# Climate and Tropical Cyclone Effects on Economic Activity: Evidence at the Firm Level from Mexico

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**Abstract**

How tropical cyclones affect the economic activity of firms of manufacturing and services sectors in Mexico? For answering this question, we constructed a unique database of monthly observations of firms' economic activity indicators and at the municipality level tropical cyclone exposure, measured as maximum sustained winds, and weather data to estimate their impact on production and remunerations per worker in manufacturing for the period 1994-2014 and revenues and remunerations per worker at the services sector for 2005-2015. Controlling by climate and other variables, we find that for an average firm located in a municipality with high frequency of tropical cyclones exposure, the maximum sustained winds show a negative impact on production and remunerations per worker in the manufacturing sector and a low and persistent negative effect in revenues of firms of the services sector. An important contribution of this paper is based on the more disaggregated temporal and spatial character of its results, which allow identifying how heterogeneity plays a role on the magnitude of the effect, which is especially useful for policy design.

**Keywords**: Tropical Cyclones, Firm level economic impact, maximum sustained wind exposure

**JEL codes**: Q54, Q51, L60, O12, O14

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## 1. Introduction

Tropical Cyclones are atmospheric phenomena with an important function in the hydrological cycle in tropical and subtropical regions of the earth since they are the mechanism to transfer heat and energy between the equator and the cooler regions toward the poles. Tropical cyclones are rotating storm systems in which strong winds lead to lower pressure, and those systems are continuously fed by warm water condensation. For arid and semiarid regions, tropical cyclones are an active source of water recharge for aquifers, rivers, lakes and dams (Aguilar-Benitez, 2011). The basic condition for their formation is a sea-surface temperature of 26°C and higher; they have well know formation patterns within seven basins around the world at the different seasons throughout the year. In the Northern hemisphere, tropical cyclones are originated in the North Atlantic and Eastern North Pacific shores, and their period goes from June to November with a peak in September.

However, tropical cyclones are one of the most dangerous natural hazards for human life and economic activities. These events cause damage and economic losses from a combination of intensity, size, forward speed, and rainfall. In particular, size and forward speed add to economic losses through the area affected and the length of time the wind blows. Tropical cyclones reach different intensities measured by their maximum sustained winds (msw), being storms and tropical depressions the lowest intensity events and hurricanes the most potential damaging events. Hurricanes are classified according to the Saffir-Simpson Hurricane Wind Scale from 1 to 5 rating, with category 3 and higher being considered as the major ones because of their potential for causing losses of life and damage.[1]

The potential devastation produced by tropical cyclones in recent decades has renovated the interest in studying the effects of these unpredictable events. Furthermore, the general concern relies on the possibility about their increasing severity and higher frequency due global warming. Around the world, since 1975 there has been a substantial and observable 25–30% increase in the proportion of Category 4 to 5 hurricanes per additional 1°C of anthropogenic global warming (Holland and Bruyere, 2014). Extreme rain has amplified alongside hurricanes; weak storms have been scaling up into higher intensities by extracting moisture from the area surrounding the core of the hurricane, which results in higher volumes of net rain, mainly in the North Atlantic basin (Mendelsohn et al., 2012). More frequent episodes of heavy rain associated to tropical cyclones may increase its destructive power in economic activities, especially in developing countries. In the near future, these

[1] A tropical depression shows maximum sustained winds of 38 mph or less and a tropical storm from 39 to 73 mph (34 to 63 km/h). A category 1 hurricane is characterized by maximum sustained winds from 74-95 mph (119-153 km/h) that usually produces some minor damage. Category 2 could produce some damage with mws of 96-110 mph (154-177 km/h). Category 3 is a major devastating damage event with 111-129 mph (178-208 km/h). Category 4 refers a sustained severe damage 130-156 mph (209-251 km/h). Category 5 (major) 157 mph or higher 252 km/h or higher indicates a catastrophic damage.

phenomena could bring devastating consequences for the Mexican population that often dampens economic activity as a short term effect to winds of hurricanes and severe storms.

In particular, since the record-breaking 2005 season that included three of the ten most intense North Atlantic hurricanes ever (Katrina, Wilma and Rita), tropical cyclones have received increasing attention because their devastation power appears to be increasing. Hurricanes Katrina and Wilma were category 5, the second costliest and the most intense (by lowest barometric pressure) North Atlantic hurricanes on record, respectively. More than a decade later, the 2017 Atlantic season was hyperactive and catastrophic by featuring 6 major hurricanes. For the first time in records, three hurricanes were simultaneously active in the same basin, and two of them reached over 150 miles per hour of maximum sustained wind.

In Houston, Hurricane Harvey devastated parts of the Texas coastline and produced more rainfall than any U.S. hurricane on record. Hurricane Irma had a record-breaking duration as a Category 5, and Maria was the tenth-most intense hurricane on record and the most intense tropical cyclone worldwide of 2017 causing human life and economic losses across Puerto Rico, Dominica, the Dominican Republic, Haiti, Guadeloupe, Virgin Islands and mainland in the U. S. Thus, empirical evidence has brought into the arena, besides the wind intensity, the relevance of studying cumulative precipitation associated with these natural events. In the economic literature, most of the economic impact of tropical cyclones exposure has been assessed in terms of maximum sustained wind, while the rain dimension remains still scarcely studied.

In México, tropical cyclones are one of the most potent sources of economic loss and the severity of the damage may differ according to the maximum sustained winds that these events may show. From 2000 to 2015, about 60% of the tough natural disasters that generated the highest economic losses and infrastructure loss are related with tropical cyclones. Thus, given the affectation that tropical cyclones cause on economic activity in Mexico, and since economic literature has documented these impacts at an aggregate scale, in this paper we focus on estimating the most disaggregated scale effect of the tropical cyclones' impact of on economic activity.

Although in the economic literature, the impact of these atmospheric events has been studied at a country level (see Hsiang, 2010; Hsiang and Jina, 2014); this paper situates in the volume of economic literature that focus on finding out the effect of tropical cyclones exposure on economic activity. In this context, one of the main contributions relies on the local scale effects estimated on the unique database that combines establishment level information from surveys and municipality level data on climate and maximum sustained winds for all tropical cyclones whose trajectories are located in the influence area for Mexico. We assemble panel data on monthly basis of economic indicators of manufacturing and services establishments from surveys and we matched them at the municipality level with tropical cyclones exposure data, measured as the maximum sustained wind, climate variables. Using this information, we quantify the effect of tropical storms in firms located at municipalities frequently exposed to hurricanes category 1 and higher using a Distributive Lagged Model for the periods 1994 – 2017 in manufacturing and 2008 – 2015 in services sector. We found a short-term negative economic effect of tropical cyclones on manufacturing and services firms. However, the negative impact is heterogeneous across sectors. The effect on services' revenue establishments is higher but of short duration for activities directly related with climate like tourism, while manufacturing firms show more persistent effects.

The rest of the paper is organized as follows. Section 2 reviews the literature about the impact of tropical cyclones on economic activity. Section 3 presents some stylized facts of the tropical cyclones in Mexico and economic activity. Section 4 cites data sources and describes data and construction of variables. Section 5 presents the model and section 6 shows the results of the econometric estimations. Finally, section 7 concludes and outlines the directions for future research.

