The Impact of Weather Conditions on Capital Bikeshare Trips

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Abstract

Automated bicycle renting systems have seen tremendous growth over the last few years, with many cities implementing systems. Washington, DC, has one of the largest systems of bikesharing in the US and recently made all their usage data publically available for analysis. One issue with promoting bicycling as a reliable alternative mode of travel is the impact of unfavorable weather conditions on usage. In theory, usage can be affected by colder weather, precipitation, and excessive heat. The research presented here analyzes the effect of weather on the use of the Washington, DC, bikeshare system. Hourly weather data, including temperature, rainfall, snow, wind, fog, and humidity levels are linked to hourly usage data and statistical models linking both number of users and duration of use are estimated. Further, we evaluate trips from bikeshare stations within one quarter mile of Metro (subway) stations at times when Metro is operating. This allows us to determine whether Metro serves as a back-up option when weather conditions are unfavorable for bicycling. Results show that cold temperatures, rain, and high humidity levels reduce both the likelihood of using bikeshare and the duration of trips. Trips taken from bikeshare stations proximate to Metro stations are affected more by rain than trips not proximate to Metro stations and less likely when it is dark. This information is useful for understanding bicycling behavior and also for those planning bikeshare systems in other cities.

Introduction

Bikesharing systems have grown rapidly over the last few years throughout the world, following on the success of their implementation in Lyon and Paris. These provide an alternative means of transportation in cities by making bicycling more convenient for users, as they do not need to worry about parking or theft of their own bicycle. Cities can benefit by providing a new sustainable transportation option that can increase access to transit, but also reduce crowding on overburdened transit systems, such as the Underground in London. Bikesharing allows users, through a membership fee, to checkout a bicycle at stations placed throughout the city, ride to their destination, and return the bicycle at a nearby station. Trips are typically free for a certain amount of time (often 30 to 60 minutes) to encourage short trips and continued use of each bicycle amongst users. A recent count of systems estimated 100 bikesharing programs in approximately 125 cities worldwide(Shaheen, Guzman and Zhang 2010). In the United States, notable systems currently exist in Denver, Boulder, Minneapolis, Boston, and Washington DC.

In Washington, DC, Capital Bikeshare (CaBi) is currently the largest in the nation with over 1,200 bicycles at 140 stations(Alta Bicycle Share, Inc. 2012).[1] The system grew out of an early bikesharing pilot project, SmartBike D.C., launched in 2008(Alta Bicycle Share, Inc. 2012). Capital Bikeshare opened in September of 2010 with 400 bicycles at 49 stations in both Washington, DC and Arlington, Virginia and has expanded gradually through both station additions and station expansions(Goodman 2010). Future expansions will result in a system of 2,800 bicycles at 288 stations by the end of 2012(Wash Cycle 2011). A wealth of data on travel behavior is being collected by these systems and Capital Bikeshare has made the trip logs of every trip taken in the system publically available.

This analysis exploits the dataset of bicycle trips made using Capital Bikeshare in order to determine how bicycle usage varies under different weather conditions. Hourly data on weather conditions for Washington, DC, are matched with the usage data. This allows us to determine

[1] This may soon be surpassed by the New York City system, due to launch in Spring 2013.

relationships between rainfall, snow, temperature (both hot and cold), humidity, windspeed, and various other weather conditions that may affect bicycle usage, measured as both the number of trips per hour and their average duration. We are also able to control for how patterns of daylight and darkness affect trip behavior. The impact of weather on bikeshare trips that are proximate to Metro stations and those further away are also examined, allowing us to determine whether Metro serves as a back-up option for bikeshare trips when weather is not conducive to bicycling. Our results have implications for understanding the sensitivity of bicycle usage to weather conditions and how this can affect the usefulness of bicycling as an alternative mode of travel. It is also informative for those planning or operating bikesharing systems.

Previous Literature

A growing body of research has examined the impacts of weather and climate on cycling in different cities, usually in combination with other factors that may affect cycling. Results have varied as to how important weather is in affecting usage. Pucher, et al. (Pucher, Komanoff and Schimek, Bicycling Renaissance in North America? Recent Trends and Alternative Policies to Promote Bicycling 1999) finds cities with relatively high cycling rates to have mild winters and often little rain compared to areas of the U.S. with extreme heat and humidity which discourage cycling. Additionally, in Pucher & Buehler's (Pucher and Buehler, Why Canadians Cycle More than Americans: A Comparative Analysis of Bicycling Trends and Policies 2006) analysis predicting percentage of bicycle trips to work in U.S. and Canadian cities, precipitation and temperature were found to be statistically significant variables correlated with lower cycling rates(Pucher and Buehler, Why Canadians Cycle More than Americans: A Comparative Analysis of Bicycling Trends and Policies 2006). However, Buehler & Pucher (Buehler and Pucher 2012) found no statistical significance for annual number of days above 90º F (32.2º C), annual number of days below 32º F (0º C), and annual inches of precipitation on bicycle commuting amongst large American Cities. Dill & Carr (Dill and Carr 2003) found the number of days of rain to be negatively correlated with bicycle commuting rates, but not statistically significant. In an investigation of impacts of individual and city-level characteristics on bicycling in Canadian cities, it was found that more days of precipitation per year and more days with freezing temperatures per year are associated with lower levels of utilitarian cycling, but average summer maximum temperature and average wind speed had no influence on cycling (Winters, et al. 2007).

