* 52 (2014), 740–798.

Deryugina, Tatyana, "The Fiscal Cost of Hurricanes: Disaster Aid versus Social Insurance," *American Economic Journal: Economic Policy* 9 (2017).

Dupor, Bill, "Aggregation and irrelevance in multi-sector models," *Journal of Monetary Economics* 43 (1999), 391–409.

Elsner, James B., James P. Kossin, and Thomas H. Jagger, "The increasing intensity of the strongest tropical cyclones," *Nature* 455 (2008), 92–95.

EM-DAT, *The International Disaster Database* (2015), http://www.emdat.be/frequently-asked-questions.

Felbermayr, Gabriel, and Jasmin Gröschl, "Naturally negative: The growth effects of natural disasters," *Journal of Development Economics* 111 (2014), 92–106.

Fetzer, Thiemo, "Can Workfare Programs Moderate Violence? Evidence from India," *STICERD Working Paper* (2014).

Gröger, André, and Yanos Zylberberg, "Internal Labor Migration as a Shock Coping Strategy: Evidence from a Typhoon," *American Economic Journal: Applied Economics* 8 (2016), 123–153.

Harris, Ian, Philip D. Jones, Timothy J. Osborn, and David H. Lister, "Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset," *International Journal of Climatology* 34 (2014), 623–642.

Holland, Greg J., "An Analytic Model of the Wind and Pressure Profiles in Hurricanes," *Monthly Weather Review* 108 (1980), 1212–1218.

Horvath, Michael, "Sectoral shocks and aggregate fluctuations," *Journal of Monetary Economics* 45 (2000), 69–106.

Hsiang, Solomon M., "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America," *Proceedings of the National Academy of Sciences of the United States of America* 107 (2010), 15367–15372.

——— "Climate Econometrics," *Annual Review of Resource Economics* 8 (2016), 43–75.

Hsiang, Solomon M., and Amir S. Jina, "The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones," *NBER working paper series* 20352 (2014).

Hsiang, Solomon M., and Daiju Narita, "Adaptation to cyclone risk: evidence from the global cross-section," *Climate Change Economics* 3 (2012), 1–28.

Islam, Nazrul, "Growth Empirics: A Panel Data Approach," *The Quarterly Journal of Economics* 110 (1995), 1127–1170.

Kahn, Matthew E., "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions," *Review of Economics and Statistics* 87 (2005), 271–284.

Kalnay, Eugenia, Masao Kanamitsu, Robert Kistler, William Collins, Dennis Deaven, Lev Gandin, Mark Iredell, Suranjana Saha, Glenn White, John Woollen, Yangiu Zhu, Ants Leetmaa, Richard Reynolds, Muthuvel Chelliah, Wesley Ebisuzaki, Wayne Higgins, John Janowiak, Kingtse C. Mo, Chester Ropelewski, Jia. Wang, Roy Jenne, and Dennis Joseph, "The NCEP/NCAR 40-Year Reanalysis Project," *Bulletin of the American Meteorological Society* 77 (1996), 437–471.

Kerry, Emanuel, "Tropical Cyclones," *Annual Review of Earth and Planetary Sciences* 31 (2003), 75–104.

Klomp, Jeroen, and Kay Valckx, "Natural disasters and economic growth: A meta-analysis," *Global Environmental Change* 26 (2014), 183–195.

Knapp, Kenneth R., Michael C. Kruk, David H. Levinson, Howard J. Diamond, and Charles J. Neumann, "The International Best Track Archive for Climate Stewardship (IBTrACS)," *Bulletin of the American Meteorological Society* 91 (2010), 363–376.

Korty, Robert, "Hurricane (Typhoon, Cyclone)" (pp. 481–494), in Peter T. Bobrowsky, ed., *Encyclopedia of natural hazards* (Dordrecht, New York: Springer, 2013).

Kousky, Carolyn, "Informing climate adaptation: A review of the economic costs of natural disasters," *Energy Economics* 46 (2014), 576–592.

Kruk, Michael C., Kenneth R. Knapp, and David H. Levinson, "A Technique for Combining Global Tropical Cyclone Best Track Data," *Journal of Atmospheric and Oceanic Technology* 27 (2010), 680–692.

Kunreuther, Howard, and Erwann Michel-Kerjan, "Costs (Economic) of Natural Hazards and Disasters" (pp. 125–129), in Peter T. Bobrowsky, ed., *Encyclopedia of natural hazards* (Dordrecht, New York: Springer, 2013).

Lazzaroni, Sara, and Peter van Bergeijk, "Natural disasters' impact, factors of resilience and development: A meta-analysis of the macroeconomic literature," *Ecological Economics* 107 (2014), 333–346.

Le Cozannet, Gonéri, Hormoz Modaressi, Rodrigo Pedreros, Manuel Garcin, Yann Krien, and Nicolas Desramaut, "Storm Surges" (p. 940), in Peter T. Bobrowsky, ed., *Encyclopedia of natural hazards* (Dordrecht, New York: Springer, 2013).

Lenzen, Manfred, Keiichiro Kanemoto, Daniel Moran, and Arne Geschke, "Mapping the structure of the world economy," *Environmental science & technology* 46 (2012), 8374–8381.

Lenzen, Manfred, Daniel Moran, Keiichiro Kanemoto, and Arne Geschke, "Building Eora: A global multi-region input-output database at high country and sector resolution," *Economic Systems Research* 25 (2013), 20–49.

Loayza, Norman V., Eduardo Olaberría, Jamele Rigolini, and Luc Christiaensen, "Natural Disasters and Growth: Going Beyond the Averages," *World Development* 40 (2012), 1317–1336.

Mendelsohn, Robert, Kerry Emanuel, Shun Chonabayashi, and Laura Bakkensen, "The impact of climate change on global tropical cyclone damage," *Nature Climate Change* 2 (2012), 205–209.

National Weather Service, *Tropical Cyclone Winds and Energy* (2015), http://www.prh.noaa.gov/cphc/pages/FAQ/Winds_and_Energy.php.

Newey, Whitney K., and Kenneth D. West, "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica* 55 (1987), 703–708.

NHC, *National Hurricane Center Forecast Verification* (2016), http://www.nhc.noaa.gov/verification/verify5.shtml.

Nickell, Sephen J., "Biases in Dynamic Models with Fixed Effects," *Econometrica* 49 (1981), 1417–1426.

Nordhaus, William D., "The Economics of Hurricanes and Implications of Global Warming," *Climate Change Economics* 1 (2010), 1–20.

Noy, Ilan, "The macroeconomic consequences of disasters," *Journal of Development Economics* 88 (2009), 221–231.

Pelli, Martino, and Jeanne Tschopp, "Comparative advantage, capital destruction, and hurricanes," *Journal of International Economics* 108 (2017), 315–337.

Pielke, Roger A., Joel Gratz, Christopher W. Landsea, Collins Douglas, Mark A. Saunders, and Rade Musulin, "Normalized Hurricane Damage in the United States: 1900-2005," *Natural Hazards Review* 9 (2008).

Strobl, Eric, "The Economic Growth Impact of Hurricanes: Evidence from U.S. Coastal Counties," *The Review of Economics and Statistics* 93 (2011), 575–589.

——— "The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions," *Journal of Development Economics* 97 (2012), 130–141.

Terry, James P., *Tropical cyclones: Climatology and impacts in the South Pacific* (New York, London: Springer, 2007).

Toya, Hideki, and Mark Skidmore, "Economic development and the impacts of natural disasters," *Economics Letters* 94 (2007), 20–25.

UNISDR, *Sendai Framework for Disaster Risk Reduction 2015 - 2030* (2015), http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.

United Nations Statistical Division, *Glossary - Definition of Term: Value added - gross* (2015a), http://unstats.un.org/unsd/snaama/glossresults.asp?gID=51.

——— *Methodology for the National Accounts Main Aggregates Database* (2015b), http://unstats.un.org/unsd/snaama/methodology.pdf.

——— *UN Data* (2015c), http://data.un.org/Explorer.aspx?d=SNAAMA.

World Bank, *Natural Hazards, Unnatural Disasters: The Economics of Effective Prevention* (2010), https://www.gfdrr.org/sites/gfdrr/files/publication/NHUD-Report_Full.pdf.

Xie, Pingping, and Phillip A. Arkin, "Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates, and Numerical Model Outputs," *Bulletin of the American Meteorological Society* 78 (1997), 2539–2558.

Appendix A: Data

A1: Lists of Countries in the Sample

List of countries – full sample

Afghanistan, Albania, Algeria, Andorra, Angola, Anguilla, Antigua and Barbuda, Argentina, Armenia, Aruba, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bermuda, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, British Virgin Islands, Brunei, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Cayman Islands, Central African Republic, Chad, Chile, China, Colombia, Comoros, Cook Islands, Costa Rica, Croatia, Cuba, Cyprus, Czech Republic, Czechoslovakia, Côte d'Ivoire, Democratic Republic of the Congo, Denmark, Djibouti, Dominica, Dominican Republic, East Timor, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, Fiji, Finland, France, French Polynesia, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Greenland, Grenada, Guatemala, Guinea, Guinea & Bissau, Guyana, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Kosovo, Kuwait, Kyrgyzstan, Laos, Latvia, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Lithuania, Luxembourg, Macao, Macedonia, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia, Moldova, Monaco, Mongolia, Montenegro, Montserrat, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Netherland Antilles, Netherlands, New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, North Korea, Norway, Oman, Pakistan, Palau, Palestine, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Republic of Congo, Romania, Russia, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, Solomon Islands, Somalia, South Africa, South Korea, South Sudan, South Yemen, Soviet Union, Spain, Sri Lanka, Sudan, Suriname, Swaziland, Sweden, Switzerland, Syria, Tajikistan, Tanzania, Thailand, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Turks and Caicos Islands, Tuvalu, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Vanuatu, Venezuela, Vietnam, Yemen, Yemen Arab Republic, Yugoslavia, Zambia, Zimbabwe.