## 2. Literature Review

The occurrence of more frequent extreme weather events around world and the more tangible climate change have increased the interest of the study of their consequences on economic activities. One of the most important advantages of these kind of studies relies on its relatively strong identification properties based on exploiting the exogeneity of random draws from complex atmospheric stochastic systems within a given spatial area; in particular, the random path and variation in severity of the maximum sustained winds of tropical cyclones allows the identification of its effects on economic activity of the firms. Thus, since weather randomly vary, the fixed effects of the defined geographical areas absorb the static spatial features, either observed or unobserved, separating the shock from many other sources of possible omitted variable bias (Dell et al., 2014). Under this approach, a broad research in economic literature has focused on studying agricultural yields, energy demand, mortality, labor productivity, exports, migration, social conflicts and violence, and economic growth (see Mendelsohn et al., 2004; Deschenes and Greenstone, 2007; Deschenes and Greenstone, 2011; Deschenes y Moretti, 2009; Dell, Jones and Olken, 2009; Jones and Olken, 2012).

However, the study of the destructive power of hurricanes and their impacts on the economy remained barely studied until 2005, when category 5 hurricane Katrina arrived in late August making landfall on the Gulf coast from central Florida to Texas, and causing severe unexpected damages in property and economic activities in the coastal areas of Louisiana and Mississippi. The same year, hurricane Wilma made several landfalls, with the most destructive effects felt in the Yucatán Peninsula of Mexico. Thus, the perspective of progressive increasing potency of tropical cyclones associated to climate change brought in to the discussion arena the effects of tropical cyclones on economic activity.

In this context, the seminal paper of Nordhaus (2010) examined the economic impacts of US hurricanes from 1900 to 2008. He used a damage function of the winds records of hurricanes and found high vulnerability to Atlantic hurricanes where damages appear to have a ninth power law respect to maximum wind speed. He also found that 2005 Atlantic season appears to have been a quadruple hurricane outlier. In addition, US hurricanes damages could increase by 0.08% due to the intensification effect of a CO2 equivalent doubling.

Moreover, Hsiang (2010) examined windstorms by constructing meteorological databases based on storm trajectories to document the response of economic activities in 28 countries of the Caribbean basin. He showed that temperature and tropical cyclones are correlated, so explicitly controlling by temperature, production losses due tropical cyclones in nonagricultural production exceeds the losses in agricultural sector. Also, they find that average temperatures during September-October-November have an important effect on sectors such as retail, restaurants and hotels and transport and communication, while in manufacturing and construction the effects are negligible and non-significant.

Hsiang and Narita (2012) documented the adaptation process of countries with different climatology using data from 1950 to 2008. They find that the most exposed countries response with a higher adaptive effort by running heavy investments in infrastructure, which reduces the impact of hurricanes in time. Later, Hsiang and Jina (2014) study the long-term effects on growth of tropical cyclones using annual fluctuations from windstorms and they found evidence of national incomes decline for all type of income countries and such negative effect decreases with tropical cyclones historical experience of countries. They found that lower growth rates in the following fifteen years after the disaster generate a significant effect in the path of growth.

Other studies have focused on Central America and the Caribbean countries exploring the effects of hurricanes using synthetic tracks based on satellite images to proxy the economic activity levels to estimate expected risk and losses of similar events for the last 30 years (Bertinelli et al., 2016; Bertinelli et al., 2016; Ishizawa et al., 2018).

## 3. Stylized Facts of Tropical Cyclones in Mexico

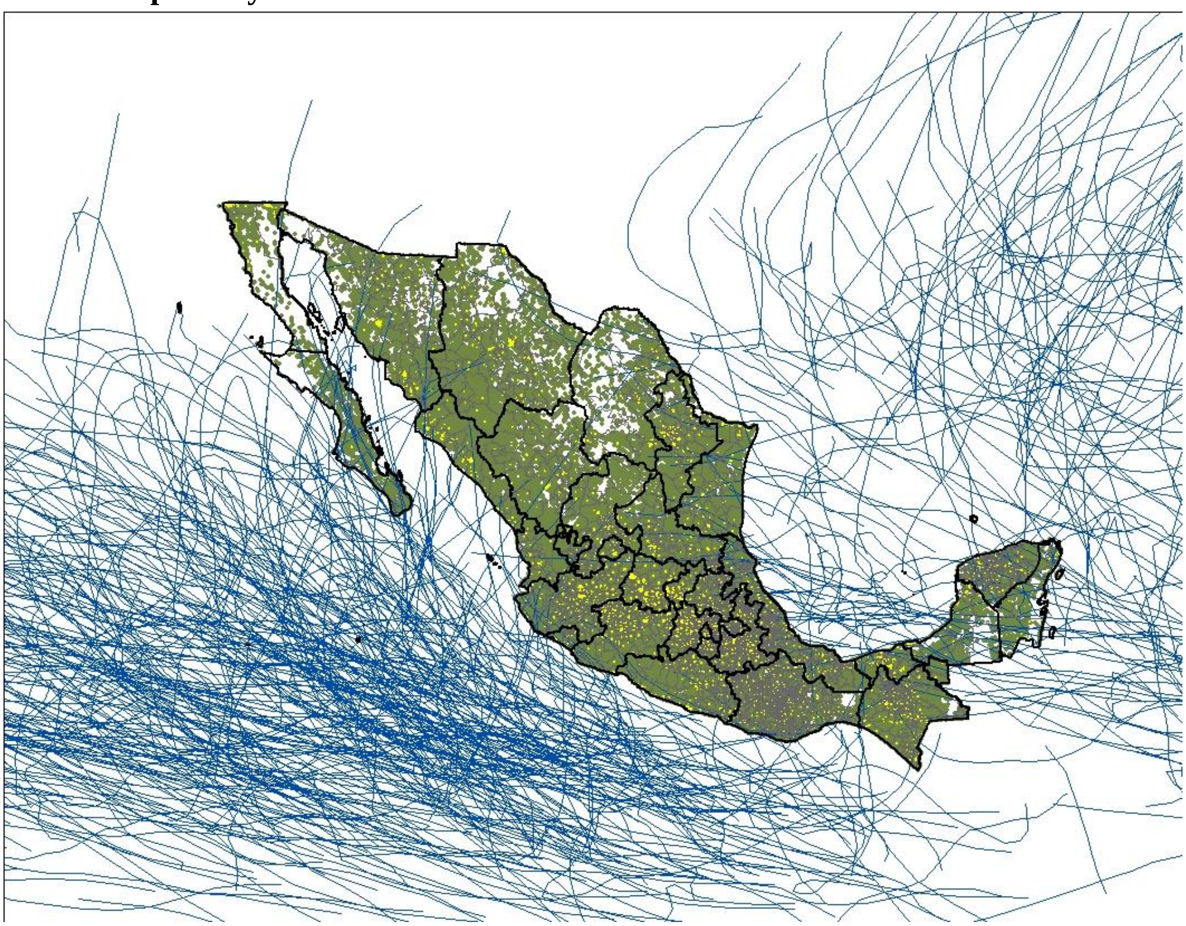
### *3.1. Stylized Facts*

Mexico is located at a middle latitude and in the vicinity of the Tropic of Cancer, which implies frequent and severe tropical cyclones, measured by maximum sustained winds in both of its shores (the North Atlantic and Eastern North Pacific). Hsiang and Jina (2014) placed Mexico as the number nine country in terms of its average frequency and severity of tropical cyclones.

México has 9,330 km of littorals with borders to the west with the Pacific Ocean and the Gulf of California; and to the east with the Gulf of Mexico and the Caribbean Sea; it has 17 coastal states (11 in the Pacific Ocean and 6 with the Gulf of Mexico, 153 municipalities constituted by 35,626 localities) that represent 56.3% of its mainland surface.