Studies have been conducted to assess the relative impact of weather on cycling trips within a city. Cervero & Duncan (Cervero and Duncan 2003) developed a bicycle mode choice model based on Bay Area Travel Survey data to predict the probability that a trip will be made by bicycle. They found that rain did not deter individuals from bicycling. An analysis of commuting patterns of students in Melbourne, Australia found seasonal weather variation to not have a significant impact, while specific weather conditions of wind, rain, and temperature were significant(Nankervis 1999). An analysis of the impacts of weather on cycling through parks in Vienna counted cycling levels through the park and related these to weather variables including rain, temperature, and thermal index, all of which were found to have a significant impact on both recreational and commuting cycling levels(Brandenburg, Matzarakis and Arnberger 2007). Of note in the Brandenburg study was the use of individual trip counts as they related to daily weather conditions. Using a survey methodology, a Swedish study found that bicycle trips decreased by 47% from summer to winter, and that temperature and precipitation were among the most important factors of concern among seasonal cyclists (Bergström and Magnusson 2003).

As bikesharing systems have proliferated, research on bikesharing systems has begun to emerge. While some research utilizes survey methodology to determine factors leading to bikeshare use(Bachand-Marleau, Lee and El-Geneidy 2011), the availability of trip-level data collected by the systems is an exciting new data source for transportation researchers. One prior study evaluated bikeshare data and linked this to weather patterns (Noland and Ishaque 2006). This study used data from the OYBike pilot scheme in the Borough of Hammersmith and Fulham, in the west of London. Monthly aggregates of trips and weather variables were graphically analyzed and showed that fewer trips occurred in colder months. Months with more rain also appeared to reduce usage and less daylight decreased usage. The data was insufficient for conducting a multivariate analysis to separate these factors. The analysis presented here provides a much richer dataset of both hourly usage and weather patterns, overcoming the data shortcomings of this previous work.

Of note for our analysis, a weblog (JDAntos) provides an analysis of daily temperatures recorded at National Airport merged with the CaBi dataset(JDAntos 2012). The analysis observed an expected trend of increased bikeshare trips per day as average temperature increased, but also noticed a decrease in July 2011 during weeks of extreme heat. After plotting daily high temperatures, it was found that trips were more scattered for temperatures between 50 and 70º F (10 and 21.1º C), indicating that more extreme temperatures played a larger role in the decision to bicycle(JDAntos 2012).

Before the public data release of Capital Bikeshare trip history data, the system's operator, Alta Bicycle Share, provided a limited dataset to researchers who conducted an analysis of bicycle infrastructure and other determinants of average daily bikeshare trips. Bicycle usage was correlated with a variety of spatially derived variables calculated using a geographic information system(Buck and Buehler 2012). These included proximity of bicycle lanes, total resident population, percent of households with no motor vehicle access, and a proxy for retail store density (liquor licenses). All had a positive association with bikeshare usage. In 2010, Barclays Cycle Hire (aka Boris Bikes) was opened in London, a far more expansive system. Research was conducted on the impact of a transit strike on bikeshare trips (Fuller, et al. 2012). A temporary increase in usage was found immediately after the strike, suggesting experimentation with the system. Levels of usage slowly diminished back to pre-strike levels. The impact of a policy change allowing casual users to access the London system resulted in more weekend usage and also increased commuting usage(Lathia, Ahmed and Capra 2012). Much of this research was made possible by Transport for London freely providing trip history data. Additional research using bikeshare trip data includes factors effecting trip generation and attraction in Barcelona and Seville(Hamphire and Marla 2011) and an analysis of bike speeds and flows in Lyon(Lathia, Ahmed and Capra 2012).

Data

Capital Bikeshare made their data publically available in January of 2012 containing anonymous individual trip data (http://www.capitalbikeshare.com/trip-history-data). The dataset downloaded for this analysis includes 1,361,074 trips from September 15, 2010 to December 31, 2011 with attributes for trip duration (seconds), start trip date and time, end trip date and time, start station, end station, bicycle number, and whether the user had a casual (1 to 5 day) or registered (monthly or annual) membership.[2] For analysis purposes, trips were removed that lasted longer than 24 hours (287). Additionally, trips that started and ended at the same station and lasted less than 60 seconds were removed (these observations were likely results of someone checking out a bicycle only to immediately return it and not actually take a trip). The first month of operation, September 2010, was also removed (4,205 trips) as the system was not fully operational and start-up effects resulted in a low number of trips and some unusually lengthy trips.

Weather data from October 1, 2010 to December 31, 2011 were obtained from Weather Underground history data which offers historical weather data for download of both daily and hourly observations, including temperature, humidity, wind speed, precipitation, and the observation of fog, rain, thunderstorms, and snow. Typically the dataset provided observations for each hour every 52 minutes after the hour. However, when additional observations were given, they were removed to maintain equal one-hour intervals. Observations which did not occur 52 minutes after the hour were assumed to occur at 52 minutes after the hour. Missing observations were imputed by averaging conditions from the preceding and following hour; these constituted less than 30 records out of 10,968 total hourly observations.

Data for the measure of darkness used were obtained from sunrise and sunset tables of the Astronomical Applications Department of the U.S. Naval Observatory (U.S. Navy 2012). The variable was coded as "dark" one-half-hour before sunrise and after sunset.

[2] At system opening, a one-day, five-day, monthly, or yearly membership was available. In the fall of 2011, a three-day membership option replaced the five-day membership option.

All variables and descriptive statistics are in Table 1. For the dependent variables analyzed, there was an average of 122.2 trips per hour with a standard deviation of 125.6. The average trip duration was 18.3 minutes ranging from as short as 2.0 minutes to 644.6 minutes (10.7 hours—represents a single trip beginning at 3:38 a.m. on October 7, 2010).