List of only exposed countries

Afghanistan, Algeria, Anguilla, Antigua and Barbuda, Aruba, Australia, Bahamas, Bangladesh, Barbados, Belize, Bermuda, Bhutan, Botswana, Brazil, British Virgin Islands, Brunei, Burkina Faso, Cambodia, Canada, Cape Verde, Cayman Islands, China, Colombia, Comoros, Cook Islands, Costa Rica, Cuba, Côte d'Ivoire, Denmark, Djibouti, Dominica, Dominican Republic, East Timor, El Salvador, Ethiopia, Fiji, France, French Polynesia, Gambia, Germany, Greenland, Grenada, Guatemala, Guinea, Guinea & Bissau, Guyana, Haiti, Honduras, Hong Kong, Iceland, India, Indonesia, Iran, Ireland, Jamaica, Japan, Kiribati, Laos, Macao, Madagascar, Malawi, Malaysia, Maldives, Mali, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia, Mongolia, Montserrat, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherland Antilles, New Caledonia, New Zealand, Nicaragua, North Korea, Norway, Oman, Pakistan, Palau, Panama, Papua New Guinea, Philippines, Portugal, Puerto Rico, Russia, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, South Korea, Sowjet Union, Spain, Sri Lanka, Swaziland, Sweden, Tanzania, Thailand, Tonga, Trinidad and Tobago, Turks and Caicos Islands, Tuvalu, United Arab Emirates, United Kingdom, United States, Vanuatu, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

A2: Detailed Description of ISIC Sector Classification

A) Agriculture, hunting and forestry
- 01) Agriculture, hunting and related service activities
- 02) Forestry, logging and related service activities

B) Fishing
- 05) Fishing, aquaculture and service activities incidental to fishing

C) Mining and quarrying
- 10) Mining of coal and lignite; extraction of peat
- 11) Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying
- 12) Mining of uranium and thorium ores
- 13) Mining of metal ores
- 14) Other mining and quarrying

D) Manufacturing
- 15) Manufacture of food products and beverages
- 16) Manufacture of tobacco products
- 17) Manufacture of textiles
- 18) Manufacture of wearing apparel; dressing and dyeing of fur
- 19) Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
- 20) Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
- 21) Manufacture of paper and paper products
- 22) Publishing, printing and reproduction of recorded media
- 23) Manufacture of coke, refined petroleum products and nuclear fuel
- 24) Manufacture of chemicals and chemical products
- 25) Manufacture of rubber and plastics products
- 26) Manufacture of other non-metallic mineral products
- 27) Manufacture of basic metals
- 28) Manufacture of fabricated metal products, except machinery and equipment
- 29) Manufacture of machinery and equipment n.e.c.
- 30) Manufacture of office, accounting and computing machinery
- 31) Manufacture of electrical machinery and apparatus n.e.c.
- 32) Manufacture of radio, television and communication equipment and apparatus
- 33) Manufacture of medical, precision and optical instruments, watches and clocks
- 34) Manufacture of motor vehicles, trailers and semi-trailers
- 35) Manufacture of other transport equipment
- 36) Manufacture of furniture; manufacturing n.e.c.
- 37) Recycling

E) Electricity, gas and water supply
- 40) Electricity, gas, steam and hot water supply
- 41) Collection, purification and distribution of water

F) Construction
- 45) Construction

G) Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
- 50) Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
- 51) Wholesale trade and commission trade, except of motor vehicles and motorcycles
- 52) Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods

H) Hotels and restaurants
- 55) Hotels and restaurants

I) Transport, storage and communications
- 60) Land transport; transport via pipelines
- 61) Water transport

62) Air transport
63) Supporting and auxiliary transport activities; activities of travel agencies
64) Post and telecommunications

J) Financial intermediation

65) Financial intermediation, except insurance and pension funding
66) Insurance and pension funding, except compulsory social security
67) Activities auxiliary to financial intermediation

K) Real estate, renting and business activities

70) Real estate activities
71) Renting of machinery and equipment without operator and of personal and household goods
72) Computer and related activities
73) Research and development
74) Other business activities

L) Public administration and defence; compulsory social security

75) Public administration and defence; compulsory social security

M) Education

80) Education

M) Health and social work

85) Health and social work

O) Other community, social and personal service activities

90) Sewage and refuse disposal, sanitation and similar activities
91) Activities of membership organizations n.e.c.
92) Recreational, cultural and sporting activities
93) Other service activities

P) Activities of private households as employers and undifferentiated production activities of private households

95) Activities of private households as employers of domestic staff
96) Undifferentiated goods-producing activities of private households for own use
97) Undifferentiated service-producing activities of private households for own use

Q) Extraterritorial organizations and bodies

99) Extraterritorial organizations and bodies

A3: Definitions and Sources of Variables

Table 5: Definitions and sources of variables

Variable	Definition	Units	Source
Growth rate pc sector A&B	Annual per capita growth rate of the ISIC sector A&B: agriculture, hunting, forestry, and fishing	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector C&E	Annual per capita growth rate of the ISIC sector C&E: mining, manufacturing, and utilities	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector D	Annual per capita growth rate of the ISIC sector D: manufacturing	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector F	Annual per capita growth rate of the ISIC sector F: construction	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector G-H	Annual per capita growth rate of the ISIC sector G-H: wholesale, retail trade, restaurants, hotels	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector I	Annual per capita growth rate of the ISIC sector I: transport, storage, communication	2005 const. $, %	United Nations Statistical Division (2015c)
Growth rate pc sector J-P	Annual per capita growth rate of the ISIC sector J-P: other activities	2005 const. $, %	United Nations Statistical Division (2015c)
WIND	Area weighted wind speed, aggregated over countries and years	km/h	Own modeling after Knapp et al. (2010)
Log per capita value added	Logarithm of the per capita value added of the respective ISIC sector	2005 const. $	United Nations Statistical Division (2015c)
Log per capita GDP	Logarithm of per capita GDP	2005 const. $	United Nations Statistical Division (2015c)
Population growth	Annual population growth rate	%	United Nations Statistical Division (2015c)
Trade openness	Imports plus exports divided by GDP	2005 const. $, %	United Nations Statistical Division (2015c)
Capital growth	Annual growth rate of the gross capital formation	2005 const. $, %	United Nations Statistical Division (2015c)
Temperature	Monthly mean air temperature	°C	Kalnay et al. (1996)
Precipitation	Monthly precipitation	mm	Xie & Arkin (1997)
Input-Output coefficients	Input-Output coefficients: Specific input divided by total input.		Lenzen et al. (2012, 2013)

Appendix B: Additional Statistics and Results

Table 6: Summary statistics for all variables

Variable	Obs.	Mean	Std. dev.	Min	Max
Growth rate pc total output	8,886	1.721	6.600	-67.06	64.64
Growth rate pc sector A&B	8,844	0.804	10.23	-80.28	109.0
Growth rate pc sector C&E	8,716	3.099	25.67	-460.2	498.9
Growth rate pc sector D	8,845	2.185	14.52	-159.6	404.0
Growth rate pc sector F	8,888	2.916	17.51	-198.9	254.0
Growth rate pc sector G-H	8,839	2.252	9.927	-80.57	115.1
Growth rate pc sector I	8,842	3.446	12.07	-173.7	243.8
Growth rate pc sector J-P	8,883	2.321	7.860	-77.67	106.8
WIND	8,899	8.964	25.45	0	291.9
Log pc value added total output	8,899	7.999	1.630	3.979	12.00
Log pc value added A&B	8,854	5.383	0.801	2.337	8.226
Log pc value added C&E	8,657	4.972	2.224	-5.796	11.23
Log pc value added D	8,856	5.677	1.842	-3.064	10.52
Log pc value added F	8,898	5.072	1.867	-1.968	9.427
Log pc value added G-H	8,854	6.056	1.707	0.494	11.00
Log pc value added I	8,831	5.378	1.775	-0.842	9.609
Log per capita value added J-P	8,899	6.786	1.944	0.433	11.41
Trade openness	8,560	164.6	603.7	0.0718	6476
Population growth	8,899	1.746	1.755	-22.02	23.97
Capital growth	8,643	6.090	25.82	-376.2	478.6
Temperature	8,375	20.44	7.281	-15.15	29.89
Precipitation	7,330	3.482	2.110	0.0400	10.69

Table 7: Distribution of the tropical cyclone intensity variable for exposed countries only