Based on data from International Best Track Archive for Climate Stewardship (IBTrACS) from the National Hurricanes Center of the National Oceanic and Atmospheric Administration of the U.S. government that contains information of every 6-hour trajectory of tropical cyclones. Figure 2 shows the trajectories of all tropical cyclones in the North Atlantic basin and the North Pacific basin occurred between 1994 and 2017.

**Figure 1**
**Tropical Cyclones Paths and its Maximum Sustained Winds 1994 – 2017**



Source: Own elaboration using the IBTrACS from NOAA.

The map reveals the trajectories of a total of 708 tropical cyclones developed in the two basins bordering Mexico.[2] Even when the Eastern North Pacific basin has experienced the highest number of hurricanes, the North Atlantic basin has recorded the most severe hurricanes. At a first glance, we can observe that the most of hurricanes' landfalls have occurred in states like Baja California Sur, Sonora, Tamaulipas, Jalisco, Yucatan and Quintana Roo. Next, Table 1 shows the frequency of tropical cyclones occurrence at Eastern North Pacific basin and North Atlantic shores for the period 1994-2017.

**Table 1.**
**Tropical Cyclones 1994-2017 Categorized by the Saffir-Simpson Scale of Maximum Sustained Winds**

| Year | Tropical depression ≤ 38 mph | Tropical Storm 39–73 mph | Hurricanes Category 1 74–95 mph | Category 2 96–110 mph | Category 3 111–129 mph | Category 4 130–156 mph | Category 5 ≥ 157 mph | Total Tropical Cyclones |
|---|---|---|---|---|---|---|---|---|
| 1994 | 4 | 14 | 4 | 0 | 1 | 4 | 0 | **27** |
| 1995 | 2 | 15 | 3 | 2 | 4 | 2 | 0 | **28** |
| 1996 | 0 | 10 | 4 | 5 | 3 | 0 | 0 | **22** |
| 1997 | 2 | 15 | 2 | 1 | 4 | 1 | 1 | **26** |
| 1998 | 1 | 11 | 7 | 4 | 2 | 3 | 0 | **28** |
| 1999 | 3 | 7 | 3 | 1 | 3 | 3 | 0 | **20** |
| 2000 | 4 | 20 | 5 | 0 | 2 | 1 | 0 | **32** |
| 2001 | 3 | 16 | 6 | 2 | 4 | 0 | 0 | **31** |
| 2002 | 2 | 14 | 4 | 1 | 2 | 3 | 0 | **26** |
| 2003 | 5 | 19 | 6 | 0 | 1 | 1 | 0 | **32** |
| 2004 | 1 | 15 | 2 | 3 | 3 | 3 | 0 | **27** |
| 2005 | 3 | 24 | 7 | 2 | 1 | 4 | 1 | **42** |
| 2006 | 2 | 13 | 4 | 3 | 1 | 2 | 0 | **25** |
| 2007 | 4 | 17 | 3 | 0 | 1 | 2 | 0 | **27** |
| 2008 | 5 | 17 | 5 | 1 | 4 | 1 | 0 | **33** |
| 2009 | 3 | 18 | 2 | 1 | 2 | 2 | 0 | **28** |
| 2010 | 3 | 11 | 6 | 1 | 3 | 2 | 0 | **26** |
| 2011 | 0 | 16 | 4 | 2 | 6 | 1 | 0 | **29** |
| 2012 | 1 | 18 | 7 | 6 | 1 | 0 | 0 | **33** |
| 2013 | 1 | 27 | 5 | 0 | 0 | 0 | 0 | **33** |
| 2014 | 2 | 12 | 5 | 3 | 4 | 3 | 0 | **29** |
| 2015 | 4 | 16 | 3 | 0 | 6 | 4 | 1 | **34** |
| 2016 | 2 | 18 | 7 | 3 | 4 | 2 | 0 | **36** |
| 2017 | 3 | 15 | 6 | 4 | 3 | 3 | 0 | **34** |
| **1994-2017** | **60** | **378** | **110** | **45** | **65** | **47** | **3** | **708** |

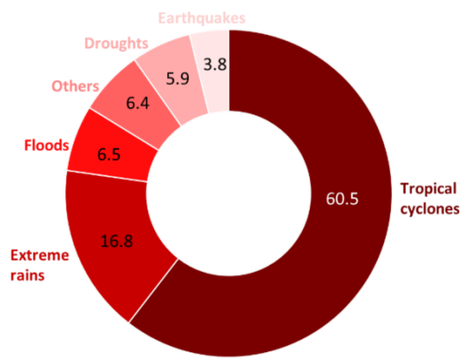
Source: Own elaboration using the IBTrACS from NOAA.

In Table 2, we can observe an increase of frequency in hurricanes in the last five years records, also the severity has raised, especially of those of categories 3 and 4. In this context, tropical cyclones constitute the most important category of natural disaster causing major economic losses in infrastructure like highways, communications and services like electricity, sewing and utilities.

[2] From 1950 to 2017, the Eastern North Pacific basin recorded a total of 1,501 tropical storms and 1,046 tropical storms at the North Atlantic basin. About 10% of these tropical cyclones reached category 3 and over in Saffir-Simpson scale.

Due the damage of natural disasters, Mexican government stablished Mexico's Natural Disaster Fund (FONDEN, by its acronym in Spanish). The FONDEN is a disaster risk management strategy to funding disaster relief and reconstruction of infrastructure affected by natural disasters at the federal, state, and municipal levels. The FONDEN was created to reduce the severity of the adverse social and economic costs and shortens supply interruptions during the post-disaster period. Figure 2 shows the share of FONDEN's resources exercised by tropical cyclones for the period 2000 – 2015. Between 2000 and 2017, a total of 9,007 municipalities were declared as disaster areas by the FONDEN, 25% were due tropical cyclones and 42% due extrema rain and flooding, most of these, also associated to tropical cyclones.

**Figure 2**
**Resources Exercised as a Result of Natural Disasters in Mexico 2000 - 2015**
Percentages




Source: Own elaboration using data from National Center for Disaster Prevention (CENAPRED).

Next, Table 5 shows details of the top seven disaster loss declarations with the major funding from the FONDEN. Mexico experienced in 2005 and 2010 important economic losses associated to hurricanes. In 2005 the hurricanes Wilma and Stan caused important economic losses in Quintana Roo and Chiapas, respectively. In 2010, the extreme rain associated to hurricanes Karl and Mathew flooded the downtown of Veracruz capital, causing power outbreaks, while hurricane Alex caused major flooding in Nuevo León producing power outbreaks and damaging installations of manufacturing firms and affecting the regular operation of economic activity in the City of Monterrey for several weeks. Also, as shown Table 2 hurricane Manuel in 2013 caused important infrastructure damage in Guerrero.