Independent variables included both weather variables and non-weather related control variables. Washington, DC recorded a wide-range of temperatures throughout the dataset spanning from 17.1º F (-8.3º C) to 102.9º F (39.4º C). Washington can be fairly humid with an average relative humidity of 63.9% and a standard deviation of 19.0. The average wind speed was 8.2 MPH; this is defined as a "gentle breeze" according to the Beaufort wind force scale(Met Office 2010). Fog and thunderstorms were rare events in the recorded data (0.2% and 0.6%), but rain (6.9%) and snow (0.9%) were observed more often. For control variables, it was interpreted to be "dark" 46.5% percent of the time. System growth is represented by 19 stations at opening in Washington, DC growing to 54 by December 2011, with a mean of 40.5 stations across all hourly observations.[3]

Preliminary analysis

A relationship between daily number of trips and average daily temperature can be seen in Figure 1[4]. System growth early on in 2010 is visible even as temperatures begin to fall. By January 2011, a clear relationship is visible between the number of trips per day and average temperature. A few outlier days can be explained by adverse weather impacts that day. August 27, 2011, for example, saw only 1,106 trips, due to 3.3 inches of precipitation that day. Between July 18, 2011 and August 2, 2011, the high temperature was 93º F (33.9º C) or higher, with four days of temperatures over 100º F (37.8º C). A drop of ridership is visible throughout these days of extreme heat. Days with low ridership are also

[3] This variable only includes stations in Washington, DC, and does not include Arlington, VA. Therefore, it does not precisely measure total system growth. However, the general trend of an increasing number of stations is represented.

[4] This graph and interpretation is a result from aggregating trips by each day and joining daily weather observations from Weather Underground, an alternate weather dataset than was used for the hourly graphs and regression analysis.

explained for reasons other than the weather, such as only 189 and 743 trips on Christmas Day in 2010 and 2011.

As humidity increases, fewer CaBi trips are made. Figure 2 shows mean trips per hour of both casual and registered users plotted against relative humidity. The relationship is fairly linear. However, the low number of trips taken in very low humidity is likely a result of colder temperatures during these times.

While a mean of 122.2 and a median of 80.5 trips per hour are made for all users, registered users make up a higher number of trips at 97.6 per hour compared to 24.6 per hour for casual users. As would be expected, in the rain, the average number of trips for both groups drops to 58.1 per hour. However, registered users are far more likely to still use bikeshare in the rain with 50.3 trips per hour (48.5% decrease) compared to 7.8 casual user trips per hour (68.3% decrease). The differences throughout an average weekday, by hour, can be seen in Figures 3 and 4. In addition to a pattern of decreased ridership due to rain, a clear commuting pattern (of morning and afternoon peaks) is seen amongst registered users, while casual users exemplify a pattern of continually increasing use throughout the day, peaking at 5:52 p.m., and then decreasing thereafter.

The average trip durations between registered (12.5 minutes) and casual (39.0 minutes) users vary significantly. This is likely due to the more utilitarian nature of trips for registered users versus the recreational nature of trips for casual users. Additionally, the impact of various weather events affects each group's trip duration differently. For registered users, trip durations decrease by 10.1% in the rain and 9.4% in the snow. Trip duration decreases are much larger for casual users in these weather conditions—22.4% in the rain and 12.1% in the snow. Additionally, fog and thunderstorms slightly increase trip durations for registered users (0.2% and 4.4% respectively) yet considerably decrease trip durations for casual users (36.1% and 29.3% respectively).

Modeling Methodology

Weather observations for each trip start date and time were merged with the trip records based on the date and time. Trips were collapsed by hour, summing the number of trips and total duration of all trips attached to each hourly observation. Mean trip time per hour was calculated by dividing hourly duration by hourly trips.

Dummy variables were created for each weather "event" (fog, rain, thunderstorm, snow). Temperature was also recoded into ten-degree-bins and converted to dummy variables, as the relationship between temperature and bicycling behavior is not expected to be linear (although this is also tested as a linear variable in the models that follow). Wind speed values were set to 0 for "Calm" and "-9999", which represent no wind data recorded. Dummy variables were created for month (time period variable—distinct between 2010 and 2011), weekend and federal holidays, and peak travel times. The peak was defined as weekday observations at 6:52 a.m., 7:52 a.m., 8:52 a.m., 3:52 p.m., 4:52 p.m., 5:52 p.m., and 6:52 p.m. (as trip starts were rounded to the nearest weather observation, this captures actual trip start times between 6:22 a.m. to 9:22 a.m. and 3:22 p.m. to 7:22 p.m.). As the system has grown over the years, a variable was also created for the number of stations in the system in DC at the time the trip was taken. [5]

Two dependent variables were analyzed: number of trips and average trip duration. To analyze the impacts of weather on the number of trips taken each hour, a negative binomial model was used. This count model was more appropriate than a Poisson regression as the variance of the dependent variable (trips) far exceeded the mean, leading to overdispersion. To analyze average trip time, an ordinary least squares regression was performed. A total of eight different models were constructed using variations of temperature, humidity, and controls for time (month bicycle used), number of stations in the system, peak vs. off-peak usage, and weekends/holidays. Interpretation of parameter estimates in the trip duration models allows us to determine the change in trip duration in minutes associated with each parameter. In

[5] This was determined from the "install date" attribute of the Capital Bikeshare GIS point dataset(District Department of Transportation 2012).

the negative binomial estimates one must calculate a point elasticity estimate, due to the functional form of the estimated equation(Washington 2003). Both are discussed in the results that follow.

The model was also tested using two truncated datasets, one consisting only of trips beginning and ending at CaBi stations within a quarter-mile of a Metro station (270,080 trips) and another of trips beginning and ending with no Metro station within a quarter-mile (399,452 trips).[6] Both datasets also removed all trips beginning at times when the Metro was not running—Saturday and Sunday 3:00 a.m. to 7:00 a.m., Monday through Friday midnight to 5:00 a.m., and appropriate holidays between 5:00 a.m. to 6:00 a.m.(Washington Metropolitan Area Transit Authority 2006)[7]. By creating these two datasets, it became possible to effectively compare weather impacts on bikeshare trips when Metro is presumed to be an option to when it is not an option; allowing us to consider whether Metro serves as a back-up option when weather conditions are unfavorable for bicycling.

Analysis of Results

Results for a model of the number of trips taken are shown in Table 2. Models of trip duration are shown in Table 3. The number of observations represents the total number of hours throughout the 15 months being analyzed from Oct 2010 to Dec 2011. Models #2, #3, #5, and #6 are for trips proximate to Metro stations and have fewer hourly observations as these do not include times when Metro is not running.