Country	Mean	Median	Std. dev.	Min	Max	p25	p75	Total no. storms
Afghanistan	0.00	0.00	0.01	0.00	0.06	0.00	0.00	1
Algeria	0.62	0.00	4.16	0.00	27.94	0.00	0.00	3
Andorra	4.10	0.00	22.84	0.00	150.17	0.00	0.00	2
Anguilla	53.21	37.42	67.29	0.00	249.88	0.00	77.47	46
Antigua and Barbuda	49.22	40.32	58.59	0.00	212.33	0.00	71.07	51
Argentina	0.00	0.00	0.00	0.00	0.02	0.00	0.00	1
Aruba	13.75	0.00	28.09	0.00	97.05	0.00	0.09	14
Australia	9.86	8.70	5.82	2.14	25.31	5.25	13.28	361
Bahamas	37.05	34.13	32.74	0.00	108.02	4.24	57.57	124
Bangladesh	17.14	12.00	15.50	0.00	64.32	7.35	26.02	83
Barbados	31.59	7.94	41.09	0.00	189.67	0.00	51.76	38
Belgium	3.18	0.00	14.67	0.00	88.33	0.00	0.00	6
Belize	22.79	2.44	37.25	0.00	143.58	0.00	31.39	47
Bermuda	91.15	85.82	54.92	0.00	242.98	60.13	114.53	120
Bhutan	0.76	0.00	5.08	0.00	34.10	0.00	0.00	1
Brazil	0.05	0.00	0.24	0.00	1.52	0.00	0.00	3
British Virgin Islands	45.48	23.87	52.21	0.00	185.47	0.00	81.39	47
Brunei	0.71	0.00	3.63	0.00	23.98	0.00	0.00	4
Burma/Myanmar	8.38	6.18	9.06	0.00	38.13	1.00	12.29	77
Cambodia	6.78	2.96	7.91	0.00	32.03	0.29	10.80	75
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	105
Cape Verde	15.21	9.96	18.60	0.00	74.42	0.00	25.27	40
Cayman Islands	35.44	6.14	56.64	0.00	213.67	0.00	45.10	46
China	5.05	4.47	1.73	2.42	10.01	3.98	5.74	503
Colombia	0.11	0.00	0.43	0.00	2.06	0.00	0.00	29
Comoros	9.26	0.00	18.77	0.00	77.93	0.00	6.39	18
Cook Islands	24.67	16.60	28.55	0.00	124.89	0.00	40.13	63
Costa Rica	1.14	0.00	3.47	0.00	15.26	0.00	0.01	13
Cuba	27.78	11.92	33.32	0.00	135.55	1.78	45.98	98
Democratic Republic	28.72	29.28	11.32	0.23	50.00	22.86	35.00	259
Denmark	2.87	0.00	13.31	0.00	81.89	0.00	0.00	3
Djibouti	0.58	0.00	3.89	0.00	26.07	0.00	0.00	1
Dominica	41.65	38.86	50.81	0.00	291.90	1.70	57.24	46
Dominican Republic	31.87	20.44	40.03	0.00	186.13	0.00	49.41	61
El Salvador	7.59	0.00	16.79	0.00	73.58	0.00	1.54	20
Ethiopia	0.06	0.00	0.39	0.00	2.62	0.00	0.00	4
Fiji	39.88	26.26	44.10	0.00	155.61	0.41	64.82	95
France	5.14	0.22	12.70	0.00	66.84	0.00	0.88	18
French Polynesia	6.67	1.27	12.86	0.00	67.38	0.00	5.74	61
Gambia	1.24	0.00	4.52	0.00	25.88	0.00	0.00	4
Germany	1.04	0.00	4.82	0.00	24.36	0.00	0.00	3
Greenland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15
Grenada	26.49	0.00	50.21	0.00	236.56	0.00	27.51	25
Guatemala	10.18	0.82	14.90	0.00	54.34	0.00	15.32	68
Guinea	0.21	0.00	1.36	0.00	9.14	0.00	0.00	3
Guinea-Bissau	1.56	0.00	6.82	0.00	42.36	0.00	0.00	4
Haiti	27.47	10.94	34.32	0.00	124.08	0.00	49.35	46

Table 7: continued

Country	Mean	Mean	St. dev.	Min	Max	p25	p75	Total no. storms
Honduras	11.82	4.19	16.81	0.00	67.65	0.00	20.94	74
Hong Kong	63.06	53.15	43.64	0.00	185.78	34.37	83.69	120
India	5.60	5.90	3.09	0.59	12.38	2.76	7.79	213
Indonesia	0.28	0.14	0.41	0.00	1.73	0.00	0.38	68
Iran	0.07	0.00	0.50	0.00	3.35	0.00	0.00	3
Ireland	18.61	0.00	36.58	0.00	114.40	0.00	1.07	21
Jamaica	31.67	0.00	55.44	0.00	247.07	0.00	40.62	33
Japan	74.98	73.20	28.73	9.05	143.42	57.75	94.39	590
Kiribati	0.01	0.00	0.02	0.00	0.09	0.00	0.00	5
Laos	20.03	18.50	12.71	0.00	48.68	10.10	29.31	157
Lesotho	0.04	0.00	0.24	0.00	1.60	0.00	0.00	1
Luxembourg	2.89	0.00	14.02	0.00	85.50	0.00	0.00	3
Madagascar	28.65	26.41	15.54	0.07	66.88	19.04	38.62	176
Malawi	0.36	0.00	1.90	0.00	12.78	0.00	0.00	11
Malaysia	0.67	0.00	2.89	0.00	14.99	0.00	0.00	14
Maldives	0.86	0.00	3.44	0.00	21.22	0.00	0.00	5
Marshall Islands	9.77	0.00	17.58	0.00	69.18	0.00	11.78	44
Mauritania	0.00	0.00	0.01	0.00	0.07	0.00	0.00	2
Mauritius	43.16	31.56	45.83	0.06	185.65	3.16	68.61	155
Mexico	17.42	17.44	7.39	5.50	38.73	12.82	22.83	595
Micronesia	18.12	14.06	15.64	0.00	73.73	7.72	26.62	194
Montserrat	47.94	44.80	56.40	0.00	290.66	0.00	73.50	42
Morocco	2.05	0.00	12.14	0.00	81.11	0.00	0.00	5
Mozambique	4.67	2.40	5.24	0.00	25.24	0.61	7.68	68
Nepal	0.00	0.00	0.01	0.00	0.09	0.00	0.00	1
Netherland Antilles	15.63	1.63	28.05	0.00	113.48	0.00	9.11	23
Netherlands	2.89	0.00	11.99	0.00	61.63	0.00	0.00	4
New Caledonia	48.38	37.78	49.08	0.00	193.64	10.24	64.12	140
New Zealand	18.46	9.52	23.61	0.00	92.35	0.00	30.71	83
Nicaragua	11.27	0.22	20.85	0.00	90.94	0.00	8.64	47
North Korea	20.17	5.04	28.53	0.00	95.47	0.00	28.67	58
Norway	2.13	0.00	5.62	0.00	23.05	0.00	0.00	9
Oman	2.76	0.00	5.32	0.00	19.02	0.00	2.01	16
Pakistan	0.83	0.00	2.69	0.00	13.50	0.00	0.07	14
Palau	24.50	0.00	40.58	0.00	170.11	0.00	36.23	38
Panama	0.36	0.00	1.44	0.00	8.86	0.00	0.00	7
Papua New Guinea	0.63	0.17	1.46	0.00	8.45	0.00	0.50	52
Philippines	48.09	48.20	15.85	12.11	78.89	39.41	58.92	465
Poland	0.04	0.00	0.27	0.00	1.81	0.00	0.00	1
Portugal	10.41	1.26	25.83	0.00	116.30	0.16	3.04	73
Puerto Rico	37.14	26.48	44.35	0.00	209.44	0.00	53.68	58
Russia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71
Saint Kitts and Nevis	44.29	36.18	51.86	0.00	227.13	0.00	65.63	43
Saint Lucia	38.33	31.28	49.25	0.00	258.04	0.00	57.76	47
Saint Vincent and the Grenadines	30.42	0.24	41.16	0.00	170.80	0.00	54.19	37
Samoa	27.79	0.00	45.13	0.00	233.80	0.00	38.56	32
Saudi Arabia	0.04	0.00	0.20	0.00	1.30	0.00	0.00	7
Senegal	0.42	0.00	1.48	0.00	7.62	0.00	0.00	5
Seychelles	3.79	0.00	8.02	0.00	37.04	0.00	2.58	33
Singapore	1.52	0.00	10.17	0.00	68.23	0.00	0.00	1

Table 7: continued

Country	Mean	Mean	St. dev.	Min	Max	p25	p75	Total no. storms
Solomon Islands	9.38	4.01	13.87	0.00	70.89	0.23	13.23	94
Somalia	1.05	0.00	2.75	0.00	13.32	0.00	0.08	16
South Africa	0.16	0.00	0.68	0.00	3.38	0.00	0.00	8
South Korea	51.72	54.81	33.02	0.00	105.77	25.03	82.59	125
Sowjet Union	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33
Spain	6.77	0.00	20.12	0.00	113.59	0.00	2.07	17
Sri Lanka	6.37	0.00	14.69	0.00	56.51	0.00	2.85	31
Swaziland	1.87	0.00	8.49	0.00	42.35	0.00	0.00	3
Sweden	0.42	0.00	1.37	0.00	6.31	0.00	0.00	5
Tanzania	0.02	0.00	0.14	0.00	0.91	0.00	0.00	6
Thailand	3.61	1.43	4.44	0.00	16.87	0.41	6.84	87
Timor-Leste	1.08	0.00	3.10	0.00	13.75	0.00	0.00	6
Tonga	43.13	39.93	37.72	0.00	149.07	17.93	64.29	96
Trinidad and Tobago	4.50	0.00	14.85	0.00	70.66	0.00	0.00	11
Turks and Caicos	32.84	12.47	46.25	0.00	180.31	0.00	51.66	47
Tuvalu	7.52	0.00	14.48	0.00	55.19	0.00	10.48	24
United Arab Emirates	0.21	0.00	0.91	0.00	5.65	0.00	0.00	3
United Kingdom	12.66	0.00	25.15	0.00	90.34	0.00	6.31	24
United States	5.79	4.17	4.46	0.86	23.39	3.06	6.39	309
Vanuatu	54.08	61.26	38.32	0.00	136.65	27.58	80.97	118
Venezuela	0.21	0.00	0.86	0.00	5.08	0.00	0.00	15
Yemen	0.93	0.00	3.62	0.00	18.51	0.00	0.28	10
Zimbabwe	1.42	0.00	4.26	0.00	19.38	0.00	0.00	7
Total	15.11	0.00	31.54	0.00	291.90	0.00	13.75	7814

