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The Impact Weather Has on NYC Citi Bike Share Company Activity

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Introduction: As individuals continue to partake in activities that release pollutants and toxins into the air, global warming has progressively became a growing concern. The effects of global warming include changes in climate that result in changes in temperature, precipitation, floods, and storms. Due to this change in the climate, I was curious to see how individual's behavior has been affected by the change and see if there has been any difference in lifestyle as global warming grows into a larger concern. I seek to answer the question of can the amount of ridership of Citi Bikes in a particular day be determined given the average temperature, predicted precipitation, the amount of accumulated snowfall and wind speed. This question is interesting because even though it seems logical that people may want to rent out a bike for a few hours during the summer time when it is warmer outside and less dangerous to ride a bike in, there may be other people who are resilient and may not alter their behavior because of a difference in weather. It is important for the Citi Bike business and for policymakers to be more aware of how individuals behave when they expect certain weather conditions and if this plays a role in individuals finding other forms of transportation that does not rely on being outdoors while commuting. I also find it interesting for policy makers to see if high wind speeds may deter individuals from riding bikes in the city, given the danger of riding alongside traffic in the city.

My hypothesis is that individuals will ride less during the winter times when the road conditions are dangerous to ride on and when it is colder outside compared to during the summer days where individuals feel more safe on the clear roads and feel more comfortable being able to ride bike without many layers of clothing. I also believe that under higher inches of precipitation, this will deter individuals from wanting to rent out a bike and find another form of transportation. Furthermore, during the warmer days of the summer and spring, I believe individuals will have more leisure time and spend more time outdoors, which will influence them to want to take a stroll on the bike. Although it is a fact that it is warmer during the summer days than winter days, global warming has become present over the past few years and this might also have led to an upwards trend in ridership throughout the entire year instead of during the spring and summer. Therefore, I believe this data analysis is important because it will provide more insight on what weather conditions people deem to be too dangerous to ride in or deter them from wanting to ride a bike in.

Brief Literature Review: Bowman Cutter and Matthew Neidell's "Voluntary information programs and environmental regulation: Evidence from 'Spare the Air'" explores whether individuals alter their method of transportation in response to Spare the Air advisories. Spare the Air (STA) is a public voluntary information program located in the San Francisco Bay Area that evokes people to reduce

automobile trips that emit a lot of ozone into the atmosphere on a day where the ground level ozone is expected to exceed the National Ambient Air Quality Standards. In order to gain an understanding of the impact of an STA release, Cutter and Neidell look at traffic conditions in Southern California where STAs are not released. After the research was completed, Cutter and Neidell found that STAs reduce traffic and moderately increases the use of public transportation proving that information programs such as Spare the Air have an impact on individuals transportation methods. By having these information programs release potential warnings about high levels of ozone in the air, people changed their behavior by ride sharing or using public transportation in order to improve the air quality and emit less pollution into the air that can affect the respiratory health of individuals in these areas. One main issue Cutter and Neidell wanted to explore during this experiment is the free rider problem, where individuals who know there will be a reduction in the traffic after a STA is released and will take more trips as a result of a shorter travel time and less exposure to pollution. Cutter and Neidell found large statistically significant decreases in traffic during and immediately after morning hours, but statistically insignificant and smaller responses during the middle of the day and into the evening. These results correlate to this research about the effect of weather on Citi Bike usage. Although carpooling, taking public transportation or using a Citi Bike to ride to work or to commute around the city imposes time costs to customers and also is not as convenient as driving in their individual automobile, the results presented in this paper and this study on Spare the Air shows that targeting households are effective in improving the environmental quality. If Citi Bike can continue to provide incentives for individuals to use the bikes to commute to work, instead of taking a taxi or using public transportation, there will be less pollution going into the atmosphere and the air quality for individuals living in the city will be healthier. For future policyholders in Citi, this case study proves that individuals will change their transportation behavior if they receive a smog alert or an excessive ozone level alert. My paper contributes to the research because it shows a variety of other weather conditions that may impact why individuals decide to not choose a Citi Bike and rely on other forms of transportation.