Temperature was included as a dummy variable in 10º F ranges (equivalent to 5.55º C ranges). Coefficients show that trips decrease as temperatures decrease, but also decrease above 90º F (32.2º C) (relative to the reference category, 50º F (10º C)). The most trips appear to be made when temperatures

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[6] GIS was used to determine if a bikeshare station was within 0.25 miles of a Metro station entrance utilizing point datasets for CaBi stations and Metro stations found on DC's Data Catalog website(District Department of Transportation 2012)(Washington Metropolitan Area Transit Authority (WMATA) 2007). For Metro stations in Arlington, VA, station entrances were first plotted in GIS using entrances/evacuation maps and then spatially compared to the location of CaBi stations(Washington Metropolitan Area Transit Authority 2012). Trips with a Metro station within 0.25 miles of only one end of the trip, were not included in either dataset.

[7] Metro opens at 7:00 a.m. instead of 5:00 a.m. on the following holidays that also fall on a weekday: New Year's Day, Memorial Day, July 4th, Labor Day, Thanksgiving Day, and Christmas Day(Washington Metropolitan Area Transit Authority 2006).

are in the 80-89º F (26.7-31.7º C) range. Elasticity estimates shown in Table 4 represent the incremental change in trip frequency associated with each temperature range. These are largest for the lowest temperature categories.

Temperatures between 10 and through the 40º F (-12.2 to 4.4º C) range are all significantly correlated ($p<0.05$) with shorter average trip duration, as opposed to when the temperature is in the 50 to 59º F (10 to 15º C) range, *ceteris paribus*. When temperatures range between 10 and 19º F (-12.2 and -7.2º C), average trip times are 9.9 minutes as opposed to 18.3 minutes, holding all other variables constant. Temperatures in the 70º F s and 80º F range (21.1 to 31.7º C) were significantly correlated with increasing trip durations, while temperatures above that were not significantly different than temperatures in the 50º F range (10 to 15º C).

Controls for month of year are included in both models, thus the temperature effect is independent of any seasonal pattern. Darkness is also controlled for and there is both less usage and shorter durations when it is dark and this is independent of any temperature effects. Darkness results in a reduction in trip frequency of about 1 (see Table 4) and a 3.1 minute decrease in trip length, which is highly significant ($p<0.001$). Thus, it is clear that there is variation in both the amount of usage and the length of trips dependent on temperature with both decreasing as it gets colder and generally increasing as it gets warmer, but not when it is excessively hot.

Other weather variables also show an association with bicycle usage and trip duration. Parameter estimates for humidity show that it is statistically significant and negative in both models. Thus, increasing humidity levels decrease usage and duration of trips, independent of temperature (see also Figure 2). The elasticity for relative humidity changes is a point elasticity estimate (-0.94) calculated at the mean value in the data (63.86%) and implies a 0.94% reduction in frequency of trips for a 1% change at the mean value. The magnitude of the reduction in duration is small, only about 0.056 minutes per trip. Rainfall also is statistically significant in both models, being associated with reductions in usage and trip duration. Trip frequency is about 0.56 less when it is raining, so less of a reduction than darkness or very cold temperatures. Trip durations are about 2.8 minutes shorter when it is raining, also less of a reduction than in very cold temperatures. Higher wind speed is also significantly correlated with fewer trips and shorter average trip durations, although actual impacts are much smaller than for other weather conditions.

The effects of fog, thunderstorms, and snow are not statistically significant for either the number of trips taken or their duration. While the number of stations in the system had an impact on the number of trips taken, it has no statistically significant impact on the average trip length[8]. This variable mainly controls for growth of the system over time. Another control is a dummy for peak travel times which shows that there is more usage in peak hours but trips are shorter than at off-peak times. Usage on weekends and holidays is not significantly different than on weekdays, however trips are over 5 minutes longer in duration, suggesting perhaps more recreational use of the bicycles.

The second and third models in Table 2 and Table 3 represent trips that begin and end proximate to a Metro station within a quarter-mile of the bikeshare station and trips (model 2) and those that are not proximate to a Metro station (model 3). Both sub-samples contain trips that occurred only when the Metro is operating. Thus, this provides a way to compare the weather impacts on bikeshare trips when Metro is an option versus when it is not. The resulting impacts of weather variables are similar in terms of direction and significance, save for the negative correlation between snow and number of trips which is shown to be highly significant. To test the differences between coefficients between these two regressions, Z scores were calculated using the following formula(Paternoster, et al. 1998):

$$Z = \frac{\beta_1 - \beta_2}{\sqrt{SE\beta_1^2 - SE\beta_2^2}}$$

The decrease in number of bikeshare trips when Metro is an option is highly significant in the rain and significant when temperatures are in the 20º F range (-6.7 to -1.7º C). The differences in the coefficient for the darkness variable are also statistically significant, as lack of daylight results in far fewer bikeshare trips when Metro is likely an option compared to when Metro is not an option. When

[8] All coefficients for the month dummy variables in model 4 (Table 3) are negative. This is a result of October 2010 serving as the reference month, which reported particularly longer trips. This is likely a result of a novelty effect due to the newness, and therefore novelty, of the system.

looking at the differences between coefficients of trip duration when Metro was an option versus when Metro was not an option, no statistically significant relationships were found between weather variables. Interestingly though, trip duration on weekends and holidays increase significantly in each regression, and more when Metro is an option.

It should be noted that all three models had a fairly low adjusted R-squared (0.108 for all trips, 0.190 for Metro trips, and 0.104 for no Metro trips). Only 10.4%, 10.8%, and 19.0% of the variation can be explained by the different models. Therefore, there are likely many other variables impacting the variation in average trip duration.