Table 8: Regression results of the main specification with temperature control variables

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0067	-0.0301	-0.0109	-0.0089	0.0114	-0.0111	-0.0073	-0.0029
	(0.0032)	(0.0063)	(0.0155)	(0.0071)	(0.0135)	(0.0048)	(0.0044)	(0.0028)
	[0.0364]	[0.0000]	[0.4838]	[0.2131]	[0.3989]	[0.0228]	[0.0961]	[0.3137]
$Temperature_t$	-0.0929	-0.3681	0.2688	0.0050	-0.0574	0.0147	0.1315	-0.0312
	(0.0948)	(0.1448)	(0.5472)	(0.1916)	(0.2109)	(0.1598)	(0.1759)	(0.0939)
	[0.3285]	[0.0117]	[0.6238]	[0.9794]	[0.7856]	[0.9268]	[0.4556]	[0.7402]
Observations	8,389	8,350	8,227	8,350	8,393	8,345	8,349	8,387
# of countries	208	207	205	208	208	207	207	208
Adj. R^2	0.0437	0.0103	0.0017	0.0142	0.0175	0.0260	0.0148	0.0174
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets [].The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 9: Regression results of the main specification with precipitation control variables

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0061	-0.0323	-0.0132	-0.0109	0.0074	-0.0102	-0.0065	-0.0022
	(0.0030)	(0.0063)	(0.0134)	(0.0070)	(0.0133)	(0.0050)	(0.0046)	(0.0026)
	[0.0438]	[0.0000]	[0.3254]	[0.1177]	[0.5785]	[0.0446]	[0.1569]	[0.4056]
$Precipitation_t$	-0.2048	0.0879	1.2626	-0.2508	-0.3264	-0.2241	-0.5352	-0.3288
	(0.1300)	(0.2100)	(1.0078)	(0.2497)	(0.3521)	(0.1590)	(0.2482)	(0.1535)
	[0.1167]	[0.6760]	[0.2117]	[0.3164]	[0.3550]	[0.1602]	[0.0322]	[0.0333]
Observations	7,346	7,312	7,213	7,322	7,349	7,308	7,311	7,343
# of countries	208	207	205	208	208	207	207	208
Adj. R^2	0.0448	0.0085	0.0026	0.0136	0.0195	0.0266	0.0164	0.0157
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets [].The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 10: Regression results of the main specification with precipitation and temperature control variables

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0060	-0.0319	-0.0155	-0.0106	0.0088	-0.0107	-0.0063	-0.0019
	(0.0032)	(0.0065)	(0.0135)	(0.0072)	(0.0142)	(0.0054)	(0.0048)	(0.0027)
	[0.0636]	[0.0000]	[0.2509]	[0.1467]	[0.5367]	[0.0469]	[0.1924]	[0.4988]
$Precipitation_t$	-0.2089	0.1420	1.4350	-0.2213	-0.3694	-0.2590	-0.6232	-0.3642
	(0.1486)	(0.2287)	(1.1179)	(0.2641)	(0.3744)	(0.1855)	(0.2627)	(0.1686)
	[0.1611]	[0.5353]	[0.2007]	[0.4031]	[0.3250]	[0.1640]	[0.0186]	[0.0319]
$Temperature_t$	-0.0084	-0.2959	-0.3085	0.0486	-0.1741	0.0852	0.2533	0.0316
	(0.1403)	(0.1744)	(0.4240)	(0.2657)	(0.2833)	(0.2227)	(0.2562)	(0.1262)
	[0.9525]	[0.0913]	[0.4676]	[0.8550]	[0.5395]	[0.7026]	[0.3240]	[0.8023]
Observations	8,389	8,350	8,227	8,350	8,393	8,345	8,349	8,387
# of countries	208	207	205	208	208	207	207	208
Adj. R^2	0.0437	0.0103	0.0017	0.0142	0.0175	0.0260	0.0148	0.0174
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 11: Regression results of the main specification with socioeconomic controls

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manu-facturing	Con-struction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communi-cation	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Controlled for logged per capita value added $sector_{t-1}$								
	-0.0050	-0.0294	-0.0097	-0.0075	0.0165	-0.0079	-0.0045	-0.0014
$WIND_t$	(0.0031)	(0.0063)	(0.0088)	(0.0069)	(0.0130)	(0.0046)	(0.0042)	(0.0029)
	[0.1057]	[0.0000]	[0.2727]	[0.2804]	[0.2039]	[0.0907]	[0.2819]	[0.6259]
Panel B: Controlled for population $growth_{t-1}$								
	-0.0067	-0.0312	-0.0134	-0.0099	0.0120	-0.0100	-0.0066	-0.0030
$WIND_t$	(0.0030)	(0.0063)	(0.0124)	(0.0071)	(0.0129)	(0.0047)	(0.0041)	(0.0027)
	[0.0265]	[0.0000]	[0.2808]	[0.1652]	[0.3534]	[0.0324]	[0.1092]	[0.2713]
Panel C: Controlled for trade $openness_{t-1}$								
	-0.0074	-0.0322	-0.0144	-0.0108	0.0105	-0.0106	-0.0071	-0.0037
$WIND_t$	(0.0031)	(0.0064)	(0.0125)	(0.0073)	(0.0127)	(0.0047)	(0.0042)	(0.0028)
	[0.0165]	[0.0000]	[0.2524]	[0.1379]	[0.4107]	[0.0269]	[0.0887]	[0.1892]
Panel D: Controlled for capital $growth_{t-1}$								
	-0.0068	-0.0313	-0.0138	-0.0102	0.0115	-0.0104	-0.0068	-0.0032
$WIND_t$	(0.0030)	(0.0063)	(0.0123)	(0.0071)	(0.0129)	(0.0047)	(0.0041)	(0.0027)
	[0.0258]	[0.0000]	[0.2634]	[0.1498]	[0.3746]	[0.0286]	[0.0979]	[0.2436]
Panel E: Controlled for all socioeconomic $controls_{t-1}$								
	-0.0053	-0.0296	-0.0104	-0.0079	0.0155	-0.0081	-0.0049	-0.0017
$WIND_t$	(0.0030)	(0.0064)	(0.0090)	(0.0072)	(0.0128)	(0.0046)	(0.0042)	(0.0029)
	[0.0804]	[0.0000]	[0.2491]	[0.2718]	[0.2267]	[0.0836]	[0.2426]	[0.5651]
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects and the respective socioeconomic control variables, which are all measured in t-1: log per capita value added of the respective sector, population growth rate, openness, investment rate. Potential outliers are excluded following the analysis described in Appendix C. The full regression tables can be found in Appendix B.