**Table 5**
**Top Seven Disaster Declaratories by Amount of Resources Exercised from FONDEN**

| | Month/Year | Name | State | Percentage of FONDEN funds |
|---|---|---|---|---|
| | September 2010 | Karl and Matthew | Veracruz | 11.1 |
| **2** | September 2014 | Odile | Baja California Sur | 10.2 |
| **3** | September 2013 | Ingrid and Manuel | Guerrero | 10.3 |
| **4** | June 2010 | Alex | Nuevo Leon | 9.7 |
| **5** | October 2005 | Wilma | Quintana Roo | 9.5 |
| **6** | October 2005 | Stan | Chiapas | 7.8 |
| **7** | September 2002 | Isidore | Yucatan | 3.8 |
| | | | | **62.4** |

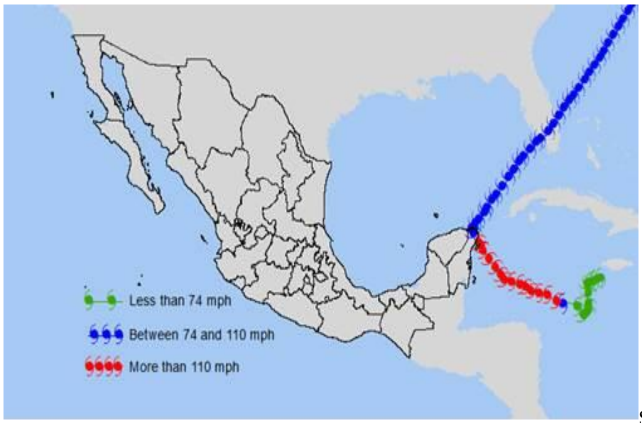
Source: Own elaboration using data from National Center for Disaster Prevention (CENAPRED).

Next, we show an aggregate perspective for the impact on economic activity of hurricane Wilma. This tropical cyclone made a first landfall on October 21st 2005 on the island of Cozumel, Quintana Roo, with a maximum sustained winds up to 150 mph (240 km/h) and a second landfall at the North of the Yucatán Peninsula. On its path, Wilma struck Cancun causing a widespread damage on an important tourist Mexican destination and its adjacent localities. Figure 3 (left) displays the geographical trajectory of hurricane Wilma, disturbing Yucatan Peninsula and Quintana Roo, where this hurricane reached its highest wind intensity. Numerous hotels, highways and electrical infrastructure were severely damaged for entire weeks. The Figure 3 (right) shows the impact of the hurricane Wilma on the economic activity in Quintana Roo.

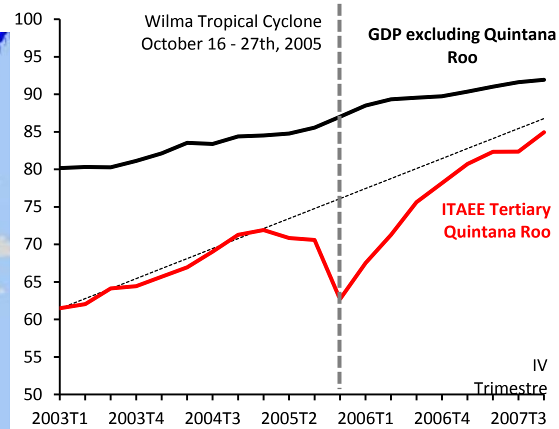
Figure 3 (right) shows the contraction of the economic activity in the tertiary sector of the state Quintana Roo in the contemporaneous quarter of the shock, when the hurricane Wilma made landfall in the Peninsula. Even when economic activity appears to turns back to its original path, an incomplete recovery is observed after 3 quarters. In contrast, the rest of the states, excluding the state of Quintana Roo, show an unaffected indicator of economic activity in the quarter of the shock and its performance remains under the same path of growth.

**Figure 3**

**Trajectory and Impact of Hurricane Wilma on Economic Activity in 2005**




Source: Own elaboration using the IBTrACS from NOAA.




Source: Own elaboration using seasonally adjusted series from the National Institute of Statistics and Geography (INEGI).

## 4. Data and Sources

### *4.1 Tropical Cyclone Exposure Measurement*

In the economic literature, wind speed has been used as a proxy variable for the intensity of tropical cyclones (Emanuel, 2011; Hsiang and Jina; 2014, Ishizawa et al., 2017; Boose et al., 2004). For this paper, we constructed an innovative and unique database containing a monthly measure of the tropical cyclones exposure measured by the maximum sustained wind that the 2,456 municipalities across the Mexican territory experienced from January 1994 to December 2017.

For the estimation of this indicator, as input data we used detailed information of all the tropical cyclones occurred in the North Atlantic and East Pacific shores from January 1994 to December 2017 employing the trajectory records from the International Best Track Archive for Climate Stewardship (IBTrACS). This database (http://www.ncdc.noaa.gov/oa/ibtracs/) contains the most comprehensive records on 6-hour basis of georeferenced tracks, the maximum sustained wind, minimum pressure and other parameters for each tropical cyclon. Although IBTrACS database contains information since 1850, season 1987 and afterwards are more accurate because they can be verified by satellite images.

For generating monthly observations of maximum sustained wind for a given municipality, we used the Storm Wind Model package in R developed by Brook Anderson from Colorado State University based on Willoughby et al. (2006).[3] For each storm track location, this algorithm use the Willoughby model to measure distance to municipality from

[3] See the code at https://github.com/geanders/stormwindmodel

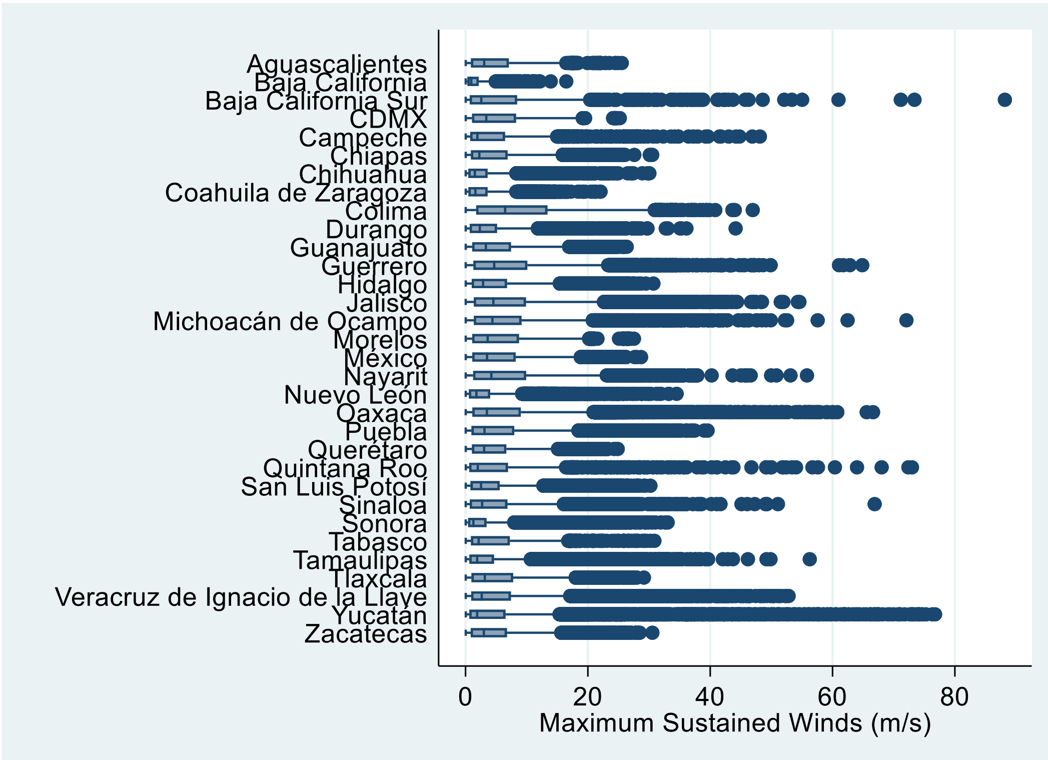
storm center (radius), calculating tangential gradient wind components at that grid point, gradient wind direction at that grid point; surface wind speed; surface wind direction, adding storm forward motion back into surface wind estimate. Thus, for each municipality center (or other grid point), the model estimates surface-level sustained wind and 3-second wind gusts at all storm observation points (i.e., all points along the interpolated storm track). Thus, the program determines for each municipality's center coordinates: the maximum sustained winds and wind gust speeds at any point on the storm's track; the duration of sustained and gust winds over a certain speed (i.e., how many minutes winds were above a cutoff).