Joshua Graff Zivin and Matthew Neidell's "Days of haze: Environmental information disclosure and intertemporal avoidance behavior" studies the impact of smog alerts that are delivered on consecutive days on discretionary outdoor activities found in Southern California using a regression discontinuity design. In California, the law requires that a smog alert be released when the ground-level ozone exceeds a certain threshold. They found that the cost of substituting activities increases over time as shown by individuals largely responding to alerts on the first day, but not responding as much with two consecutive day alerts. More specifically, they found that when an alert is released on one day only,

attendance at the Zoo decreased by 15% and attendance at the Observatory decreased by 8%. However, the response to the alert on the second day falls to a decrease in attendance in the Zoo by 5% and no change in the Observatory. As a result of these activities being a form of leisure, Zivin and Neidell find that the cost of avoiding this activity are higher than obligated attendance such as going to work. This paper connects back to the impact weather has on Citi Bike ridership because individuals change their behavior based on the predicted weather forecast, despite the forecasted weather not being completely accurate. It is important for policyholders in Citi Bike to understand how individuals are optimizing their behavior when it comes to them changing their transportation methods as a result of a certain weather condition outside. Furthermore, Citi Bike needs to find ways for individuals to be able to use the bikes regardless of certain weather conditions. Many individuals decide not to use Citi Bikes under certain weather conditions because of the risk they take by riding on the street next to cars.

Data: The data I received for the amount of ridership that occurred in the New York City comes from the Citi Bike website https://www.citibikenyc.com/system-data. I decided to use the data from 7/1/2013 to 12/5/2015, which equals out to 888 observations in total. Ridership per day is the primary dependent variable I am using in the paper. The data for the weather conditions during these dates comes from the National Climatic Data Center, focused in on the climate in Manhattan, New York.

A single observation is constituted by an individual renting out a Citi Bike from one of the 493 bike stations that are scattered throughout Manhattan, Brooklyn, Queens, and Jersey City. In total, there are approximately 8,000 bikes available to rent out. As for a single observation of weather data, the National Climatic Data Center provides information on all aspects of the climate for each particular day. In this paper, the Climate Data Center provided information for the average temperature, which is the average of the lowest recorded temperature and the highest recorded temperature, the precipitation, which includes any rain, sleet or hail fall, accumulated snowfall and wind speed. The data tested and collected in this paper is time series since I use observations of weather on a daily basis collected from the same Climate Data Center and also use information from the Citi Bike website that provides the amount of ridership in a given day based in New York City.

Citi Bike is ideal for individuals who are looking to get from one place to the other in a quicker time because the company allows people to take a bike out from any station and then return it to any station in the city. However, a limitation to the data set is that individuals are busy during the weekdays when they are working. This may limit the amount of ridership seen in the middle of the day, but

a greater amount of ridership around 7:00AM to 9:00 AM when individuals are commuting to work and around 5:00PM when the work day is typically over. Another limitation that may exist is that individuals do not like to be outdoors during the cold winters. As a result of the colder and unpleasant conditions during the winter, the amount of ridership might be significantly less than it is during days with warmer temperatures and safer riding conditions.

One reason I decided to focus the climate in Manhattan is because I assume that most people travel into the city to attend work and also leave out of Manhattan in order to get back home. To further back up this assumption, Sarah M. Kaufman and Jenny O'Connell from NYU Rudin Center for Transportation found in their case study that 83% of trips started and ended in Manhattan, and only 1.6 % both started and ended in either Brooklyn or Queens.

Below, I included the data summary statistics table of all of the data that is included into the model.

Variables	N	Mean	SD	Min	Max
trips	888	27,138	12, 352	978	52,706
Max tempt	888	64.21	19.19	17.24	98.06
Min tempt	888	49.68	18.10	2.120	82.94
temperature	888	56.94	18.50	10.67	89.51
precipitation	888	0.121	0.351	0	4.968
windspeed	888	5.211	2.259	0	14.54
snowfall	888	0.121	0.796	0	10.98
logtrips	888	10.04	0.667	6/887	10.87
Tempt2	888	3,584	1,987	113.8	8,012

Equation:

$$trips\ per\ day = \alpha + \beta 1 \cdot temperature + \beta 2 \cdot precip + \beta 3 \cdot windspeed + \beta 4 \cdot snowfall$$

Empirics:

After regressing the amount of trips per day individuals in New York City and Jersey City took from 7/1/2013 to 12/5/2015 on the average temperature, precipitation, average wind speed, and the accumulated amount of snowfall found in Regression 1 the coefficients match the signs of my hypothesis. The first step in determining if the data is statistically significant, I looked at the P < l t l and see that all of the variables are statistically significant from 0.