Table 12: Regression results of the main specification for total output with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Total output	Total output	Total output	Total output	Total output
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0050	-0.0067	-0.0074	-0.0068	-0.0053
	(0.0031)	(0.0030)	(0.0031)	(0.0030)	(0.0030)
	[0.1057]	[0.0265]	[0.0165]	[0.0258]	[0.0804]
Log pc value added $sector_{t-1}$	-3.4630				-3.4619
	(0.5239)				(0.5350)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.2109			-0.1977
		(0.1257)			(0.1468)
		[0.0948]			[0.1795]
Capital $growth_{t-1}$			0.0301		0.0010
			(0.0054)		(0.0006)
			[0.0000]		[0.0877]
Trade $openness_{t-1}$				0.0008	0.0298
				(0.0005)	(0.0054)
				[0.0883]	[0.0000]
Observations	8,665	8,680	8,630	8,547	8,497
# of countries	213	213	212	208	207
Adj. R^2	0.0623	0.0420	0.0531	0.0411	0.0782
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 13: Regression results of the main specification for agriculture, hunting, forestry, and fishing with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Agriculture, hunting, forestry, fishing	Agriculture, hunting, forestry, fishing	Agriculture, hunting, forestry, fishing	Agriculture, hunting, forestry, fishing	Agriculture, hunting, forestry, fishing
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0294	-0.0312	-0.0322	-0.0313	-0.0296
	(0.0063)	(0.0063)	(0.0064)	(0.0063)	(0.0064)
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Log pc value added $sector_{t-1}$	-8.0622				-8.2466
	(1.0028)				(1.0103)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.3060			-0.4246
		(0.1738)			(0.2080)
		[0.0798]			[0.0425]
Capital $growth_{t-1}$			0.0088		0.0106
			(0.0046)		(0.0046)
			[0.0565]		[0.0215]
Trade $openness_{t-1}$				0.0005	0.0011
				(0.0003)	(0.0004)
				[0.0959]	[0.0039]
Observations	8,624	8,640	8,590	8,506	8,456
# of countries	212	212	211	207	206
Adj. R^2	0.0516	0.0102	0.0092	0.0092	0.0558
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 14: Regression results of the main specification for mining and utilities with socio-economic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Mining, utilities	Mining, utilities	Mining, utilities	Mining, utilities	Mining, utilities
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0097	-0.0134	-0.0144	-0.0138	-0.0104
	(0.0088)	(0.0124)	(0.0125)	(0.0123)	(0.0090)
	[0.2727]	[0.2808]	[0.2524]	[0.2634]	[0.2491]
Log pc value added $sector_{t-1}$	-4.3234				-4.3794
	(1.5665)				(1.6033)
	[0.0063]				[0.0069]
Population $growth_{t-1}$		-0.3689			0.1840
		(0.3549)			(0.3606)
		[0.2998]			[0.6104]
Capital $growth_{t-1}$			0.0328		0.0310
			(0.0183)		(0.0171)
			[0.0741]		[0.0709]
Trade $openness_{t-1}$				0.0028	0.0035
				(0.0013)	(0.0016)
				[0.0275]	[0.0283]
Observations	8,407	8,500	8,451	8,366	8,239
# of countries	209	209	208	204	202
Adj. R^2	0.0151	0.0027	0.0034	0.0031	0.0171
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 15: Regression results of the main specification for manufacturing with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Manufacturing	Manufacturing	Manufacturing	Manufacturing	Manufacturing
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0075	-0.0099	-0.0108	-0.0102	-0.0079
	(0.0069)	(0.0071)	(0.0073)	(0.0071)	(0.0072)
	[0.2804]	[0.1652]	[0.1379]	[0.1498]	[0.2718]
Log pc value added $sector_{t-1}$	-6.1287				-6.1254
	(1.1237)				(1.1640)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.1889			-0.2267
		(0.2074)			(0.2622)
		[0.3636]			[0.3882]
Capital $growth_{t-1}$			0.0449		0.0429
			(0.0128)		(0.0128)
			[0.0006]		[0.0010]
Trade $openness_{t-1}$				0.0009	0.0018
				(0.0007)	(0.0013)
				[0.2320]	[0.1787]
Observations	8,616	8,633	8,585	8,500	8,448
# of countries	212	212	211	207	206
Adj. R^2	0.0433	0.0151	0.0196	0.0145	0.0494
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 16: Regression results of the main specification for construction with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Construction	Construction	Construction	Construction	Construction
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	0.0165	0.0120	0.0105	0.0115	0.0155
	(0.0130)	(0.0129)	(0.0127)	(0.0129)	(0.0128)
	[0.2039]	[0.3534]	[0.4107]	[0.3746]	[0.2267]
Log pc value added $sector_{t-1}$	-6.6374				-6.8815
	(0.9377)				(1.0014)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.2070			-0.0003
		(0.1928)			(0.2586)
		[0.2842]			[0.9991]
Capital $growth_{t-1}$			0.0717		0.0746
			(0.0152)		(0.0152)
			[0.0000]		[0.0000]
Trade $openness_{t-1}$				0.0005	0.0013
				(0.0008)	(0.0011)
				[0.5034]	[0.2552]
Observations	8,667	8,684	8,636	8,551	8,499
# of countries	213	213	212	208	207
Adj. R^2	0.0485	0.0165	0.0270	0.0159	0.0608
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 17: Regression results of the main specification for wholesale, retail trade, restaurants, and hotels with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Wholesale, retail trade, restaurants, hotels	Wholesale, retail trade, restaurants, hotels	Wholesale, retail trade, restaurants, hotels	Wholesale, retail trade, restaurants, hotels	Wholesale, retail trade, restaurants, hotels
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0079	-0.0100	-0.0106	-0.0104	-0.0081
	(0.0046)	(0.0047)	(0.0047)	(0.0047)	(0.0046)
	[0.0907]	[0.0324]	[0.0269]	[0.0286]	[0.0836]
Log pc value added $sector_{t-1}$	-5.1653				-5.1398
	(0.6438)				(0.6318)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.2581			-0.2063
		(0.1328)			(0.1423)
		[0.0532]			[0.1485]
Capital $growth_{t-1}$			0.0292		0.0306
			(0.0068)		(0.0069)
			[0.0000]		[0.0000]
Trade $openness_{t-1}$				0.0004	0.0008
				(0.0005)	(0.0008)
				[0.3769]	[0.2885]
Observations	8,622	8,638	8,633	8,505	8,498
# of countries	212	212	212	207	207
Adj. R^2	0.0542	0.0252	0.0289	0.0245	0.0620
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 18: Regression results of the main specification for transport, storage, and communication with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Transport, storage, communication	Transport, storage, communication	Transport, storage, communication	Transport, storage, communication	Transport, storage, communication
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0045	-0.0066	-0.0071	-0.0068	-0.0049
	(0.0042)	(0.0041)	(0.0042)	(0.0041)	(0.0042)
	[0.2819]	[0.1092]	[0.0887]	[0.0979]	[0.2426]
Log pc value added $sector_{t-1}$	-3.7775				-3.6719
	(0.5628)				(0.5513)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.1513			-0.1474
		(0.1648)			(0.1889)
		[0.3596]			[0.4362]
Capital $growth_{t-1}$			0.0300		0.0329
			(0.0072)		(0.0069)
			[0.0000]		[0.0000]
Trade $openness_{t-1}$				0.0000	0.0000
				(0.0006)	(0.0006)
				[0.9580]	[0.9470]
Observations	8,595	8,633	8,629	8,500	8,471
# of countries	212	212	212	207	207
Adj. R^2	0.0433	0.0220	0.0258	0.0214	0.0484
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 19: Regression results of the main specification for other activities with socioeconomic control variables

	Dependent variables: Growth rate (%) pc in sector				
	Other activities	Other activities	Other activities	Other activities	Other activities
	(1)	(2)	(3)	(4)	(5)
$WIND_t$	-0.0014	-0.0030	-0.0037	-0.0032	-0.0017
	(0.0029)	(0.0027)	(0.0028)	(0.0027)	(0.0029)
	[0.6259]	[0.2713]	[0.1892]	[0.2436]	[0.5651]
Log pc value added $sector_{t-1}$	-3.9246				-3.9202
	(0.5820)				(0.5809)
	[0.0000]				[0.0000]
Population $growth_{t-1}$		-0.1310			-0.1326
		(0.1404)			(0.1701)
		[0.3518]			[0.4365]
Capital $growth_{t-1}$			0.0232		0.0221
			(0.0061)		(0.0061)
			[0.0002]		[0.0004]
Trade $openness_{t-1}$				0.0007	0.0007
				(0.0005)	(0.0006)
				[0.1601]	[0.2381]
Observations	8,664	8,680	8,631	8,547	8,496
# of countries	213	213	212	208	207
Adj. R^2	0.0383	0.0172	0.0216	0.0172	0.0441
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 20: Regression results of the main specification with Newey-West standard errors

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0067	-0.0304	-0.0093	-0.0090	0.0102	-0.0105	-0.0075	-0.0031
	(0.0028)	(0.0063)	(0.0127)	(0.0069)	(0.0118)	(0.0046)	(0.0045)	(0.0029)
	[0.0177]	[0.0000]	[0.4670]	[0.1894]	[0.3863]	[0.0210]	[0.0964]	[0.2756]
Observations	8,907	8,865	8,739	8,868	8,911	8,861	8,865	8,905
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered Newey-West standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. For all regressions Newey-West standards with a maximum lag length of 10 are calculated. Potential outliers are excluded following the analysis described in Appendix C.

Table 21: Regression results of the main specification with Conley HAC standard errors

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0067	-0.0304	-0.0092	-0.0089	0.0103	-0.0106	-0.0074	-0.0031
	(0.0032)	(0.0065)	(0.0130)	(0.0078)	(0.0114)	(0.0047)	(0.0046)	(0.0031)
	[0.0347]	[0.0000]	[0.4815]	[0.2574]	[0.3657]	[0.0243]	[0.1056]	[0.3112]
Observations	8,842	8,801	8,674	8,803	8,846	8,796	8,800	8,840
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with Conley HAC standard errors in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. For all regressions, Conley HAC standards with a maximum lag length of 10 and a spatial cutoff of 1000 km are calculated. Potential outliers are excluded following the analysis described in Appendix C.

Table 22: Regression results of the main specification with regional clustering of the standard errors

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0067	-0.0304	-0.0093	-0.0090	0.0102	-0.0105	-0.0075	-0.0031
	(0.0020)	(0.0035)	(0.0185)	(0.0102)	(0.0165)	(0.0019)	(0.0033)	(0.0012)
	[0.0144]	[0.0001]	[0.6354]	[0.4130]	[0.5582]	[0.0013]	[0.0639]	[0.0348]
Observations	8,907	8,865	8,739	8,868	8,911	8,861	8,865	8,905
# of countries	213	212	210	213	213	212	212	213
Adj. R^2	0.0434	0.0102	0.0024	0.0146	0.0178	0.0256	0.0153	0.0181
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by geographical regions in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Geographical regions are Latin America & Caribbean, South Asia, Sub-Saharan Africa, Europe & Central America, Middle East & North Africa, East Asia & Pacific, North America. Potential outliers are excluded following the analysis described in Appendix C.