#### *4.1.1 The maximum sustained winds of Tropical Cyclones*

The final database included a total of 708 tropical cyclones whose influence area is determined by their trajectories in the North Atlantic shore reflected in length coverage from 45 ° to 105 ° west and for the Northeastern Pacific recorded on the covering lengths of 80 ° to 140 ° west. So, an observation in a given municipality and a given month will be determined by the collapse of the maximum sustained winds of all the tropical cyclones happening in that period of time.

Figure 4 shows the maximum sustained winds as an average measure of exposure to tropical cyclones estimated by the Rwind Model at the state level. Boxes are interquantiles ranges, dark blue lines represent the mean and balls represent outliers for every state. The estimations are at the level of municipality; however, for the sake of simplicity exposure to tropical cyclones in terms of maximum sustained winds is presented at the state level. The most noticeable states because of the outliers are: Baja California Sur, Yucatán, Quintana Roo and Oaxaca.

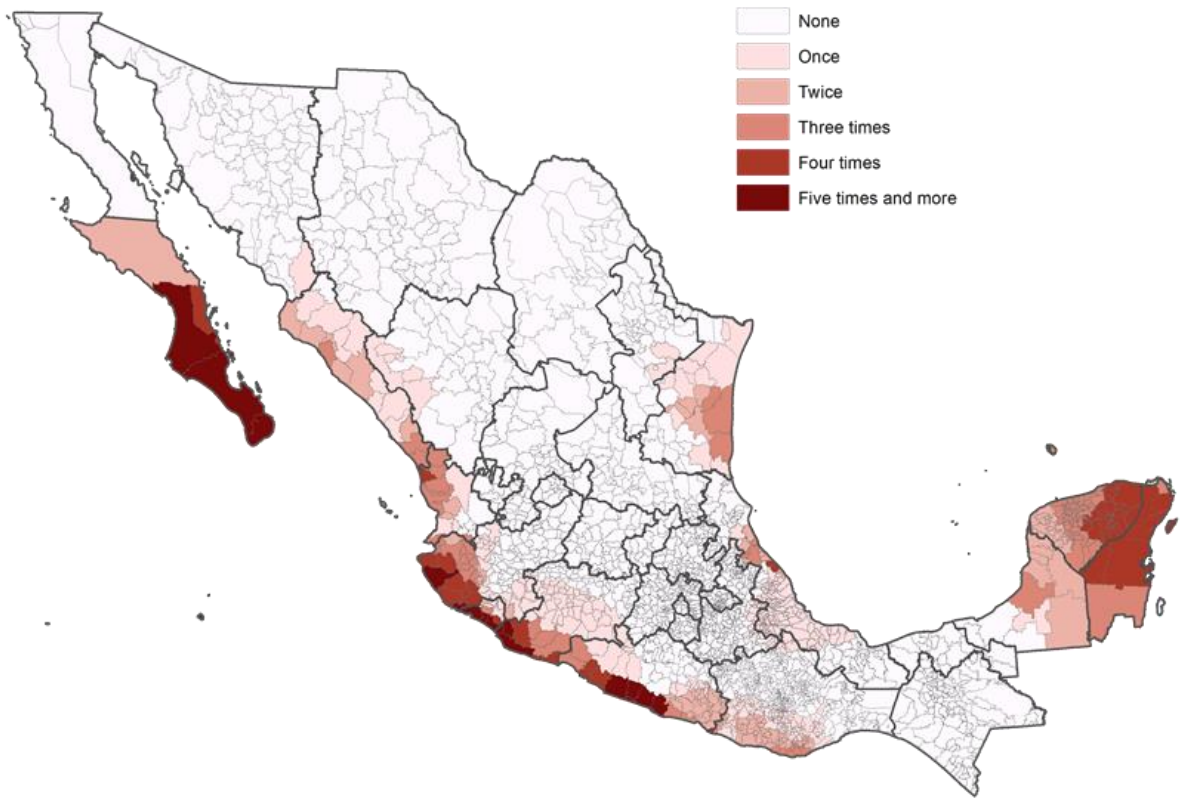
**Figure 4.**
**Box-Plot of within-State Distribution of Maximum Sustained Winds in Mexico 1994-2017 Averages by Municipality**




Source: Own estimations based on the RwindStorm Model.

Next, we show a frequency map in Figure 5 that details the recurrence of these atmospheric events at the municipality level for the period 1994-2017. This map was calculated by counting the times a municipalities deal with maximum sustained winds equivalent to hurricane category 1 and higher (≥74 mph, ≥33m/s).

**Figure 5**
**Maps of Frequency to Hurricane Category 1 and Higher, 1994 – 2017**




Source: Own elaboration using the IBTrACS from NOAA.

Figure 5a shows 682 municipalities in dark red that have experienced a high frequency of hurricanes category one and higher. More than 60% of those municipalities are in the Pacific shore in municipalities of the states of Baja California Sur, Jalisco, Colima, Michoacan, Guerrero and Oaxaca. While in the Atlantic shore, the most frequently affected municipalities are concentrated in the states of Veracruz, Tamaulipas, Quintana Roo and Campeche, in the North Atlantic shore.

### *4.1 Weather Database*

In addition, we include weather information of ground station data from the National Meteorological System that provides daily records of precipitation, maximum and minimum temperature from about 3,000 weather stations located across all states of the country. Next, in order to decrease measurement error, we carried out a control quality process of the weather stations and ruled out those stations with incomplete entries or frequent missing data.

Since the distribution of weather stations is far from being uniform and some regions may have a sparse coverage, we interpolate station data over a grid to provide gridded data that displays a comprehensive coverage at the municipality level, Thus, we constructed a balanced panel data with monthly observations on cumulative precipitation, and average maximum and minimum temperatures for the 2,546 municipalities across Mexico from January 1994 to December 2017. However, we only used climate information for 578 municipalities with firm facilities.

### *4.2 Economic Surveys*

In Mexico, during the first quarter of 2018 the manufacturing contributed in the Gross Domestic Product with 15.9%, while the tertiary sector participation was about 65%. Thus, studying the firm level impact of natural disasters on these two sectors, we can carry out a comprehensive assessment of these effects on the gross economic activity.

#### *4.2.12 Manufacturing Sector*

We use monthly microdata for observations of firms' facilities from the monthly Survey of the Mexican Manufacturing Sector carried out by the National Institute of Statistics and Geography (INEGI, by its acronym in Spanish). This survey records monthly information at the firm level for different variables that measures the performance of every firm and every facility is identified by its location at the municipality level. In general, observations include all manufacturing facilities and excludes those dedicated to basic petrochemicals, oil refining, as well as those firms with less than fifteen workers. Since 2005 and onwards, the survey also incorporates manufacturing establishments dedicated to maquila and maquila export, and basic petrochemical and oil refining. The information at the firm level in this survey represent about 80% of the gross value added of the manufacturing sector for the period 1994-2017.