Regression 1

VARIABLES	Model 1
temperature	502.1 ***
	(13.69)
precipitation	-8,485 ***
	(1,237)
windspeed	-319.6 ***
	(118.7)
snowfall	-520.0 **
	(253.2)
Constant	1,303
	(1,255)
Observations	888
R-Squared	.702
Robust standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1	

Regression of ridership on four dummy variables: temperature, precipitation, windspeed and snowfall.

In Regression 1, for an extra degree increase in the average temperature in degrees Fahrenheit, the models states that ridership for Citi Bikes will increase by 502.1191 rides, rounded up to about 503 rides. This matches the sign of B1 and seems logical because the warmer it is outside, the more inclined individuals are going to be to want to travel outside and be willing to bike ride around in order to get from place to place. With warmer temperatures, individuals are able to feel more comfortable while riding a bike because they will not need to wear as many layers of clothing and will also not have to face dangerous weather conditions such as ice on the ground. For an extra inch increase in the precipitation falling, the models states that ridership for Citi Bikes will decrease by 8484.871 rides, rounding up to about 8485 rides. This matches the predicted negative sign of my hypothesis for B2 because the more condensation of atmospheric water vapor that falls onto the Earth in the form of rain, sleet or hail is going to deter an individual from wanting to bike ride in these dangerous conditions. For an extra mile per hour increase in wind speed, the model states that ridership for Citi Bikes decreases by 319.596 rides, rounded up to about 320 rides. This matches the predicted negative sign of my hypothesis for B3 because bike riding in the wind can be dangerous since most Citi Bike riders ride in the street alongside cars. Higher wind speeds may also deter individuals from wanting to commute through bike because the wind can significantly reduce the speed of the bike if the individual is not riding in the direction of the wind and an individual will have to

put in more effort to bike ride when it is windier. The model shows that wind speed does not deter individuals as much from renting out a Citi Bike, proving that this is not a significant main deterrent for riders. For an extra inch in snow fall, the model states that the amount of ridership for Citi Bikes decreases by 520.0434 riders, rounded up to about 521 riders. This matches the predicted negative sign of my hypothesis for B4 since snow can be dangerous for individuals to ride bike on, especially if the city has not cleared up the streets throughout the day.

Regression 2

VARIABLES	Model 1
temperature	1,038 ***
	(76.81)
precipitation	-9,010 ***
	(1,306)
windspeed	-305.5 **
	(120.2)
snowfall	-153.8
	(257.7)
tempt2	-5.019 ***
	(0.717)
Constant	-11,298***
	(2,048)
Observations	888
R-Squared	.720
Robust standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1	

Regression of ridership on five dummy variables: temperature, precipitation, windspeed, snowfall and a generated temperature squared variable tempt2.

Although Regression 1 proves that as the temperature increases, the amount of ridership increases, Regression 2 includes a generated variable defined as tempt2. The variable tempt2 is the temperature variable squared in order to test the quadratic relationship between temperature and the ridership on a daily basis. After completing the regression, I found that the tempt2 variable received a coefficient of -5.019 with a statistical significance at the 1 percent level. Due to it having a negative coefficient, this means that as the amount of ridership does increase as it begins to warm up from lower temperatures ranging from 10 degrees Celsius to 50 or 60 degrees Celsius, but once temperature reaches a certain degree Celsius, ridership begins to increase at a decreasing rate. This

means that as the temperature gets very hot, people will not want to ride in these conditions as well because of the lack of comfort individuals face when riding in high temperatures. Therefore, at some point the ridership does not grow and it reaches the optimal temperature level that consumers prefer to ride bike in. Afterwards, the amount of ridership begins to fall and this shows that the amount of ridership begins to decrease when it is too hot outside.

Regression 3

VARIABLES	Model 1
temperature	331.4 ***
	(29.29)
precipitation	-8,207 ***
	(1,186)
windspeed	-294.6 ***
	(0.00680)
snowfall	-105.8
	(219.8)
2.month	-1,550 **
	(654.4)
3.month	481.1
	(745.8)
4.month	5,768 ***
	(1,063)
5.month	8,535 ***
	(1,337)
6.month	8,725 ***
	(1,472)
7.month	6,494 ***
	(1,655)
8.month	9,334 ***
	(1,536)
9.month	13,541 ***
	(1,450)
10.month	14,141 ***
	(1,257)
11.month	8,428 ***
	(1,132)
12.month	1,889 **
	(913.8)
Constant	3,792***
	(1,338)
Observations	888
R-Squared	.788
Robust standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1	

Regression of ridership on weather variables correlated to each month throughout the year in order to test for seasonal effects.

