STORMS, CLIMATE CHANGE, AND THE US ECONOMY: A REGIONAL ANALYSIS

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Abstract:
Climate change models predict that storm frequency should decrease over time, while storm intensity should increase. This paper looks at the region specific effects of storm frequency and storm intensity on various industries in the US economy, using yearly data from 1977 through 1997. The results indicate that a 7% predicted decrease in storm frequency results in a $279.7 million loss for the farm industry, but that effect is limited to the states in the southern region of the US. Also, a 6% predicted increase in storm intensity leads to a projected loss of $586.4 billion in retail trade in states in the northeast, and a total loss of $12.3 billion for a number of manufacturing sectors in southern states. Finally, the predicted 6% increase in storm intensity benefits the health services sector by $412.2 billion in the Midwestern states. The impacts of the predicted change in storm intensity are much stronger than those of storm frequency.The region specific impacts of predicted storm changes add up to 2.3% of the US economy in 1997. Thus, the economic effects of storms on the US economy are not negligible.
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1. Introduction

Climate change models predict that a rise in temperature will be accompanied by changes in precipitation amounts and patterns, changes in atmospheric concentrations of carbon dioxide and rises in sea levels. Moreover, climate change theory suggests that as the planet becomes warmer, year-round storm frequency should decline,

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and storm intensity should increase[1]. While studies of the economic impacts of climate change have focused on the effects of the rise in temperature, changes in precipitation, changes in atmospheric concentrations of carbon dioxide and rises in sea level on various sectors of the economy, few other studies[2] have looked at the economic impact of changes in year-round storm frequency and intensity. The current study follows up on Saad-Lessler and Tselioudes (2008), but we focus on the regional impacts of changes in storm frequency and intensity.

This study estimates the regional impact of changes in year-round storm frequency and intensity on the US economy, using a data set created at the NASA Goddard Institute for Space Studies (GISS) on the year-round frequency and intensity of storms in the continental US from 1961 through 1998[3]. We pair the storm data with data on gross state products by industry from 1977 through 1997, from the Bureau of Economic Analysis. We estimate the regional effects of year round storm frequency and intensity on each industry's gross state product, conditional on state and year fixed effects.

We find that yearly deviations in storm frequency and intensity around their averages have a statistically significant regional effect on the gross state products of a number of industries. We use these estimated impacts to calculate the regional costs of the changes in storm frequency and intensity that are predicted by climate change models. The results imply that a predicted drop in storm frequency of 7% results in a $279.7 million loss for the farm industry, but that effect is limited to the states in the southern region of the US. Also, the predicted increase in storm intensity leads to a

[1] Population and Development Review (2001) provides a summary of climate change predicted effects.

[2] Nordhaus(2006) looks at the impact of hurricane characteristics on hurricane damages. Saad-Lessler and Tselioudes (2008) evaluate the national impacts of changes in year round storm frequency and intensity in the continental US.

[3] The storms included are rain or snow storms that occur all year round all over the US. The data does not include hurricanes, which only impact coastal areas of the US.

projected loss of $586.4 billion in retail trade in states in the northeast, and a total loss of $12.3 billion for a number of manufacturing sectors in southern states. Finally, the predicted increase in storm intensity benefits the health services sector by $412.2 billion in the Midwestern states. The impacts of the predicted change in storm intensity are much stronger than those of storm frequency.

The regional impacts of the predicted storm changes add up to 2.3% of the US economy in 1997. Thus, the regional economic effects of storms on the US economy are significant. However, since our analysis does not take into account the adaptation measures that businesses undertake to minimize the costs of climate change, our predictions overestimate the true costs of changes in storm conditions due to climate change.

In the next section, we go over the relevant literature in this field. Section two sets up the empirical model. Section three describes the data, section four discusses the results and section five concludes.

