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

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Abstract:

Climate change models predict that storm frequency will decrease over time, while storm intensity will increase. This paper looks at the national effects of storm frequency and storm intensity on various industries in the US economy, using yearly data from 1977 through 1997. We find that yearly deviations in storm frequency and intensity around their state specific and year specific averages have a statistically significant effect on the gross state products of a number of industries. We use these estimated impacts to calculate the national economic consequences of changes in storm frequency and intensity that are predicted by climate change models.

The results imply that a predicted drop in storm frequency leads to $5.6 billion in losses (0.07% of the US economy in 1997), while a predicted increase in storm intensity has no significant economic impact. Thus, though the effects of storms on gross industry product are statistically significant, their economic effects are small.

JEL classification code: Q51, Q54
Keywords: Climate change, Storm frequency, Storm intensity.

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, 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, no other study[2] has looked at the economic impact of changes in year-round storm frequency and intensity.

This study estimates the impact of changes in year-round storm frequency and intensity on the US economy, using a new 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 effect of year round storm frequency and intensity on each industry's gross state product, conditional on state, and year fixed effects. Thus, the storm

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

[2] A recent paper by Nordhaus (2006) estimates the effects of certain hurricane characteristics (such as wind speed) on hurricane damages.

[3] The storms included are rain or snow storms that occur all year round all over the US. The data does not include hurricanes, as discussed in the scientific background in the annex.

parameters are identified from deviations in storm conditions about their state specific and year specific averages.

Because we work with the yearly fluctuations of storm conditions around their averages, the analysis does not capture the effects of longer term changes in storm conditions. Typically, businesses alter their behavior to minimize any losses they face when they perceive a long term shift in storm conditions. To the extent that our analysis cannot address these adaptation mechanisms, our predictions will overestimate the true costs of changes in storm conditions due to climate change.

Since we focus on the variation in storm conditions about their year specific and state specific averages, and compare it with the variation of gross state product by industry about their year specific and state specific averages, it is unlikely that we encounter omitted variable bias[4]. However, we also run regressions that include state specific variables to ensure that our estimates are robust to any omitted variable bias.

We find that yearly deviations in storm frequency and intensity around their averages have a statistically significant effect on the gross state products of a number of industries. We use these estimated impacts to calculate the economic consequences 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% hurts the farming sector, the construction sector, the printing and publishing, trucking and warehousing, retail trade, depository institutions, auto repair, services and parking, and health service sectors. The predicted increase in storm intensity, however, has no impact the economy.

If we sum up all the damage estimates due to predicted changes in storm frequency, we get $5.6 billion in losses. The total impact adds up to 0.07% of the US economy in 1997. Thus, while the effects of storms on gross industry product are statistically significant, their economic effects are small.

In the next section, we go over the relevant literature in this field. Section two explains why storm activity may impact the economy and 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

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[4] If we conducted the analysis using levels of gross state product, we would be more likely to encounter omitted variable bias, because it is more difficult to include every possible determinant of the level of gross state product by industry.

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 impact of changes in year round storm frequency and intensity on the US economy. We use a cross sectional-time series data set on the frequency and intensity of year round storms in the US from 1961 through 1998, paired with data on gross state products by industry from 1977 through 1997. 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.

3. Theory and Empirical Specification[5]

There are many reasons to expect year round storm frequency and intensity to impact the economy. For example, storm frequency may affect the desire of consumers to shop, and therefore, we would expect storm frequency to impact retail trade. Storm frequency and intensity may affect the insurance industry since storm damage claims have to be paid out. Agriculture may be affected depending on the particular weather event – an ice storm would impact crops negatively, while a mild rain storm may be beneficial because it brings needed precipitation.

[5] For more scientific background on climate change and storm activity, refer to the annex

In this study, we wish to get an *initial* idea of how changes in year round storm frequency and intensity affect US industries. We measure the effects of year round storm frequency and intensity on US industries by comparing the log of gross industry product across states where different storm conditions prevail, 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. We use the following specification:

$$\begin{aligned}(1)\quad \ln GP_{ist} &= \alpha_{is} + \delta_{it} + \beta_i Frequency_{st} + \gamma_i \left(Frequency_{st}\right)^2 \\ &+ \lambda_i Intensity_{st} + \phi_i \left(Intensity_{st}\right)^2 + \varepsilon_{ist}\end{aligned}$$

where ln *GP* refers to the log of gross product for a particular industry *i*, in state *s*, in year *t*. α_{is} is a state specific dummy that captures the state fixed effect for each industry, δ_{it} is a year dummy that absorbs the year fixed effect for each industry, and ε_{ist} is an error term. Because we include in our specification year effects and state effects, the dependent variable is transformed into the deviation of gross industry product from its state specific and year specific average, and the independent variables become the deviation of storm frequency and intensity from their state specific and year specific averages. So, if a state experienced an unusually high number of storms relative to what it usually gets, and relative to what all other states got that year, this is associated with the value of gross industry product that is also purged of the state and year averages. The equation is run separately for each industry, yielding a separate estimated impact of storm frequency and intensity for each industry. However, the estimated impacts are the same across all states.