Looking at the same regression with a focus on each month of the year in Regression 3, I found that the least amount of ridership occurs during the winter time from December to March. In February, we find that over the 2 and a half years of data, February is the only month that has a negative recorded amount of ridership's when compared to the month of January. I find that the most amount of rides occur during the summer time, which shows that when individuals enjoy the weather outside, they tend to spend more leisure time outdoors and tend to rent more Citi Bikes. September with *13521.33* more rides than the month of January and October with *14141.08* more rides than the month of January, are the two highest amounts of ridership that occurs throughout the entire year, proving that warmer weathers and less dangerous weather conditions on the road incentivize people to want to travel on a bike throughout the city.

An interesting result from the model is that average temperature, precipitation, wind speed and snowfall explained 70.11 percent of the Citi Bike ridership variability data. Therefore, weather does play a very significant role in if the company is going to attract a lot of individuals in the city to bike around to commute or if they are going to feel less inclined to ride the bike and find another form of transportation.

Regression 4

VARIABLES	Model 1
temperature	0.0253 ***
	(0.000867)
precipitation	-0.482 ***
	(0.0511)
windspeed	-0.00944
	(0.00680)
snowfall	-0.170***
	(0.0309)
Constant	8.731***
	(0.0773)
Observations	888
R-Squared	.728
Robust standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1	

Regression of ridership on weather variables that are logged in order reduce any skewed effects and in order to eliminate outliers.

Furthermore in regression 4, I decided to take the log of the total amount of trips per day dependent variable in order to reduce and limit the skew in the data and not allow the data to be influenced by any outliers. After taking the log of the dependent variable *trips per day*, I found that the R-squared statistic increased to 72.76, and I found that all of the variables were statistically significant from 0 except for the effect of average wind speed, which has a p-value of .127. Overall, the signs of the coefficients for each of the dummy variables match my hypothesis signs.

Conclusion and Summary: In this paper, I sought to ascertain the relationship between bicycle ridership under the Citi Bike sharing program and weather by analyzing the relationship between ridership on a daily basis and weather variables such as temperature, precipitation, snowfall, and wind speed. As policy makers in Citi Bike continue to discuss ways on how to increase ridership, this paper shows that individuals are deterred from riding bikes under more precipitation, extra snowfall, and higher wind speeds. Under these weather conditions, individuals in New York City and Jersey City are beginning to use other forms of transportation that are safer and more convenient for them. In order for individuals to see the improvements they are making to the environment by using Citi Bike, there needs to be more voluntary programs that provide insight on how bad the air quality is as a result of automobile pollution. It is also necessary that New York begins to implement air quality standards and restrictions that limit the amount of cars that are on the road and overall limit the amount of ozone and pollutants. By making individuals living in the city more environmentally aware and by developing safer methods of transportation for bike riders, people will change their behaviors and there will be less automobiles on the road. This work contributes to policy makers in Citi Bike because it shows that by finding a way to provide accessible and safe roads for people to ride in, people will alter their transportation methods to bike riding throughout the entire year.

For future research, Citi Bike needs to explore potential solutions to the dangers weather brings to bike riders in order to attain supporters of the fight against global warming. One shortcoming to this research presented is that I was not able to attain information on which riders were annual subscribers or if they were renting out the bike for a few hours in order to test the bike. Another shortcoming is that I was not able to attain information on how long the bikes were being rented out for and the primary locations of where individuals were biking in order to see popular commuting trips. By having an understanding of where riders are renting out the bikes, Citi Bike may be able to know how individuals are using the bike such as if they are heading over to parks for leisure activities or if they were driving to work for mandatory activities. With information on what type of consumer Citi Bike appeals to, we will be able to

better understand why the consumers behave the way they do. Furthermore, the last shortcoming in this research is that I was not able to attain information on personal variables for the consumers such as gender or age that could influence how safe they feel to bike ride in certain weather conditions. These are areas to research more into the future in order to have a better understanding of who Citi Bike sharing program appeals to and who is aligned with the values of bike riding instead of using other forms of transportation.