2. Literature

There is a growing literature on the economic effects of climate change. One approach used in this literature is to model the production function of a particular sector of the economy, listing explicitly the various inputs and outputs in production based on empirical evidence. Temperature, precipitation, and other aspects of the climate enter the model as inputs. The economic effects of climate change are then estimated by comparing the output of the sector with and without the warming scenario. Studies that use this methodology include Sohngen and Mendelsohn (1999), Adams et al (1999), Hurd et al (1999), Yohe et al. (1999), and Lee D. and Lyon K. (2004). One of the problems with this method is that it can only take into consideration the factors explicitly included in the model. This misses any adaptation mechanisms that are undertaken in the face of changing weather conditions. Moreover, this method assumes that results derived in a lab setting apply in other settings as well. This may not always be correct.

An alternative approach to calculating the economic effects of climate change is to compare the economic performance of industries across geographic areas with different climates. This cross sectional approach works like a natural experiment, and it has been employed in such studies as Mendelsohn, Nordhaus and Shaw (1994), and Mendelsohn and Dinar (2003). The problem with this method is that researchers have to control for all other differences between geographic locales that can lead to differences in outputs. As a result, estimates derived from this method often suffer from omitted variable bias.

Yet another method for deriving the economic effects of climate change is to compare the economic performance of an industry over time, for a particular geographic location. Studies that use such time series data include Cammarota (1988), and Starr-McCluer(2000). One difficulty encountered in such studies is that there must be enough variation in weather over the span of the data to be able to identify the effects of weather changes on the economy. An additional problem is that the findings of such studies do not necessarily generalize to other geographic locations.

A fourth approach, utilized recently by Deschenes and Greenstone (2004) and Galeotti, Goria, Mombrini and Spantidaki (2004), uses cross sectional-time series data. This improves on the cross sectional approach by allowing the inclusion of year specific and locale specific fixed effects into the analysis. The fixed effects absorb all year specific and locale specific differences between the geographic areas. This limits the potential for omitted variable bias. However, it also limits the analysis to yearly deviations in industry outputs and in climate from their year specific and locale specific averages. This does not allow the analysis to capture the effects of longer term changes in climate, and it therefore misses the behavior adaptation measures that business undertake over time in the face of permanent changes in weather. Therefore, the estimates that result from this method overestimate the true costs of climate change.

In the current study, we look at the regional impacts of changes in year round storm frequency and intensity on the US economy, using cross sectional-time series data. In order to make use of both the cross sectional and the time series dimensions of the data, we use the same method utilized by Deschenes and Greenstone to identify the effects of storms on the economy. The same caveats with respect to overestimating the true costs of climate change apply.

2. Theory and Empirical Specification

We measure the regional effects of year round storm frequency and intensity on US industries by comparing the log of gross industry product across states with different storm conditions within a region, and over time. We model the impact of storm conditions on gross industry product using a quadratic specification, following the lead of other research in the field, and for the sake of simplicity in interpretation. We control for state specific fixed effects, to account for permanent differences across states in the frequency and intensity of year round storms they face, as well as in the level of gross industry product they produce. We also allow for year specific effects, to account for years when year round storm activity was unusually high or low for all states, or when gross industry product was unusually high or low for all states. The equation is run separately for each industry and region, yielding a separate estimated impact of storm frequency and intensity for each industry and region[4]. Since the analysis is done separately for each region, the year effect is really a region-year specific effect.

Because we include in our specification region-year effects and state effects, the dependent variable is transformed into the deviation of gross industry product from its state specific and region-year specific average, and the independent variables become the deviation of storm frequency and intensity from their state specific and region-year specific averages.

We add to the regression equation state level variables, like the fraction of the state that is urban[5], the educational and age distribution of the state's population[6], the size of the state's

[4] The same equation is run at the national level in Saad-Lessler and Tselioudes (2008). We add to the national equation regional dummy variables interacted with the storm variables and test whether the regional coefficients are jointly significant. Results are in table A of the annex, and they show that the regional coefficients are jointly significant. Therefore, the regional analysis generates results that are statistically different from the national coefficients.

[5] Urban status refers to being in a central city, or outside the central city (as opposed to not being in a metro area at all).