For this period, this survey was updated three times with the Economic Census to improve the coverage of the surveyed activities and to better represent the states considered in the sample.[4] For period 1994-2005, observations came from the Monthly Industrial Survey

[4] For all surveys, the sampling design was a four-step based selection process of manufacturing firms' facilities based on reported revenues and employed personnel as their main selection variables. In the first stage, within a number of economic activities (North American Industrial Classification System, NAICS, 6-digit industry class group) establishments with the highest reported revenue value and employed personnel) are deterministically selected. In the second stage, a quota sampling procedure for each industry class group of firms representing above 80% of the value of revenues in the Economic Census are selected. In the third stage, establishments with 300 or more employed personnel and not selected in the previous sampling procedure were included. In the fourth stage, for highly concentrated within industry class groups, all

(*Encuesta Industrial Mensual*, EIM, by its acronym in Spanish) that considers 205 class groups (NAICS 6-digit activities) with a 6,867 firms' facilities sample. Microdata for the period 2005-2006 were obtained from the Expanded Monthly Industrial Survey (*Encuesta Industrial Mensual Ampliada*, EIMA, by its acronym in Spanish) that considers 230 class groups and a sample size of 7,238 economic units. Finally, firms' facilities data for 2007 and onwards were from the Monthly Survey of Manufacturing Industry class (*Encuesta Mensual Industrial Manufacturera*, EMIM, by its acronym in Spanish), with a sample of 11,406 firms sample representing 240 class activities (NAICS 6-digit class groups).

For the complete period, the survey has an unbalanced panel structure that contains information about 18,000 firms that are geographically distributed through all states and 578 municipalities of the country. However, 19 of 32 states show an important manufacturing profile: Aguascalientes, Coahuila, Chihuahua, Mexico City, Guanajuato, Jalisco, Estado de Mexico, Nuevo Leon, Puebla, Queretaro de Arteaga, San Luis Potosi, Sonora and Veracruz Baja California, Durango, Morelos, Sinaloa, Tlaxcala and Yucatan, most of these states located at the North and Center of the country.

Thus, the final database was an unbalanced panel composed of 18,511 establishments with different periods of observation. A total of 2,542 establishments had a complete sample of 288 observations.

#### *4.2.13 Services Sector*

For microdata of the services sector, we use the Monthly Services Survey (EMS, by its acronym in Spanish) with microdata information at the firm level for the period 2008-2015. The EMS covers 105 NAICS 6-digit class groups that represent about 85% of the revenue value reported at the Economic Census 2004 and it collects information from the non-financial services, excluding services related to insurance services, corporate management and agricultural, forestry and mining activities, public sector activities and government, international and extraterritorial organizations, unions, and non-profit units.[5]

The total sample includes an unbalanced panel of 7,465 establishments that represent 105 economic classes. The sample has a total of 4,921 firms with a complete period of 95 observations. We ruled out information of all establishments with less than 12 observations Thus, the final sample included 6,887 establishments across the country with different

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establishments were incorporated. Finally, under this design the sampled establishments represent about 70-80% of the valued added for all industry class groups.

[5] The sampling methodology of the EMS considers: fist, a complete census of all firms in 45 NAICS 6-digit level class groups. Second, a high level of representativeness for 45 classes by a quota sampling procedure that includes all establishments that by its level of revenue represent above 80% of the value of revenues in the class. Third, medium level of -representativeness for 12 classes by a random selection process for each class representing a range of 70- 80% of the value of revenues.

periods of observations. Table 6 summarize some of the main characteristics of the surveys used in this study by sector.

**Table 6**
**Summary of Surveys**

| | Survey | Period | NAICS 6-digit | Firms | Observations per Firm Minimum | Observations per Firm Maximum |
|---|---|---|---|---|---|---|
| **Manufacturing** | | | | | | |
| | EIM | 1994-2008 | 205 | 6,867 | 12 | 168 |
| | EIMA | 2005-2010 | 230 | 7,238 | 12 | 72 |
| | EMIM | 2007-2017 | 240 | 11,406 | 120 | 12 |
| **Services** | | | | | | |
| | EMS | 2005-2015 | 105 | 7,465 | 1 | 95 |

Source. INEGI, Microdata Laboratory.

Table 7 shows some variables of the surveys that will be considered for the model estimation. Surveys of manufacturing focuses on production values, worked hours and remunerations, while surveys for firms in the services sector are focused on revenues, remunerations and remunerations.

**Table 7**
**Descriptive Statistics of Variables for the Analysis**

| Variable | Survey | Mean | Std. Dev. |
|---|---|---|---|
| Employed Personnel (Persons) | EMS 2008-2015 | 217 | 2,151 |
| Remunerations (Millions pesos) | EMS 2008-2016 | 2.69 | 24,900,000 |
| Revenues (Millions pesos) | EMS 2008-2017 | 79,435 | 1,671,517 |
| Operational Expenses (Millions pesos) | EMS 2008-2018 | 3.60 | 71,400,000 |
| Worked hours by employed personnel | EIM 1994-2008 | 46 | 46 |
| Remunerations (Millions pesos) | EIM 1994-2008 | 2,103 | 3,199 |
| Employed Personnel (Persons) | EIM 1994-2008 | 235 | 236 |
| Value of production (Millions pesos) | EIM 1994-2008 | 25,999 | 72,036 |
| Worked hours by employed personnel | EIMA 2005-2010 | 43 | 46 |
| Employed Personnel (Persons) | EIMA 2005-2010 | 218 | 235 |
| Value of production (Millions pesos) | EIMA 2005-2010 | 38,237 | 93,736 |
| Worked hours by employed personnel | EMIM 2007-2017 | 49 | 55 |
| Employed Personnel (Persons) | EMIM 2007-2017 | 249 | 281 |
| Value of production (Millions pesos) | EMIM 2007-2017 | 40,514 | 106,819 |

Source: EIM, EIMA, EMIM, INEGI, Microdata Laboratory.

## 5. Model Specification

Because tropical cyclones are random realizations of complex ocean and atmospheric systems, the stochastic timing, direction and their strength allows identifying the causal effect on an output variable using quasi-experimental techniques (Angrist and Pische, 2008). In this paper, we exploit tropical cyclones' random intensity and trajectory month to month within municipality variation in intensity and trajectories and we assume that our exposure measure variable, maximum sustained wind, is exogenous and uncorrelated as in Deschenes and Greenstone (2007). Following Hsiang and Narita (2012), tropical cyclones exposure is based on normalized measure of 10 meters maximum sustained wind and the resulting observations at the municipality level capture physically differentiated effect in municipalities. Since intensity across storms is not spatially correlated with the dynamic of the economic activity, this means that no correlation exist between the most frequently affected regions are also the most economically active municipalities.

However, as other authors suggest, temperature and precipitation are correlated with patterns of tropical cyclone exposure over time (see Hsiang, 2010; Auffhammer, 2014; Auffhammer, Hsiang, Schlenker and Sobel, 2013). Some authors have focused on studying the influence of tropical cyclones on rainfall in Mexico, they found that some regions of Mexico receive an important rainfall contribution from tropical cyclones like the Baja California Peninsula in the Northwestern region that receive between 55 and 60% of the total mean annual precipitation from this source; also, the Central Northern Pacific coasts and the Yucatan Peninsula that present an non-minor contribution about 20% (Brenia-Naranjo, et al., 2015). In consequence, the influence of tropical cyclones on economic activity must consider as controls climate variables of temperature and precipitation in order to avoid that the omitted variables bias in the response estimate.