Table 23: Regression results of the main specification with different WIND measure (mean instead of maximum)

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0069	-0.0322	-0.0137	-0.0133	0.0142	-0.0089	-0.0101	-0.0040
	(0.0031)	(0.0071)	(0.0158)	(0.0080)	(0.0168)	(0.0049)	(0.0051)	(0.0034)
	[0.0280]	[0.0000]	[0.3867]	[0.1004]	[0.4003]	[0.0701]	[0.0512]	[0.2334]
Observations	8,907	8,865	8,739	8,868	8,911	8,861	8,865	8,905
# of countries	213	212	210	213	213	212	212	213
Adj. R^2	0.0433	0.0094	0.0024	0.0146	0.0178	0.0254	0.0153	0.0181
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 24: Regression results of the past influence of tropical cyclones on total output, agriculture, hunting, forestry, fishing, mining, and utilities

	Dependent variables: Growth rate (%) pc in sector					
	Total output	Total output	Agriculture, hunting, forestry, fishing	Agriculture, hunting, forestry, fishing	Mining, utilities	Mining, utilities
	(1)	(2)	(3)	(4)	(5)	(6)
$WIND_t$	-0.0059	-0.0057	-0.0316	-0.0325	-0.0109	-0.0109
	(0.0029)	(0.0029)	(0.0063)	(0.0063)	(0.0127)	(0.0122)
	[0.0450]	[0.0538]	[0.0000]	[0.0000]	[0.3943]	[0.3754]
$WIND_{t-1}$	-0.0029		-0.0046		-0.0063	
	(0.0028)		(0.0056)		(0.0133)	
	[0.3014]		[0.4077]		[0.6385]	
$WIND_{t-2}$	-0.0089		0.0153		0.0123	
	(0.0031)		(0.0063)		(0.0109)	
	[0.0038]		[0.0159]		[0.2591]	
$WIND_{t-3}$	-0.0063		0.0021		-0.0054	
	(0.0023)		(0.0049)		(0.0108)	
	[0.0072]		[0.6614]		[0.6160]	
$WIND_{t-4}$	0.0001		0.0071		-0.0288	
	(0.0024)		(0.0073)		(0.0107)	
	[0.9813]		[0.3308]		[0.0074]	
$WIND_{t-5}$	-0.0055		-0.0017		-0.0089	
	(0.0027)		(0.0082)		(0.0088)	
	[0.0433]		[0.8331]		[0.3123]	
Observations	7,842	7,842	7,805	7,805	7,702	7,702
# of countries	213	213	212	212	210	210
Adj. R^2	0.0329	0.0317	0.0084	0.0078	0.0015	0.0014
Country FE	Yes	Yes	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	Yes	Yes	

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. As the lag structure decreases the sample size, I also re-estimate the main model (I) with the reduced sample, to verify whether the results of my main specification still hold. This is displayed in the second column for each dependent variable. Potential outliers are excluded following the analysis described in Appendix C.

Table 25: Regression results of the past influence of tropical cyclones on manufacturing, construction, whole sale, restaurants, and hotels

	Dependent variables: Growth rate (%) pc in sector					
	Manufacturing	Manufacturing	Construction	Construction	Wholesale, retail trade, restaurants, hotels	Wholesale, retail trade, restaurants, hotels
	(1)	(2)	(3)	(4)	(5)	(6)
$WIND_t$	-0.0088	-0.0089	0.0105	0.0128	-0.0095	-0.0092
	(0.0072)	(0.0071)	(0.0128)	(0.0137)	(0.0048)	(0.0048)
	[0.2210]	[0.2072]	[0.4118]	[0.3495]	[0.0480]	[0.0574]
$WIND_{t-1}$	-0.0081		0.0139		-0.0032	
	(0.0071)		(0.0131)		(0.0053)	
	[0.2580]		[0.2891]		[0.5458]	
$WIND_{t-2}$	-0.0174		-0.0235		-0.0135	
	(0.0081)		(0.0109)		(0.0047)	
	[0.0335]		[0.0320]		[0.0043]	
$WIND_{t-3}$	-0.0008		-0.0355		-0.0101	
	(0.0075)		(0.0089)		(0.0032)	
	[0.9175]		[0.0001]		[0.0022]	
$WIND_{t-4}$	0.0080		-0.0106		0.0032	
	(0.0068)		(0.0082)		(0.0043)	
	[0.2395]		[0.1972]		[0.4563]	
$WIND_{t-5}$	-0.0050		-0.0063		-0.0058	
	(0.0087)		(0.0082)		(0.0043)	
	[0.5685]		[0.4407]		[0.1777]	
Observations	7,813	7,813	7,846	7,846	7,803	7,803
# of countries	213	213	213	213	212	212
Adj. R^2	0.0118	0.0116	0.0215	0.0190	0.0237	0.0228
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. As the lag structure decreases the sample size, I also re-estimate the main model (I) with the reduced sample, to verify whether the results of my main specification still hold. This is displayed in the second column for each dependent variable. Potential outliers are excluded following the analysis described in Appendix C.

Table 26: Regression results of the past influence of tropical cyclones on transport, storage, communication, and other activities

	Dependent variables: Growth rate (%) pc in sector			
	Transport, storage, communication	Transport, storage, communication	Other activities	Other activities
	(1)	(2)	(3)	(4)
$WIND_t$	-0.0075	-0.0073	-0.0021	-0.0020
	(0.0040)	(0.0043)	(0.0029)	(0.0028)
	[0.0651]	[0.0918]	[0.4690]	[0.4653]
$WIND_{t-1}$	-0.0034		-0.0033	
	(0.0054)		(0.0027)	
	[0.5345]		[0.2178]	
$WIND_{t-2}$	-0.0179		-0.0045	
	(0.0053)		(0.0038)	
	[0.0008]		[0.2369]	
$WIND_{t-3}$	0.0043		-0.0050	
	(0.0078)		(0.0026)	
	[0.5790]		[0.0516]	
$WIND_{t-4}$	-0.0029		-0.0011	
	(0.0055)		(0.0032)	
	[0.5942]		[0.7242]	
$WIND_{t-5}$	-0.0035		-0.0033	
	(0.0053)		(0.0034)	
	[0.5066]		[0.3425]	
Observations	7,805	7,805	7,841	7,841
# of countries	212	212	213	213
Adj. R^2	0.0121	0.0117	0.0110	0.0111
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. As the lag structure decreases the sample size, I also re-estimate the main model (I) with the reduced sample, to verify whether the results of my main specification still hold. This is displayed in the second column for each dependent variable. Potential outliers are excluded following the analysis described in Appendix C.

Table 27: Regression results of the past cumulative influence of tropical cyclones

Additive Effect of $WIND_t$ after following years	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	-0.0059	-0.0316	-0.0109	-0.0088	0.0105	-0.0095	-0.0075	-0.0021
	(0.0029)	(0.0063)	(0.0127)	(0.0072)	(0.0128)	(0.0048)	(0.0040)	(0.0029)
	[0.0450]	[0.0000]	[0.3943]	[0.2210]	[0.4118]	[0.0480]	[0.0651]	[0.4690]
1	-0.0088	-0.0363	-0.0171	-0.0168	0.0244	-0.0127	-0.0109	-0.0054
	(0.0039)	(0.0070)	(0. 0120)	(0.0079)	(0.0218)	(0.0070)	(0.0067)	(0.0035)
	[0.0270]	[0.0000]	[0.1551]	[0.0339]	[0.2643]	[0.0722]	[0.1055]	[0.1226]
2	-0.0177	-0.0209	-0.0048	-0.0343	0.0009	-0.0262	-0.0287	-0.0099
	(0.0053)	(0.0078)	(0.0154)	(0.0123)	(0.0200)	(0.0086)	(0.0096)	(0.0044)
	[0.0011]	[0.0081]	[0.7552]	[0.0059]	[0.9636]	[0.0026]	[0.0032]	[0.0267]
3	-0.0240	-0.0188	-0.0102	-0.0351	-0.0345	-0.0363	-0.0244	-0.0149
	(0.0068)	(0.0085)	(0.0212)	(0.0134)	(0.0224)	(0.0089)	(0.0130)	(0.0053)
	[0.0005]	[0.0280]	[0.6303]	[0.0098]	[0.1247]	[0.0001]	[0.0611]	[0.0057]
4	-0.0239	-0.0117	-0.0390	-0.0270	-0.0451	-0.0331	-0.0273	-0.0161
	(0.0074)	(0.0108)	(0.0191)	(0.0141)	(0.0203)	(0.0101)	(0.0122)	(0.0065)
	[0.0015]	[0.2835]	[0.0417]	[0.0572]	[0.0272]	[0.0013]	[0.0266]	[0.0150]
5	-0.0295	-0.0134	-0.0480	-0.0320	-0.0515	-0.0388	-0.0309	-0.0193
	(0.0085)	(0.0153)	(0.0203)	(0.0165)	(0.0208)	(0.0115)	(0.0148)	(0.0084)
	[0.0007]	[0.3811]	[0.0187]	[0.0542]	[0.0139]	[0.0009]	[0.0381]	[0.0222]
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results of the cumulative effects of equitation (II) with clustered standard errors by countries in parentheses (), and p-values in brackets [].The sample covers the period 1971 through 2015. WIND is the area-weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 28: Descriptive statistics for Input-Output coefficients