Discussion of Results

The results found here are not surprising and confirm what would theoretically be assumed as to the impact of weather on Capital Bikeshare trips. Adverse weather such as very cold temperatures, rain, high humidity, and increased wind speeds decreases the number of bikeshare trips in Washington. However, it was surprising to find that the number of trips significantly increased for temperatures in the 90º F range (32.2 to 37.2º C) as opposed to the 50º F range (10 to 15º C), as one might expect temperatures in the 90º F range (32.2 to 37.2º C) to be uncomfortably hot for cycling. As these temperature impacts hold while other variables are held constant, including humidity, one can infer that while increased humidity decreases trips, high temperatures necessarily do not.

While the CaBi dataset does not provide us with other modes chosen instead of bikeshare, the regressions on trips at and to locations where Metro stations exist compared to trips where Metro stations do not exist provided one way to analyze the differing weather impacts when an alternative transit option is more likely to exist. Indeed, the significant coefficient differences between the two regressions on the rain variable is evidence that more people will choose to bike in the rain if transit is less of an option. The vast difference in the darkness variable suggests that people much prefer to take the Metro, if possible, after nightfall. However, a Metro station simply existing at the beginning and end of a person's trip is only one aspect a person must consider when choosing a mode of travel. Modal choice also includes the number of transfers and overall transit trip time, compared to the bikeability of the trip which would include factors such as bicycle infrastructure (lanes), topography, and general safety and ease of the trip. As these details are not included, the models are fairly coarse in their ability to consider if Metro is an option and how weather affects the choice of mode.

The results for average trip durations suggest that in certain conditions (rain, darkness, cold temperatures, increased wind speeds, and higher humidity), people utilized CaBi for shorter trips and may either take another mode or forego longer trips in such conditions. The results could also be interpreted as adverse weather affecting the ability to complete a trip in the same amount of time compared with more temperate weather. For example, it makes theoretical sense that people bicycle more slowly in the rain or when it is especially windy. The impact of more recreational riding (which tends to be longer) during nice weather is also likely to have an impact. Further research analyzing trip durations at selected origin and destination pairs in different weather conditions could be conducted to address with more precision the impact of trip durations for specific trips.

Conclusions

In the world of bicycle research, data collection is often both challenging and expensive. Since the number of trips made by cycling is relatively small compared with alternative modes, it can be difficult to deduce trends from existing surveys. Additionally, research regarding the relationship between weather and cycling is typically conducted based on daily averages and not necessarily at the precise time that the trip was taken. The latter is more meaningful as weather can vary throughout the day. Through data collection technology embedded within bikeshare systems, the ability to understand different impacts on at least bikeshare trips is possible. The weather of Washington, DC contains almost all variations. It rains and snows, has very cold days and very hot days (especially in 2011) and can be especially humid at times and windy. This analysis helps to better document the relative impact of various weather conditions on bikesharing trips in Washington, DC, considering the precise weather observation at the time the trip was taken. The results of this analysis show that fewer trips are made in the rain, high humidity, high wind speeds, and low temperatures. Trips increase with higher temperatures up through temperatures in the 90º F range (32.2 to 37.2º C). The availability of Metro may also cause a larger decrease in cycling trips in the rain and cold temperatures. While many of these effects are not surprising, the impact may be less pronounced than many would assume. The sentiment that "no one bikes in the rain" is simply not true. While these results are directly related to bikeshare usage in Washington, DC, the results would be expected to be fairly applicable to general cycling as well. Of course, one should be cautious in generalizations, as different types of cyclists may be wont to use bikeshare versus a personal bicycle, and therefore, may respond differently to various weather conditions. Regardless, Capital Bikeshare has proven to be immensely successful in providing an additional mode of transportation to either complete a full trip or better access existing transit. The system is useful to people at most during fair-weather conditions, but also, still useful to many during adverse conditions as well.