[6] Educational distribution: fraction of the state's population who have a high school degree or less, fraction of the state's population who have a college

population[7], and the fraction of the population who are unemployed in the state[8]. These variables capture aspects of each state's labor market, and including them ensures that the storm frequency variables are not picking up the effects of changes in a state's labor market on changes in gross product (in case the changes in storm conditions are spuriously correlated with changing labor market conditions).

We use the following specification:

$$\begin{aligned}(1)\quad \ln GP_{ist} &= \alpha_{ris} + \delta_{rit} + \beta_{ri} Frequency_{st} + \gamma_{ri}\left(Frequency_{st}\right)^2 \\ &+ \lambda_{ri} Intensity_{st} + \phi_{ri}\left(Intensity_{st}\right)^2 + \sum_{j=1}^{10} \pi_{rij} * Z_{jst} + \varepsilon_{ist}\end{aligned}$$

where ln GP_{ist} refers to the log of gross product for a particular industry *i*, in state *s*, in year *t*. Z_{jst} , j=1,…,10, refers to the 10 state level variables. α_{ris} is the parameter of a dummy variable that captures the state fixed effect for each industry, and δ_{rit} is a dummy variable that absorbs the region-year fixed effect for each industry. *r* refers to geographic region and ε_{ist} is an error term.

Because we work with the yearly fluctuations of storm conditions around their averages, our analysis captures the adaptation mechanisms that businesses undertake during the course of a year, but it misses any long term adaptation mechanisms that occur over many years. Therefore, our cost estimates overshoot the true economic costs of long term changes in storm conditions due to climate change. In this paper, we assume that each state is a price

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degree, fraction of the state's population who have more than a high school degree, but less than a college degree. Age distribution: fraction of the state's population over age 16 who are aged 16-25 (age group 1), fraction of the state's population over age 16 who are aged 26-50 (age group 2), fraction of the state's population over age 16 who are aged 51-65 (age group 3), fraction of the state's population over age 16 who are aged 66+ (age group 4).

[7] Civilian population refers to any person who is an adult civilian, not a child, and not in the armed forces.

[8] We limit the labor force to those aged 18-65 when computing the fraction of people who are unemployed.

taker in a regional goods market. Any changes in goods prices occur for all states within a region at the same time. Therefore, any change in prices would be absorbed in the region-year specific fixed effect that we include.

3. Data sources and summary statistics

3a. The data.

The data in this study comes from two sources. The economic data is data on gross product, by state, and by industry. This data is collected annually from 1977 through 1997, and it is available for each industry, defined down to the 3 digit SIC level. Data on storm frequency and intensity come from the National Center for Environmental Prediction analysis of meteorological conditions. The frequency and intensity of storms are tracked monthly from 1961 through 1998, for each geographic unit.

The geographic units are small grids, defined by longitude and latitude. In order to conduct the analysis on the level of US states, the geographic units were matched to states. The data is available for the 48 contiguous states (Hawaii and Alaska are excluded). We convert the monthly storm data into annual form by summing storm frequency over the months in a year, and by taking the average storm intensity over the months of that year. In order to work with both data sources, we limit the analysis to the years 1977 through 1997. We define four regions of the country[9].

It is important to note that in this study we examine only rain and snow storms that are known as fronts and occur mostly in the winter. We do not examine the effects of tropical storms that affect mostly the southern states and occur in the late summer and early fall. We also do not include hurricanes[10].

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[9] These are Region 1: North East: CT,ME,MA,NH,RI,VT,NJ,NY, PA. Region 2: Mid West: IL,IN,MI,OH,WI,IA,KS,MN,MO, NE,ND,SD. Region 3: South: DE,FL,GA,MD,NC,SC,VA, WV,AL, KY, MS, TN, AR, LA, OK,TX. Region 4: West: AZ,CO,ID,MT,NV,NM,UT,WY,CA,OR,WA.

[10] For more discussion of this issue, refer to the scientific background provided in the annex.