Variable	Obs.	Mean	Std. dev.	Min	Max
$IO^{A\&B,A\&B}$	4658	0.16271390	0.16680850	0.00000100	0.99988900
$IO^{A\&B,C\&E}$	4658	0.01220390	0.01242000	0.00000017	0.13698420
$IO^{A\&B,D}$	4658	0.08602910	0.05547210	0.00000187	0.29982900
$IO^{A\&B,F}$	4658	0.00382200	0.00435680	0.00000000	0.13122400
$IO^{A\&B,G-H}$	4658	0.03607410	0.03550470	0.00000005	0.41751040
$IO^{A\&B,I}$	4658	0.02233090	0.01813120	0.00000026	0.18595210
$IO^{A\&B,J-P}$	4658	0.07270950	0.05504780	0.00000100	0.46910000
$IO^{C\&E,A\&B}$	4658	0.00083990	0.00167800	0.00000004	0.02588130
$IO^{C\&E,C\&E}$	4658	0.15054040	0.11721510	0.00007760	0.99963590
$IO^{C\&E,D}$	4658	0.05470040	0.05661350	0.00008700	0.88436900
$IO^{C\&E,F}$	4658	0.02864180	0.02404030	0.00000002	0.18346780
$IO^{C\&E,G-H}$	4658	0.01953390	0.01470170	0.00000129	0.10631420
$IO^{C\&E,I}$	4658	0.04958980	0.03135490	0.00001600	0.39845400
$IO^{C\&E,J-P}$	4658	0.09043620	0.05435020	0.00003480	0.47481830
$IO^{D,A\&B}$	4658	0.05530960	0.05382890	0.00000014	0.53598390
$IO^{D,C\&E}$	4658	0.03868220	0.04537050	0.00000800	0.60063000
$IO^{D,D}$	4658	0.24109900	0.11170600	0.00040070	0.99983140
$IO^{D,F}$	4658	0.00453810	0.00287030	0.00000007	0.03168640
$IO^{D,G-H}$	4658	0.05348620	0.02311120	0.00000400	0.21441400
$IO^{D,I}$	4658	0.03583530	0.01524670	0.00000554	0.14807160
$IO^{D,J-P}$	4658	0.08617050	0.04061830	0.00001100	0.34764290
$IO^{F,A\&B}$	4658	0.00341100	0.00625210	0.00000000	0.08438400
$IO^{F,C\&E}$	4658	0.01590490	0.01380220	0.00000027	0.12730870
$IO^{F,D}$	4658	0.20998900	0.07239280	0.00000084	0.50438670
$IO^{F,F}$	4658	0.03975870	0.08553050	0.00000000	0.99960700
$IO^{F,G-H}$	4658	0.06451070	0.02928120	0.00000110	0.21019250
$IO^{F,I}$	4658	0.03956490	0.01945270	0.00000422	0.14511880
$IO^{F,J-P}$	4658	0.09955550	0.04848610	0.00002200	0.37610500
$IO^{G-H,A\&B}$	4658	0.00839950	0.01095630	0.00000165	0.11565330
$IO^{G-H,C\&E}$	4658	0.01574710	0.00911050	0.00000937	0.09687740
$IO^{G-H,D}$	4658	0.07182600	0.04468980	0.00000400	0.62418100
$IO^{G-H,F}$	4658	0.00627980	0.00452070	0.00000001	0.05534940
$IO^{G-H,G-H}$	4658	0.05401600	0.07282230	0.00006930	0.99832200
$IO^{G-H,I}$	4658	0.06141320	0.03289510	0.00001900	0.47343600
$IO^{G-H,J-P}$	4658	0.14142170	0.06281020	0.00027640	0.65543420
$IO^{I,A\&B}$	4658	0.00041230	0.00133000	0.00000002	0.01570700
$IO^{I,C\&E}$	4658	0.00997520	0.00877890	0.00002000	0.09905100
$IO^{I,D}$	4658	0.06265890	0.04004090	0.00002660	0.30600280
$IO^{I,F}$	4658	0.00898280	0.00648950	0.00000002	0.04584890
$IO^{I,G-H}$	4658	0.02765340	0.02947960	0.00000300	0.25210700
$IO^{I,I}$	4658	0.11070080	0.07785550	0.00003060	0.99850180
$IO^{I,J-P}$	4658	0.13259910	0.06292550	0.00013690	0.57129040
$IO^{J-P,A\&B}$	4658	0.00260480	0.00907710	0.00000600	0.25743200
$IO^{J-P,C\&E}$	4658	0.01200890	0.00746520	0.00004110	0.07169680
$IO^{J-P,D}$	4658	0.05652770	0.03004160	0.00007510	0.27031930
$IO^{J-P,F}$	4658	0.01733480	0.00902710	0.00000000	0.07605100
$IO^{J-P,G-H}$	4658	0.02305490	0.01196060	0.00002530	0.10703650
$IO^{J-P,I}$	4658	0.03169370	0.01447210	0.00004480	0.13646430
$IO^{J-P,J-P}$	4658	0.14809730	0.08285600	0.00026200	0.99855500

Table 29: Regression results of Input-Output coefficients

		Dependent variables: Input-Output coefficients						
		A&B: Agriculture, hunting, forestry, fishing	C&E: Mining, utilities	D: Manufacturing	F: Construction	G-H: Wholesale, retail trade, restaurants, hotels	I: Transport, storage, communi-cation	J-P: Other activities
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	A&B	-0.00000655	0.00000011	0.00000520	0.00000035	0.00000101	0.00000002	0.00000076
		(0.00001275)	(0.00000014)	(0.00000357)	(0.00000044)	(0.00000094)	(0.00000004)	(0.00000060)
(2)	C&E	-0.00000157	0.00004304	0.00000041	0.00000091	0.00000148	-0.00000033	0.00000057
		(0.00000172)	(0.00002633)	(0.00000234)	(0.00000115)	(0.00000058)	(0.00000062)	(0.00000054)
(3)	D	-0.00001102	-0.00000466	-0.00001843	0.00000642	-0.00000028	-0.00000326	0.00000217
		(0.00000490)	(0.00000263)	(0.00001148)	(0.00000676)	(0.00000429)	(0.00000409)	(0.00000225)
(4)	F	0.00000008	-0.00000516	-0.00000010	-0.00001696	0.00000060	-0.00000077	-0.00000034
		(0.00000058)	(0.00000196)	(0.00000029)	(0.00001205)	(0.00000097)	(0.00000071)	(0.00000059)
(5)	G-H	-0.00000411	-0.00000325	0.00000042	0.00000259	0.00001065	-0.00000008	0.00000015
		(0.00000383)	(0.00000177)	(0.00000314)	(0.00000284)	(0.00001731)	(0.00000276)	(0.00000113)
(6)	I	-0.00000184	-0.00000425	0.00000052	0.00000018	0.00000141	0.00000938	0.00000043
		(0.00000285)	(0.00000331)	(0.00000195)	(0.00000221)	(0.00000276)	(0.00000843)	(0.00000153)
(7)	J-P	-0.00000473	-0.00001030	0.00000237	0.00000504	-0.00000033	-0.00000920	-0.00000571
		(0.00000815)	(0.00000560)	(0.00000612)	(0.00000433)	(0.00000062)	(0.00000884)	(0.00000720)

Notes: OLS regression results with clustered standard errors by countries in parentheses ().The sample covers the period 1990 through 2015. The coefficient shown correspond to the WIND variable, which is the area-weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects, and a lagged dependent variable. The columns display the output sector j and the rows the respective input sectors k. For example, the coefficient 0.00000148 in column (5) and row (2) indicates that due to an increase of tropical cyclone intensity by 1 km/h the sector G-H uses 0.00000148 less units of input from sector C&E to produce one unit of output.

Table 30: Regression results of the main specification for developed countries

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0019	-0.0118	0.0024	-0.0016	0.0187	0.0029	-0.0061	-0.0050
	(0.0036)	(0.0152)	(0.0132)	(0.0056)	(0.0194)	(0.0069)	(0.0056)	(0.0052)
	[0.5970]	[0.4425]	[0.8547]	[0.7715]	[0.3415]	[0.6787]	[0.2845]	[0.3488]
Observations	1,385	1,340	1,295	1,385	1,385	1,385	1,385	1,385
# of countries	33	32	31	33	33	33	33	33
Adj. R^2	0.2456	0.0317	0.0507	0.1755	0.0959	0.0870	0.1334	0.0804
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results of the main specification for developed countries only with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity, forwarded by one period, and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Table 31: Regression results of the main specification for developing countries

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0074	-0.0323	-0.0108	-0.0104	0.0095	-0.0128	-0.0078	-0.0030
	(0.0033)	(0.0066)	(0.0169)	(0.0075)	(0.0139)	(0.0048)	(0.0045)	(0.0030)
	[0.0239]	[0.0000]	[0.5255]	[0.1673]	[0.4955]	[0.0086]	[0.0861]	[0.3068]
Observations	7,522	7,525	7,444	7,483	7,526	7,476	7,480	7,520
# of countries	180	180	179	180	180	179	179	180
Adj. R^2	0.0419	0.0110	0.0022	0.0114	0.0180	0.0263	0.0149	0.0189
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results of the main specification for developing countries only with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity, forwarded by one period, and its unit is km/h. All regressions include country and year fixed effects. Potential outliers are excluded following the analysis described in Appendix C.

Appendix C: Outlier Analysis

I conduct two strategies to identify potential outliers. First, I perform various graphical analyses such as simple scatter plots for the dependent variables and the respective independent variables, as well as leverage-versus-squared-residual plots and partial regression plots for the variable of main interest. Second, I cross-check the identified outliers with a more formal analysis. I exclude outliers if their leverage is above the threshold (2k+2)/n, where k is the number of independent variables and n the total number of observations. As a second threshold, I eliminate observations above an absolute value of the residuals of 10.