Figure 1: Number of Trips Per Day as Related to Average Temperature Each Day

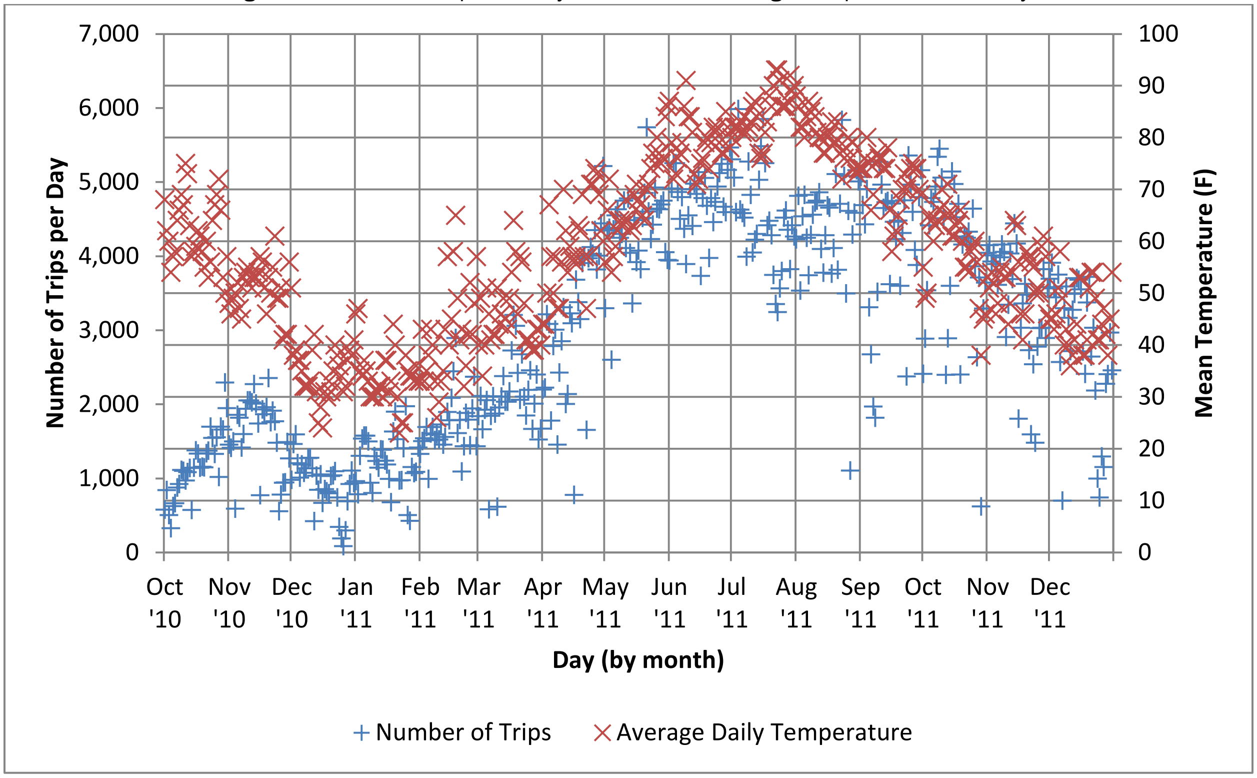

Figure 2: Mean Number of Trips Per Hour for each Humidity Observation for Registered Users and Casual Users

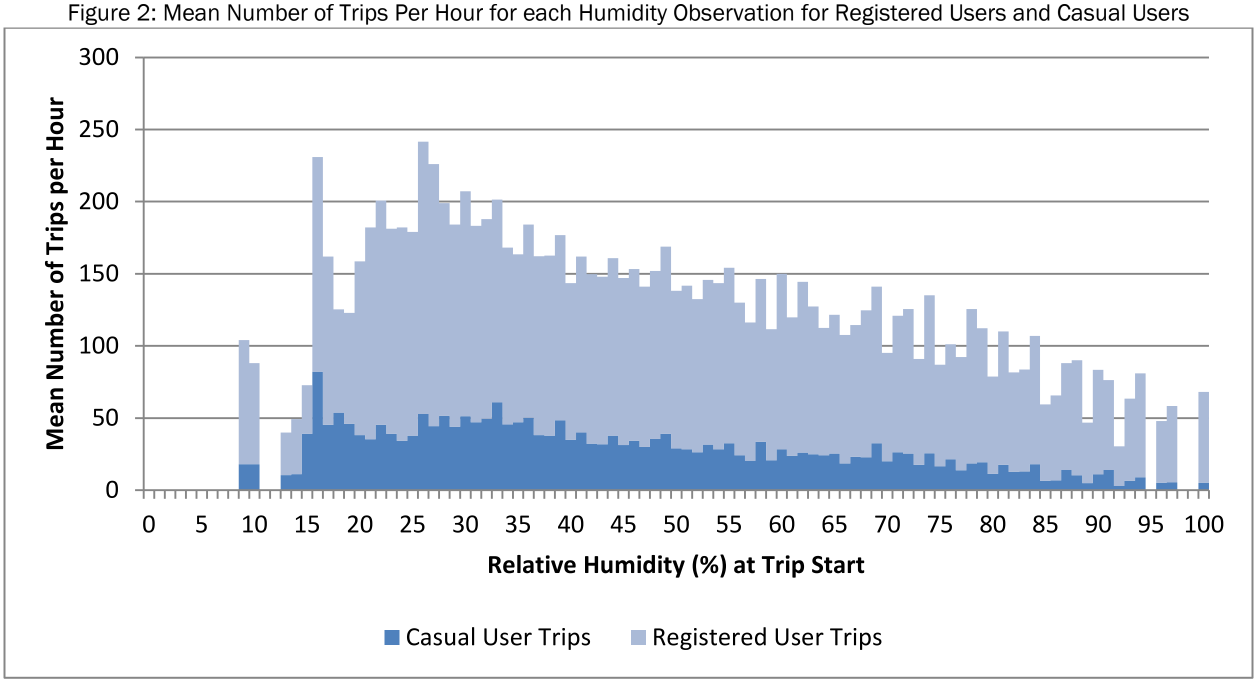

Figure 3: Mean Number of Trips for Registered Users When Raining versus Not Raining on Weekdays