3b. Summary statistics

Our analysis identifies the regional effect of year round storm frequency and intensity on the US economy using the variation of storm frequency and intensity across states within a region and over time. The more variation in storm frequency and intensity across states and over time, the more precise will be our estimates. Table 1 lists the average storm frequency and storm intensity values for each state over the years in the sample. The table also displays the quartile of such values relative to other states. Thus, we find that a state like New York is in the highest quartile for storm frequency, but in the lowest for storm intensity (many low level storms), whereas Florida gets among the lowest numbers of storms, but those it gets tend to be very intense. This table shows that indeed, states do differ substantially in their storm characteristics, and therefore, there is a lot of variation with which we can work.

Table 1.

State	Average Storm Frequency	Frequency quartile	Average Storm Intensity	Intensity Quartile
Region 1: North East				
CT	8.1	3	999.4	1
ME	12.6	4	997.0	1
MA	11.7	4	998.9	1
NH	13.8	4	998.1	1
NJ	8.3	3	1000.7	2
NY	9.5	4	999.8	1
PA	8.0	3	1000.6	2
RI	9.1	3	999.2	1
VT	10.7	4	998.3	1
Region 2: Mid West				
IL	8.6	3	1001.8	3
IN	9.2	4	1002.1	3
IA	8.7	3	1000.4	2
KS	10.1	4	1001.4	2
MI	11.5	4	1000.0	1
MN	9.0	3	999.1	1
MO	8.4	3	1002.1	3

NE	10.4	4	1000.1	2
ND	9.9	4	999.5	1
OH	6.6	3	1001.3	2
SD	8.6	3	999.9	1
WI	11.3	4	999.9	1
Region 3: South				
AL	2.8	1	1003.9	4
AR	4.5	2	1003.5	4
DE	6.7	3	1001.4	2
FL	1.5	1	1028.0	4
GA	2.8	1	1003.5	4
KY	4.9	2	1002.7	3
LA	3.0	1	1003.7	4
MD	5.6	2	1001.5	2
MS	2.9	1	1003.9	4
NC	4.7	2	1003.4	3
OK	6.8	3	1002.9	3
SC	3.1	1	1002.6	3
TN	3.7	1	1003.5	4
TX	6.1	2	1003.7	4
VA	5.4	2	1003.0	3
WV	5.2	2	1002.5	3
Region 4: West				
AZ	2.4	1	1005.6	4
CA	1.7	1	1005.6	4
CO	7.1	3	1045.9	4
ID	3.5	1	1002.2	3
MT	6.3	2	1000.7	2
NV	4.0	2	1004.0	4
NM	5.1	2	1003.1	3
OR	2.3	1	1001.6	2
UT	4.2	2	1002.4	3
WA	2.2	1	1000.3	2
WY	6.3	2	1001.0	2

* Storm numbers are an average for each state 1977-1997.

Moreover, an analysis of residuals from a regression of storm frequency (intensity) on year and state dummies shows that the residuals vary over time for each state, indicating that in fact, these deviations in storm values are random[11].

4. Results

We regress equation (1) using OLS, with robust standard errors. The regression is run separately for each industry in every region. The number of observations for each regression depends on the number of states that comprise each region, and how many of those states have such an industry. Since some industries, like mining, are only found in a small number of states, the number of observations for those sectors dips below the regional average number of observations.[12]

The effect of a change in storm frequency on the log of gross product depends on □□frequency and □frequency^2, and the effect of a change in storm intensity on the log of gross product depends on □intensity and intensity^2. Because of the quadratic form of these effects, their calculated value depends on the storm frequency/ intensity we use as the baseline value. We use the mean regional storm frequency/ intensity realization over the years in the sample as the baseline value for constructing the regional storm effects on the log of gross product.

Climate change theories predict that over the next 100 years, there may be approximately a 7% decrease in storm frequency, and a 6% increase in storm intensity. We run equation (1) for each region separately, and we use the region specific coefficients to calculate the effects of a 7% decrease in the mean *regional* realization of storm frequency, and of a 6% increase in the mean *regional* realization of storm intensity. Then, we multiply the region specific predicted effect for each industry by the regional value of gross product for that industry in 1997, to translate the predicted effects into dollar figures. This allows us to derive the expected costs to each region of the US economy of a change in storms due to climate change.