I can identify the following country-year observation outliers of the regressions with the respective dependent variables. It should be noted that I analyzed all variables included in the main specification regarding outliers:

- Per capita growth rate of total output: ETH1990, KWT1992, LBN1977, LBR1997, LBY2012, NRU2008, SDN2008, SSD2009-SSD2015, TLS2004
- Per capita growth rate of sector aggregate *agriculture, hunting, forestry, and fishing*: ERI2005, ETH1990, LBY2012, SDN2008, SSD2009-SSD2015, XKX2005
- Per capita growth rate of sector aggregate *mining and utilities*: ARM1994, BEN1983, BGD1977, COD1996, ECU1972, FJI1976, FJI1983, KWT1992, LBR2000, MDA1993, MMR1977, PLW1998, SLB1998, SSD2009-SSD2015, SYC1991, SYC1992, SYC1994, TCD2003, TLS2004
- Per capita growth rate of sector *manufacturing*: LBR2000, LBR2001, NRU2008, NRU2010, SSD2009-SSD2015
- Per capita growth rate of sector *construction*: COD1996, EGY1982, LBR2001, SSD2009-SSD2015, ZWE2009
- Per capita growth rate of sector aggregate *wholesale, retail trade, restaurants, and hotels*: AFG1990, AFG2002, ARM1994, BRN1977, ETH1990, GEO1995, LBR1996, LBR1997, MNG1986, SSD2009-SSD2015
- Per capita growth rate of sector aggregate *transport, storage, and communication*: LBR1997, NRU2008, RWA1995, SSD2009-SSD2015, SYC1992, TUV1994

Table 32: Regression results of the main specification including potential outliers

	Dependent variables: Growth rate (%) pc in sector							
	Total output	Agriculture, hunting, forestry, fishing	Mining, utilities	Manufacturing	Construction	Wholesale, retail trade, restaurants, hotels	Transport, storage, communication	Other activities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$WIND_t$	-0.0068	-0.0305	0.0452	-0.0152	0.0083	-0.0104	-0.0087	-0.0032
	(0.0030)	(0.0062)	(0.0905)	(0.0093)	(0.0130)	(0.0046)	(0.0050)	(0.0028)
	[0.0240]	[0.0000]	[0.6183]	[0.1050]	[0.5236]	[0.0249]	[0.0806]	[0.2573]
Observations	8,967	8,877	8,809	8,924	8,967	8,922	8,922	8,967
# of countries	215	213	212	215	215	214	214	215
Adj. R^2	0.0335	0.0086	-0.0002	0.0010	0.0088	0.0154	0.0055	0.0070
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS regression results with clustered standard errors by countries in parentheses (), and p-values in brackets []. The sample covers the period 1971 through 2015. WIND is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and year fixed effects.

- Per capita growth rate of sector aggregate *other activities*: AFG2002, ARM1994, ETH1990, GEO1996, KIR1981, LBR1997, MNG1986, MRT1983, RWA1991, RWA1995, SSD2009-SSD2015

Table 32 shows that all regression estimates remain robust to the inclusion of the potential outliers.

Appendix D: Heterogeneous Effects

In this specification, I analyze how the sectoral growth rates of different country groups react to the occurrence of tropical cyclones. Above all, this analysis connects to work done by Kahn (2005) and Strobl (2012). To compare economically developing and developed countries, I separate the sample following the OECD's Development Assistance Committee (DAC) criteria.

The results of this sample separation are presented in Figure 11. It shows that sectoral growth rates react differently to tropical cyclones in developing and developed countries. As could be expected, developing countries seem to be more vulnerable to the effects of tropical cyclones. For developing countries, all effects found in the main specification can be replicated. There exists a negative effect of tropical cyclones on the GDP per capita growth rate which can be attributed to the sector aggregates *agriculture, hunting, forestry, and fishing*; *wholesale, retail trade, restaurants, and hotels*, and *transport, storage, and communication*. In contrast, I

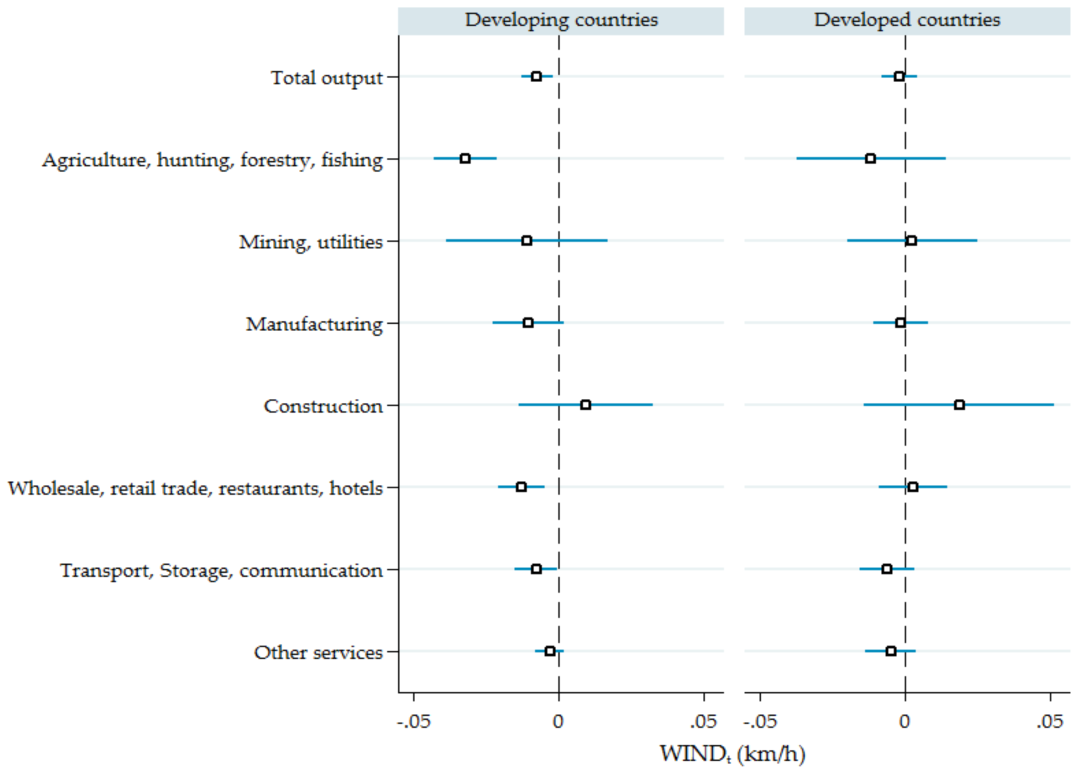

Figure 11: Coefficient estimates of the variable WIND$_t$ (km/h) (blue squares), together with the 90% confidence bands (blue line). The sample covers the period 1971 through 2015. WIND$_t$ is the area weighted measure for tropical cyclone intensity and its unit is km/h. All regressions include country and time fixed effects. Detailed regression tables of the estimations used in can be found in Appendix B.

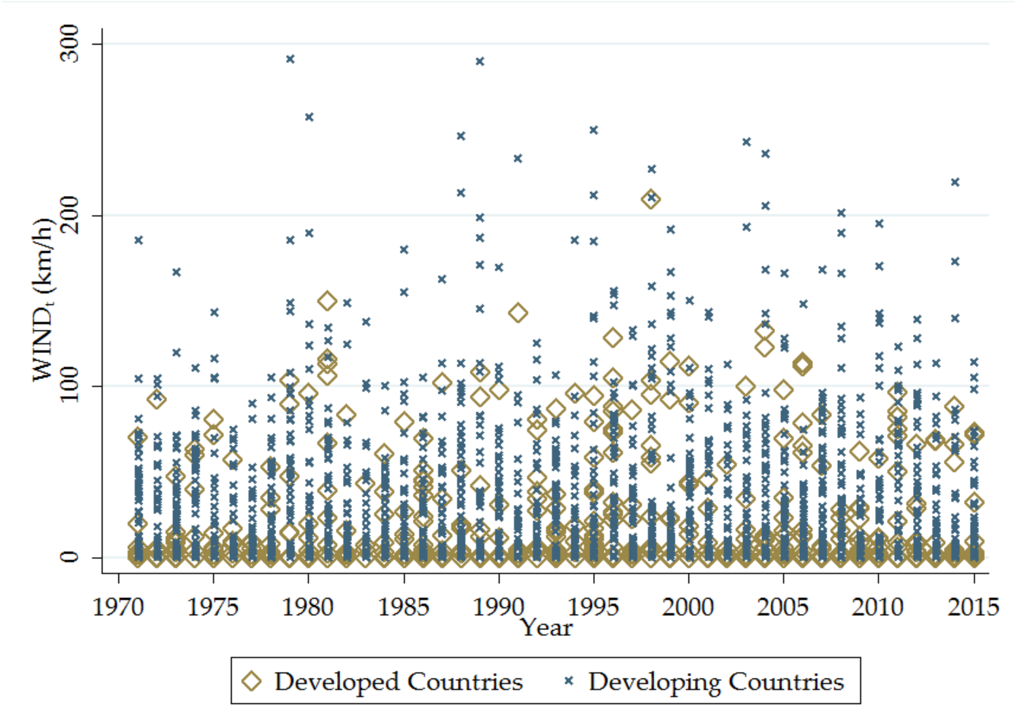

Figure 12: Distribution of the tropical cyclone intensity variable WIND$_t$ for developing and developed countries from 1970-2015.

cannot identify a negative GDP growth effect for developed countries, as well as for the sectoral aggregates. This might be an indication that developed countries can better cope with the destruction occurred after a tropical cyclone had hit a country. However, Figure 12 demonstrates that developing countries experience more tropical cyclones, in number and intensity, than developed countries. Thus, it remains unclear what drives the effect, less frequency or less intensity of tropical cyclones, or better coping strategies of developed countries.