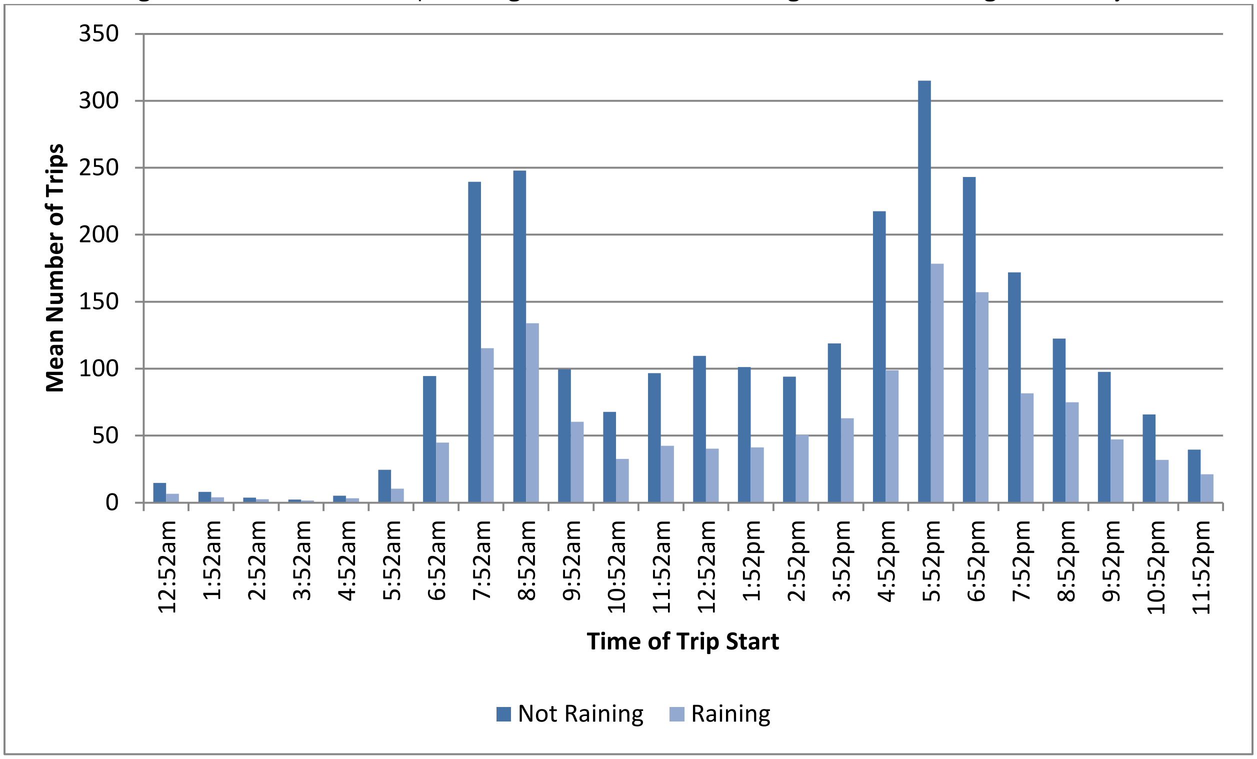

Figure 4: Mean Number of Trips for Casual Users When Raining versus Not Raining on Weekdays

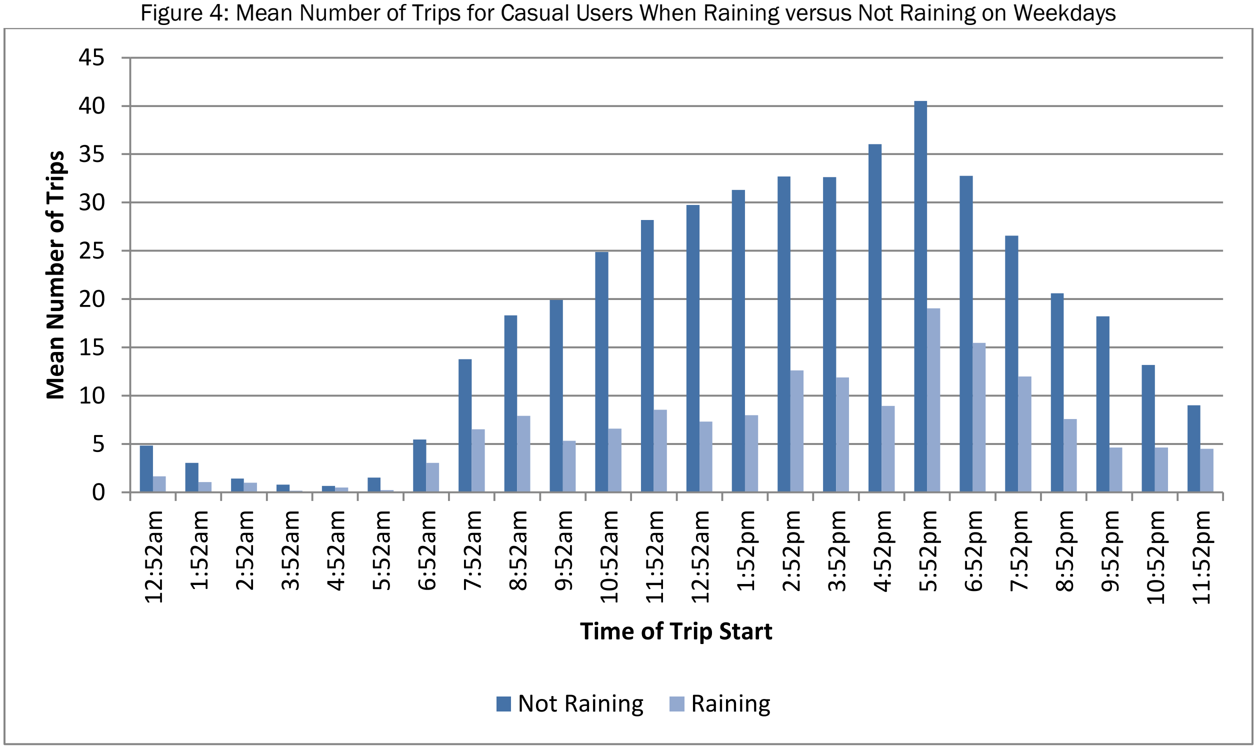

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Dependent Variables				
Trips per hour	122.226	125.584	0	807
Average trip duration per hour	18.324	16.306	2.033	644.617
Independent Variables, weather				
Temperature (ºF)*	57.315	17.678	17.1	102.9
Temperature - 10s (ºF)	0.003	0.050	0	1
Temperature - 20s (ºF)	0.035	0.184	0	1
Temperature - 30s (ºF)	0.168	0.374	0	1
Temperature - 40s (ºF)	0.163	0.370	0	1
Temperature - 50s (ºF)	0.188	0.390	0	1
Temperature - 60s (ºF)	0.154	0.361	0	1
Temperature - 70s (ºF)	0.166	0.372	0	1
Temperature - 80s (ºF)	0.097	0.296	0	1
Temperature - 90s (ºF)	0.024	0.154	0	1
Temperature - 100s (ºF)	0.001	0.038	0	1
Relative Humidity	63.859	19.042	9	100
Wind Speed (MPH)	8.236	5.202	0	41.4
Fog	0.002	0.040	0	1
Rain	0.069	0.253	0	1
Thunderstorm	0.006	0.079	0	1
Snow	0.009	0.095	0	1
Independent Variables, control				
Darkness	0.535	0.499	0	1
October 2010	0.068	0.251	0	1
November 2010	0.066	0.248	0	1
December 2010	0.068	0.251	0	1
January 2011	0.068	0.251	0	1
February 2011	0.061	0.240	0	1
March 2011	0.068	0.251	0	1
April 2011	0.066	0.248	0	1
May 2011	0.068	0.251	0	1
June 2011	0.066	0.248	0	1
July 2011	0.068	0.251	0	1
August 2011	0.068	0.251	0	1
September 2011	0.066	0.248	0	1
October 2011	0.068	0.251	0	1
November 2011	0.066	0.248	0	1
December 2011	0.068	0.251	0	1
Number of Stations in System	40.531	6.215	19	54
Peak Travel Hours	0.292	0.455	0	1
Weekends / Holidays	0.317	0.465	0	1

*Equivalent temperature ranges in Celsius begin at about -12.2º C and ranges are about 5.55º C for each bin.