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[11] For more detail, refer to table B in the Annex

[12] For a listing of the number of observations for each industry by region, look at table C in the annex.

We also construct standard errors for these predicted effects (PE), using the following formula:
Standard Error (PE) = PE/F, where F is the F statistic for a test that PE=0. The calculated standard errors allow us to derive for each estimate a t-statistic and a level of statistical significance.

The costs of the predicted drop in storm frequency are listed in table 2, while the costs of the predicted increase in storm intensity are listed in table 3 (costs are in millions of $1996). In the interest of saving space, we only include results from industries that showed a statistically significant effect in at least one region. Industries are referred to by code[13].

These results indicate that the predicted decrease in storm frequency results in a $279.7 million loss for the farm industry, but that effect is limited to the states in the southern region of the US.

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[13] Listing of Industries: Farms 1, Agricultural services, forestry, and fishing 2, Metal mining 3, Coal mining 4, Oil and gas extraction 5, Nonmetallic minerals, except fuels 6, Construction 7, Lumber and wood products 8, Furniture and fixtures 9, Stone, clay, and glass products 10, Primary metal industries 11, Fabricated metal products 12, Industrial machinery & equipment 13, Electronic and other electric equipment 14, Motor vehicles and equipment 15, Other transportation equipment 16, Instruments and related products 17, Miscellaneous manufacturing 18, Food and kindred products 19, Tobacco products 20, Textile mill products 21, Apparel and other textile products 22, Paper and allied products 23, Printing and publishing 24, Chemicals and allied products 25, Petroleum and coal products 26, Rubber and misc. plastics products 27, Leather and leather products 28, Railroad transportation 29, Local and interurban pass. Transit 30,Trucking and warehousing 31, Water transportation 32, Transportation by air 33, Pipelines, except natural gas 34, Transportation services 35, Communications 36, Electric, gas, and sanitary services 37, Wholesale trade 38, Retail trade 39, Depository institutions 40, Non depository institutions 41, Security and commodity brokers 42, Insurance carriers 43, Insurance agents, brokers &services 44, Real estate 45, Holding and other investment offices 46, Hotels and other lodging places 47, Personal services 48, Business services 49, Auto repair, services, and parking 50, Miscellaneous repair services 51, Motion pictures 52, Amusement and recreation services 53, Health services 54, Legal services 55, Educational services 56, Social services 57, Membership organizations 58, Other services 59, Private households 60.

Table 2. Regional cost of predicted change in storm frequency

I	Region 1	Region 2		Region 3		Region 4	
1	-16.60	17.75		-279.72	**	-25.43	
7	-162.09	216.91	*	-557.20	*	-183.96	
9	0.52	24.48		-29.55	*	-9.00	*
10	9.47	19.98		-59.51	*	-15.98	
15	-6.84	-64.33		-277.28	*	-24.54	
19	118.44	-59.58		-126.82	*	-3.89	
24	29.52	-83.11		-62.03	*	-39.64	
25	-201.89	239.89	*	-233.85		-71.69	
30	5.26	-10.47		-12.04	*	-5.35	
32	5.37	14.08	*	-6.24		-30.08	
33	-4.52	82.65		48.88		-56.86	*
39	-73.91	-7.64		-421.92	*	-300.60	
40	-84.18	6.69		-244.57	*	-151.85	
43	57.56	-6.44		-2.39		-70.20	*
45	265.18	-46.91		-469.25		-601.22	*
50	-1.75	3.90		-7.74		-30.81	*
55	-55.03	-34.86		-78.47	*	-56.21	
57	-21.24	27.34	*	-7.75		-10.07	
58	-3.53	-15.29		6.88		8.97	*
Total[14]:	0.00	0.00		-279.72		0.00	

The logic behind this result is that an *increase* in storm frequency positively affects the farming sector, probably due to the accompanying precipitation. Since climate change theories predict there will be a 7% *reduction* in storm frequency, there will be a *loss* sustained by the farming sector compared with the non-climate change scenario. This finding is in line with other research, which also finds that farming benefits from increased precipitation. As for the fact that only farms in the southern region are affected, this is

[14] * indicates significance at the 5% level. ** indicates significance at the 1% level. Totals are only calculated for results that were significant at the 1% level.

related to the sensitivity of agriculture to precipitation changes in the southern states, which is a function of the types of crops that are grown in those states. As for storm intensity, its predicted increase leads to a projected loss of $586.4 billion in retail trade in states in the northeast. This result seems intuitive because when an intense storm hits an area, shoppers stay home.