Given the structure of our data, we can estimate the causal effect of the tropical cyclones and other climatic variables on the output variables of the firm as dependent variables using a multivariate panel and the differences-in-differences approach for modeling first differences logarithm. For manufacturing firms, the dependent variables that we model are: i) production index; ii) worked hours and iii) real remunerations per worker. For firms of services, the dependent variables are: i) real revenues; ii) remunerations per worker and iii) operative expenses.

As in the model of Hsiang and Jina (2014), we use an Augmented Distributed Lagged Autoregressive Model using Ordinary Least Squares (OLS)

$$\begin{aligned}\Delta\ln(FirmOutput_{i,\mathrm{j},t}) \\ = \alpha_i + \sum_{M=0}^{4}[\beta_{iwind}Wind_{j,t-M} + \beta_{iT}Temp_{j,t-M} + \beta_{iR}TC\_Rain_{j,t-M}] + \rho_t \\ + \mu_j + \gamma_{ij}xt + \eta_{jt} + \lambda_t \mathrm{S} + \varepsilon_{ijt} \qquad (1)\end{aligned}$$

For firm $i$ in municipality j and month t; the $\beta_{windi}$ stands for the coefficients of the variables of interest that meaning the marginal effects of the tropical cyclones exposure; $\beta_{iTemp}$ are the marginal effects of average temperature on output of the firm; $\beta_{iT}$ is the marginal effect of cumulative rain when a tropical cyclones is present; $\alpha_i$ stands for the establishment fixed-effect, $\rho_t$ is a month and year fixed-effect that controls stationarity patterns of the month and year affecting the economic activity, $\mu_j$ are municipality fixed-effects, $\gamma_{ij}$ are municipality specific trends for each firm that captures the heterogeneity in the growth trend of every municipality and time; $\lambda_t$ controls for specific dynamics of the subsectors of economic activity (3-digit SCIAN) and, finally $\varepsilon_{i,j,t}$ is the error term of the model.

The $\text{Wind}_{i,t}$ exposure measures the cumulative exposition to the 10-meters-sustained wind in every point of its trajectory for every municipality $j$ in the period $t$. Under this setup, the coefficients of interest are the $\beta_i$, which represent the derivatives on the output variable respect to fluctuations on tropical cyclones exposure and climate variables at the municipality $j$ and $t$ months after the shock.

### *5.1 Results of the Manufacturing Sector*

In this section, we show the results of the estimations performed for the manufacturing establishments located in municipalities that show high recurrence of tropical cyclones in its territory for the period 1994-2017. Presumably maquila export industry class firms may not be present for the period 1994-2004. Table 4 presents the cumulative effects of tropical cyclones on the production index, real remuneration per worker and employed personnel for the firms in the manufacturing sector relative to a firm situation before the event baseline trend.

**Table 8**

**Marginal Cumulative Effects of Sustained Wind of Tropical Cyclones (m/s) on Manufacturing Establishments for Highly Vulnerable Municipalities, 1994-2017**

| | Production Index 2008=100 | Real Remuneration per worker | Worked Hours by Employed Personnel |
|---|---|---|---|
| $Tcyclones_{t}$ | 0.056 ** | -0.053 | 0.042 *** |
| $Tcyclones_{t-1}$ | -0.114 *** | -0.896 *** | -0.033 *** |
| $Tcyclones_{t-2}$ | -0.013 *** | -2.033 *** | 0.018 *** |
| $Tcyclones_{t-3}$ | -0.025 | -2.241 | 0.016 |
| $Tcyclones_{t-4}$ | 0.050 * | -2.186 | 0.031 |
| $Tcyclones_{t-5}$ | 0.108 * | -2.904 * | 0.052 *** |
| $Tcyclones_{t-6}$ | 0.030 | -2.773 | 0.046 |
| $Tcyclones_{t-7}$ | 0.001 | -3.599 * | -0.017 |
| $Tcyclones_{t-8}$ | 0.149 * | -3.951 | 0.095 |
| $Tcyclones_{t-9}$ | 0.095 | -4.050 | 0.050 |
| $Tcyclones_{t-10}$ | 0.063 | -4.433 | 0.040 |
| $Tcyclones_{t-11}$ | 0.191 | -4.454 | 0.071 |
| $Tcyclones_{t-12}$ | 0.205 | -4.596 | 0.045 |
| FE, YE, ME | Y | Y | Y |
| State trends | Y | Y | Y |
| NAICS 3-digit | Y | Y | Y |
| Observations | 704,024 | 369,666 | 640,343 |

Source: Authors' estimations using the using the Monthly Industrial Survey (1994-2005), the Extended Monthly Industrial Survey (2005-2006) and the Monthly Survey of Manufacturing Industry class (2007-2017).
In these estimations, we controlled for mean temperature and cumulative precipitation by municipality, industry class specific trends (2-digit SCIAN activities), state-time-specific constants, month-specific constants and year-specific constants.
The high exposed municipalities are located in the following entities: Baja California Sur, Colima, Guerrero, Jalisco, Michoacan, Nayarit, Oaxaca, Puebla, Quintana Roo, Sinaloa, Tamaulipas, Veracruz and Yucatan.
***P < 0.01, **P < 0.05, *P < 0.1 stands for statistical significance at 1%, 5% and 10%, respectively; standard errors are robust to spatial correlation by state. Estimates for monthly temperature and cumulative precipitation are available upon request to the authors.

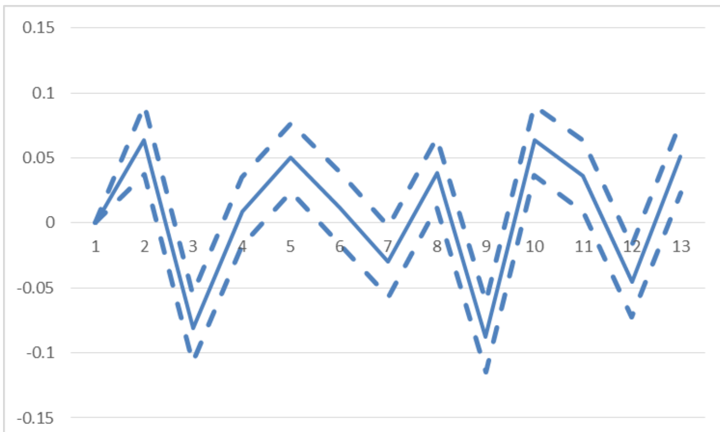
Column 1 in Table 5 shows the estimates of the cumulative effect of tropical cyclones wind exposure on establishments' production index 2008=100. We found statistically significant positive effect of 0.06 percentage points (pp) in the production index for every percentage point increase exposure to maximum sustained winds of tropical cyclones. This effect turns to negative for the first and second months after the shock, 0.11 and 0.01 respectively. After the fourth month, the effect changes to positive and statistically significant for the fifth month and the eight month.

In the second column, we can observe the most negative effect on the real remuneration per worker of the maximum sustained winds of tropical cyclones at the establishment level.

The magnitude of the effect is large, even after one month of the shock, given an increase of 1 additional m/s of maximum sustained wind exposure the real remunerations per worker decrease in 0.90 percentage points one month after the shock, for the second period after the shock, the real remunerations per worker decrease 2.2 p.p. and this magnitude increases every month and is statistically significant for the period 5 and 7 after the shock.