One concern with the specification is that states are fairly large units, and that our estimated coefficients may suffer from omitted variable bias. In other words, there may be other factors that explain the log of gross product in a state that we failed to include in our specification, and that are correlated with the storm conditions. First, we must underline that the estimated coefficients are capturing the impact of the deviation of storm conditions around their state and year specific averages on the deviation of the log of gross product around its state and year specific average. Because the averages are eliminated from the equation, that takes care of most of the omitted variables. Any residual omitted variables are only problematic if they are correlated with both the deviation of log gross product around its state and year specific average, and with the deviation of storm conditions around their state and year specific averages.

However, to address the possibility that there is omitted variable bias, we run an additional regression which adds in state level variables, like the fraction of the state that is urban, the educational and age distribution of the state's population, the size of the state's population, and the fraction of the population who is unemployed in the state. Including the state level variables 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 conditions. We use the following specification:

$$\ln GP_{ist} = \eta_{is} + \chi_{it} + \psi_i Frequency_{st} + \mu_i \left(Frequency_{st}\right)^2$$
$$(2) \quad + \rho_i Intensity_{st} + \sigma_i \left(Intensity_{st}\right)^2 + \sum_{j=1}^{10} \pi_{ij} * Z_{jst} + \nu_{ist}$$

Where Z_j , j=1,…,10, refers to the 10 state level variables. We then check whether the added state level variables are jointly statistically significant. If they are jointly statistically significant, then we adopt regression (2) as the preferred specification. We assume that each state is a price taker in a national goods market. Any changes in goods prices occur at the national level for all states, and therefore would be absorbed in the year specific fixed effect that we include.

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 using the following rule: if a geographic unit falls within a state, it is attributed completely to that state. If a geographic unit comprises parts of more than one state, that unit is assigned to the state with the majority of the area. Once each geographic unit is assigned a particular state, the geographic units are collapsed into states. The data is only available for the 48 contiguous states (Hawaii and Alaska are excluded). In order to work with both data sources, we limit the analysis to the years 1977 through 1997.

A storm is defined as a local minimum in surface pressure. The passage of a storm from a particular location implies a lowering of the pressure, an increase in the winds, and the occurrence of clouds and often rain or snow. Each time a storm passes through an area, it increases the storm frequency for that area by one point. Storm intensity is defined by the magnitude of the central pressure of the storm. Lower central pressure implies a stronger storm with higher winds and more precipitation. If there were no storms in a particular month, the storm intensity variable is recorded as missing. Since gross state product is measured on an annual basis, 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. It is important to note here 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[6].

3b. Summary statistics:

Our analysis identifies the effect of year round storm frequency and intensity on the US economy using the variation of storm frequency and intensity across states and over time. The more variation in storm frequency and intensity across states and over

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

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.

Table 1.

State	Average Storm Frequency	Frequency quartile	Average Storm Intensity	Intensity Quartile
AL	2.8	1	1003.9	4
AZ	2.4	1	1005.6	4
AR	4.5	2	1003.5	4
CA	1.7	1	1005.6	4
CO	7.1	3	1045.9	4
CT	8.1	3	999.4	1
DE	6.7	3	1001.4	2
FL	1.5	1	1028.0	4
GA	2.8	1	1003.5	4
ID	3.5	1	1002.2	3
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
KY	4.9	2	1002.7	3
LA	3.0	1	1003.7	4
ME	12.6	4	997.0	1
MD	5.6	2	1001.5	2
MA	11.7	4	998.9	1
MI	11.5	4	1000.0	1
MN	9.0	3	999.1	1
MS	2.9	1	1003.9	4
MO	8.4	3	1002.1	3
MT	6.3	2	1000.7	2
NE	10.4	4	1000.1	2
NV	4.0	2	1004.0	4
NH	13.8	4	998.1	1
NJ	8.3	3	1000.7	2
NM	5.1	2	1003.1	3
NY	9.5	4	999.8	1
NC	4.7	2	1003.4	3
ND	9.9	4	999.5	1
OH	6.6	3	1001.3	2
OK	6.8	3	1002.9	3
OR	2.3	1	1001.6	2
PA	8.0	3	1000.6	2
RI	9.1	3	999.2	1
SC	3.1	1	1002.6	3
SD	8.6	3	999.9	1
TN	3.7	1	1003.5	4
TX	6.1	2	1003.7	4
UT	4.2	2	1002.4	3
VT	10.7	4	998.3	1

VA	5.4	2	1003.0	3
WA	2.2	1	1000.3	2
WV	5.2	2	1002.5	3
WI	11.3	4	999.9	1
WY	6.3	2	1001.0	2

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

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 from which we can work.

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[7].

4. Results

We regress equation (1) using OLS, with robust standard errors. Each industry is evaluated independently. For each industry, we have 48 values for each year, resulting in 1008 observations.