Table 3. Regional cost of predicted change in storm intensity

I	Region 1		Region 2		Region 3		Region 4	
7	-160,750		280,244		-6,687	*	6,992	
10	2,820		27,029		-968	*	35	
11	-85,669		-173,013		-1,462	**	-1,034	
13	46,779		598,200		-5,006	**	2,859	
15	-110,393		815,297		-4,414	**	-439	
16	-172,277	*	180,184		-1,385	**	-177	
18	-2,423		41,914		-370	*	-93	
25	-51,164		-61,848		-555		3,654	*
36	-236,329	*	-171,634		-1,585		1,924	
38	-605,528		427,271	*	-3,204		4,204	
39	-586,377	**	397,485	*	-4,209		2,949	
40	-157,261		473,521	*	-2,227		1,460	
44	-51,086	*	43,279		-478		396	
45	-1,469,258	*	496,537		-3,412		4,416	
48	-43,631	*	2,769		-72		185	
53	-89,920	*	9,466		-470		1,598	
54	-46,160		412,172	**	-2,799		-1,945	
55	-28,886		57,321		-1,306	*	-680	
59	-315,332		335,672	*	-2,866		-1,664	
Total:-586,377			412,172		-12,267		0	

An increase in storm intensity benefits the health services sector by $412.2 billion in the Midwestern states. This could be because intense storms cause injuries that require medical attention. An increase in the number of patients due to an increase in storm intensity would result in an increase in the services provided by the health services sector. Finally, an increase in storm intensity affects a number of manufacturing sectors in southern states, resulting in a total loss of $12.3 billion. This result is also somewhat intuitive, because when there is an intense storm, factories stay closed, resulting in a loss of production.

Again, since industries are not identical across regions, it is likely that the same industry exhibits a different level of sensitivity to climate change depending on the geographic region it is in. Moreover, the theory states that there will be a 7% decrease in storm frequency, and a 6% increase in storm intensity for all regions of the mainland US. Since different regions have a different baseline level of storm frequency and storm intensity, the total predicted changes will vary in strength across regions. Both of these explanations clarify why storm effects vary by region.

Looking at the total effects of climate change, we find that the impacts of storm intensity are much stronger than the storm frequency effect. How large are these effects? If we add up all the damage estimates due to predicted changes in storm frequency and intensity, we get $598.9 billion in losses, and a benefit of $412.2 billion for the health sector. The total impact adds up to 2.3% of the US economy in 1997. Thus, the economic effects of storms on the US economy are significant.

5. Conclusion.

Climate change theory predicts that in the next 100 years, storm frequency should decrease by 7%, while storm intensity should increase by 6%. This paper looks at the regional effects of these predicted changes in storm frequency and intensity on various industries in the US economy. The results indicate that the predicted decrease in storm frequency results in a $279.7 million loss for the farm industry, but that effect is limited to the states in the southern region of the US. Also, the predicted increase in storm intensity leads to a projected loss of $586.4 billion in retail trade in states in the northeast, and a total loss of $12.3 billion for a number of manufacturing sectors in southern states. Finally, the predicted increase in storm intensity benefits the health services sector by $412.2 billion in the Midwestern states. The impacts of the predicted change in storm intensity are much stronger than those of storm frequency.The total impact adds up to 2.3% of the US economy in

1997. Thus, the regional economic effects of storms on the US economy are significant.In future work, we intend to look more closely at each specific industry in order to understand the estimated effects better.

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