Finally, for the worked hours for the personnel, the evidence is mixed because the contemporaneous month is positive in 0.04 pp. and then one month after the shock the effect turns to negative and in the second month after the shock becomes positive.

**Figure 6**
**Long-Run Multiplier for Production Index**




Source: Own elaboration using the EMS microdata from INEGI.

### *5.2 Results of the Services Sector*

Table 9 shows the estimated effects of tropical cyclones on firms of the services sector for the output variables in municipalities of high recurrence of tropical cyclones. The variables analyzed are: revenue index, real remunerations per worker and operative expenses.

**Table 9**

**Marginal Cumulative Effects of Services Establishments of Sustained Winds (m/s) of Tropical Cyclones for Highly Vulnerable Municipalities 2008-2015**

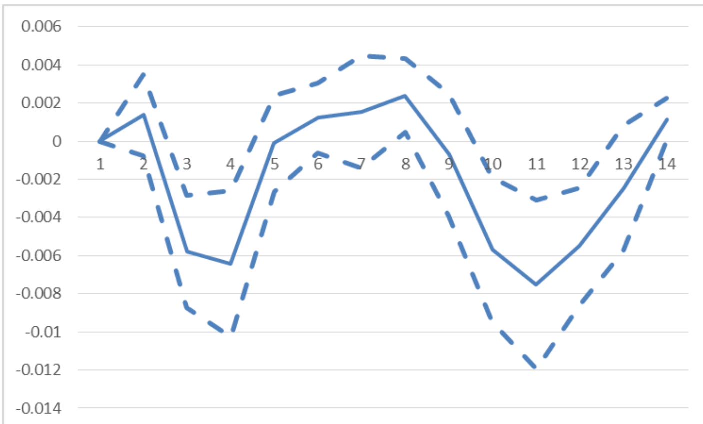
| | Revenue Index 2008=100 | Remunerations per worker | Operative Expenses |
|---|---|---|---|
| $Tcyclones_t$ | 0.001 | -0.014 | -0.026 |
| $Tcyclones_{t-1}$ | -0.004 *** | 0.005 | -0.120 ** |
| $Tcyclones_{t-2}$ | -0.011 *** | -0.037 | 0.057 *** |
| $Tcyclones_{t-3}$ | -0.011 | -0.044 | 0.064 |
| $Tcyclones_{t-4}$ | -0.010 | -0.058 | -0.026 * |
| $Tcyclones_{t-5}$ | -0.008 | -0.023 | 0.077 |
| $Tcyclones_{t-6}$ | -0.006 * | -0.012 | -0.002 |
| $Tcyclones_{t-7}$ | -0.007 | 0.015 | -0.090 |
| $Tcyclones_{t-8}$ | -0.012 *** | 0.001 | 0.030 |
| $Tcyclones_{t-9}$ | -0.020 *** | 0.033 | -0.033 |
| $Tcyclones_{t-10}$ | -0.025 *** | 0.014 | -0.298 |
| $Tcyclones_{t-11}$ | -0.028 | -0.012 | -0.261 |
| $Tcyclones_{t-12}$ | -0.027 * | -0.006 | -0.256 |
| FE, YE, ME | Y | Y | Y |
| State trends | Y | Y | Y |
| NAICS 3-digit | Y | Y | Y |
| Observations | 200,172 | 155,697 | 190,345 |

Source: Authors' estimations using the using the Monthly Services Survey (2008-2015).
We controlled for mean temperature and cumulative precipitation by municipality, sector specific trends (2-digit SCIAN sector), state-time-specific constants, month-specific constants and year-specific constants.
The high exposed municipalities are mainly located in the following entities: Baja California Sur, Colima, Guerrero, Jalisco, Michoacan, Nayarit, Oaxaca, Puebla, Quintana Roo, Sinaloa, Tamaulipas, Veracruz and Yucatan.
***P < 0.01, **P < 0.05, *P < 0.1 stands for statistical significance at 1%, 5% and 10%, respectively; Standard errors are robust to spatial correlation by state.. Estimates for monthly temperature and cumulative precipitation are available upon request to the authors.

As expected, we observe a consistent negative effect on the revenue index, every additional month after the shock up to the fourth month is more negative; however, only 7 of 13 periods of time are statistically significant: one, two, six, nine and ten months after the shock. Effect increases from -0.004 pp. in the first moth after the shock to 0.01 pp. two months later, and then the effect loose magnitude and recovers again in the eight month after the shock.

In the second column are the effects of tropical cyclones on Real remunerations per worker. Even when these are consistently negative up to the sixth periods after the shock, they are not statistically significant. Third column of Table 6 shows the effects maximum sustained winds of tropical cyclones on operative expenses of the establishments, which show a negative impact during the contemporaneous and the first month after the shock. Thus, one pp. increase in maximum sustained wind speed of tropical cyclones exposure decreases by 0.12 pp. the growth of operative expenses. This result might be a direct consequence of a fall in the activity since the firms will need fewer inputs because they may reduce their scale operation after the shock of a TC.

**Figure 7**
**Long-Run Multiplier for Revenue Index**




Source: Own elaboration using the EMS microdata from INEGI.

## 6. Conclusions

In this paper, based on the identification properties of tropical cyclones, we estimate their effects on economic activity taking advantage of a more disaggregated set of information for one of the most exposed countries in the world. In Mexico, tropical cyclones are one of the primary causes of economic losses and large scale damage in infrastructure. The importance of this research relies on the positive relationship between global warming and severity of TC, so the expectation of deeper climate change rises concern about their policy challenges for supporting adaption and economic resilience in the most vulnerable areas.

In this context, using data of TC's trajectories from IBTrACS for both basins neighboring Mexico, we found about 769 municipalities show the highest levels of exposure. Nevertheless, the North Atlantic basin has been showing an increasing trend in the severity of hurricanes. The most exposed municipalities are mostly located in coastal states of the EP shore like Baja California Sur, Jalisco, Colima, Michoacan, Guerrero and Oaxaca an in the North Atlantic shore in Veracruz, Tabasco, Campeche, and Quintana Roo. Some of these states, in both shores, have the lowest levels of economic development.

All our findings are consistent with the international evidence (Hsiang, 2010; and Hsiang and Jina 2014). In Mexico, we found that firms from manufacturing and services show negative effects of tropical cyclones exposure. However, the impacts appear to be transitory since it disappears one year after the shock, depending of the sector. For an average firm of the manufacturing sector, the exposure to tropical cyclones, measured by the maximum sustained winds, generates negative and more persistent effects on production and real remuneration per worker. Thus, we observe increasing negative and persistent effects on firms of manufacturing sector. In contrast, services establishments show a short-run negative sensitivity in revenue but low persistence.

Even when our results are statistically significant, and show the expected signs, the structure of the data imposes some limitations in terms of the attrition of the sample, which is common in this kind of surveys, however, this issue could limit the validity of our results. For future research, it is imperative to incorporate in the analysis the effect of the attrition on the results and carry out other specifications that allow to exploit the heterogeneity contained on the data base since NAICS 3-digit level industry has statistical representativeness in manufacturing and NAICS 3-digit level activities in services has the same statistical validity. Also, it is important to estimate adaptation effects of the tropical cyclones in the economic activity, in order to identify the most effective strategies to increase the economic resilience of the states and locations. Finally, as an extension, it would be interesting to incorporate the climate change scenarios in to the estimations of impact for dimensioning the possible future risks.

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