The effect of a one point change in storm frequency on the log of gross product is $\beta_i + 2\gamma_i$ frequency, and the effect of a one point change in storm intensity on the log of gross product is $\lambda_i + 2\phi_i$ intensity. Because of the quadratic form of the estimating equation, the effect of a one point change in storm frequency/ intensity depends on the value of storm frequency/ intensity we use as a baseline. We use the mean national storm frequency/ intensity realization over the years in the sample as the baseline value for storm frequency/ intensity.

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 calculate the effects of a 7% decrease in the mean national realization of storm frequency, and of a 6% increase in the mean national realization of storm intensity, separately. 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. Finally, we multiply the predicted effect for each industry by the national 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 the US economy of a change in storms due to climate change. These costs are listed in table 2 under the column entitled 'baseline'. In the interest of space saving, we only include results from industries that showed a statistically significant effect in at least one column. Industries are referred to by code[8]. All costs are in millions of $1996.

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[7] For more detail, refer to table A in the Annex

[8] 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

Table 2.

	Storm Frequency Damage				**Storm Intensity Damage**			
I	**Baseline**		**Added var.**		**Baseline**		**Added var.**	
1	-472.70	**	-496.39	**	-1,140.50		-1,561.30	
4	64.91		89.72		1,722.52		2,375.30	*
7	-971.43	*	-1,424.27	**	-12,749.4		-14,403.3	
9	-89.32	*	-92.12	*	-479.42		-86.38	
10	-78.71		-118.97	*	-2,010.11		-2,351.19	*
11	-56.42		45.74		-9,750.01	*	-9,190.37	*
14	-1,043.81	*	-897.89		-211.36		-2,926.75	
15	-394.22		-497.84		-14,618.2	*	-14,245.3	*
19	-285.18	*	-274.70	*	1,581.03		1,428.13	
23	-173.54		-232.16	*	-177.01		-15.73	
24	-172.04	*	-275.29	**	800.71		797.45	
25	-465.20		-471.45	*	778.48		-759.71	
31	-97.56		-194.78	**	-822.14		-616.22	
34	-39.24	*	-34.19	*	-71.35		-122.22	
38	-527.74		-954.14	*	-6,953.48		-6,849.05	
39	-1,115.36	*	-1,703.78	**	-8,779.29		-9,876.91	
40	-452.30		-733.23	**	-4,279.04		-3,945.17	
44	-69.92		-79.48	*	-316.09		-455.54	
45	-1,314.53		-2,154.31	*	-7,122.44		-10,059.9	
50	-60.01		-108.55	**	-35.30		86.79	
53	-211.45	*	-128.05		306.83		115.73	
54	-480.61	*	-700.81	**	-6,618.85		-7,359.35	
55	-63.84		-183.55	*	-2,999.76		-3,759.98	*
59	-285.35		-537.14	*	-9,572.44	*	-10,094.7	*
Total	-472.70		-5,637.10		0.00		0.00	

** denotes significance at 1%, * at 5%.

If we only consider the baseline estimates that are significant at the 1% level or better, the predicted change in storm frequency due to climate change has a detrimental effect on the farming sector only. On the other hand, the predicted increase in storm intensity has no significant effect on the national economy.

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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.

To address the concern that our estimates suffer from omitted variable bias, we run regression (2), which adds state level variables to the specification, and we test for the joint significance of the state level variables. Results suggest that for most industries we can reject the null hypothesis that the added variables are insignificant[9].

Therefore, regression (2) is a better specification than regression (1). We recalculate the costs to the US economy of a 7% predicted decrease in storm frequency and a 6% predicted increase in storm intensity using the coefficients from regression (2). Those results are also in table 2 under the column entitled ‘added variables’. Here we find that the predicted decrease in storm frequency not only hurts the farming sector, but it also harms the construction sector, the printing and publishing, trucking and warehousing, retail trade, depository institutions, auto repair services and parking, and health service sectors. The predicted increase in storm intensity still has no impact the economy at the 1% level of significance.

If we add up all the damage estimates due to predicted changes in storm frequency, we get $5.6 billion in losses. This total impact adds up to 0.07% of the US economy in 1997. Thus, though the effects of storms on gross industry product are statistically significant, their economic effects are small.

5. Conclusion.

Climate change theories predict that in the next 100 years, storm frequency should decrease by 7%, while storm intensity should increase by 6%. This paper looks at the national effects of these predicted changes in storm frequency and storm intensity on various industries in the US economy.

The results indicate that the predicted decrease in storm frequency hurts the farming sector, the construction sector, the printing and publishing, trucking and warehousing, retail trade, depository institutions, auto repair, services and parking, and health service sectors. The predicted increase in storm intensity, however, has no impact the economy.

If we add up all the damage estimates due to predicted changes in storm frequency, we get $5.6 billion in losses. The total impact adds up to 0.07% of the US economy in 1997. Thus, though the effects of storms on gross industry product are statistically significant, their economic effects are small.

In future work, we intend to look more closely at each specific industry in order to understand the estimated effects better. Moreover, we intend to conduct the analysis at a regional level, to address the fact that industries behave differently depending on the region of the country they operate in.

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

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