Table 2: Negative Binomial Regression Model for Weather Impacts on Number of Trips

Variable	(1) Trips coefficients	(1) Trips t-statistic	(2) Trips to/from Metro coefficients	(2) Trips to/from Metro t-statistic	(3) Trips to/from no Metro coefficients	(3) Trips to/from no Metro t-statistic	Z value difference between β(2) and β(3)
Temp - 10s (ºF)^	-1.887***	(-10.68)	-1.758***	(-9.22)	-1.370***	(-7.48)	-1.470
Temp - 20s (ºF)	-1.073***	(-18.04)	-0.887***	(-17.54)	-0.743***	(-14.88)	-2.024*
Temp - 30s (ºF)	-0.713***	(-18.68)	-0.602***	(-19.68)	-0.535***	(-18.07)	-1.583
Temp - 40s (ºF)	-0.274***	(-9.16)	-0.266***	(-11.41)	-0.241***	(-10.69)	-0.764
Temp - 60s (ºF)	0.203***	(6.58)	0.193***	(8.10)	0.173***	(7.50)	0.615
Temp - 70s (ºF)	0.460***	(11.70)	0.360***	(12.15)	0.336***	(11.80)	0.588
Temp - 80s (ºF)	0.673***	(13.38)	0.496***	(13.33)	0.482***	(13.48)	0.285
Temp - 90s (ºF)	0.439***	(6.05)	0.248***	(4.76)	0.273***	(5.48)	-0.349
Temp - 100s (ºF)	-0.0186	(-0.08)	-0.260	(-1.71)	-0.193	(-1.33)	-0.314
Relative Humidity	-0.0148***	(-27.19)	-0.0114***	(-27.18)	-0.0107***	(-26.38)	-1.214
Wind Speed (MPH)	-0.00702***	(-3.93)	-0.00866***	(-6.35)	-0.00554***	(-4.20)	-1.646
Fog	-0.0710	(-0.35)	0.169	(0.95)	0.258	(1.49)	-0.358
Rain	-0.560***	(-15.55)	-0.714***	(-24.33)	-0.541***	(-18.73)	-4.204***
Thunderstorm	0.0685	(0.64)	-0.0343	(-0.41)	0.0506	(0.63)	-0.735
Snow	-0.0671	(-0.73)	-0.363***	(-4.47)	-0.309***	(-3.83)	-0.478
Dark	-0.695***	(37.21)	-0.569***	(38.09)	-0.195***	(13.38)	-17.871***
November 2010^^	0.249***	(4.11)	0.149**	(3.08)	0.253***	(5.34)	-1.539
December 2010	0.198**	(2.75)	-0.0649	(-1.13)	0.0375	(0.66)	-1.268
January 2011	0.556***	(7.71)	0.318***	(5.54)	0.328***	(5.84)	-0.123
February 2011	0.586***	(8.51)	0.381***	(7.02)	0.437***	(8.23)	-0.729
March 2011	0.507***	(7.70)	0.424***	(8.13)	0.486***	(9.53)	-0.848
April 2011	0.550***	(8.05)	0.558***	(10.25)	0.634***	(11.88)	-0.996
May 2011	0.428***	(4.66)	0.557***	(7.58)	0.526***	(7.35)	0.303
June 2011	-0.00250	(-0.02)	0.231**	(2.89)	0.275***	(3.53)	-0.396
July 2011	-0.0469	(-0.46)	0.215**	(2.63)	0.256**	(3.22)	-0.359
August 2011	0.0159	(0.16)	0.239**	(2.97)	0.240**	(3.06)	-0.006
September 2011	0.385***	(3.78)	0.489***	(6.01)	0.430***	(5.42)	0.521
October 2011	0.498***	(4.82)	0.558***	(6.75)	0.468***	(5.79)	0.784
November 2011	0.436***	(3.95)	0.472***	(5.34)	0.352***	(4.06)	0.969
December 2011	0.0806	(0.56)	0.0421	(0.36)	0.0998	(0.88)	-0.356
No. of Stations	0.0578***	(10.37)	0.0511***	(11.30)	0.0480***	(10.86)	0.504
Peak Travel Hours	0.651***	(33.42)	0.509***	(36.07)	0.361***	(26.44)	7.558***
Weekends/Holidays	-0.0145	(-0.80)	-0.129***	(-9.17)	0.215***	(16.14)	-17.762***
Constant	2.298***	(13.82)	1.566***	(11.59)	1.194***	(9.07)	1.972*
Overdispersion	0.719***	(-24.74)	0.321***	(-66.94)	0.278***	(-69.13)	
Observations	10,968		8,806		8,806		
Pseudo R-squared	0.064		0.105		0.096		
chi2	8059.1		9137.1		7142.3		

t statistics in parentheses * p<0.05 ** p<0.01 *** p<0.001

^Equivalent temperature ranges in Celsius begin at about -12.2º C and ranges are about 5.55º C for each bin. "Temp – 50s (ºF)" served as a reference group for temperature bin dummy variables.

^^"October 2010" served as a reference group for month dummy variables.

Table 3: Ordinary Least Squares Regression Model for Weather Impacts on Hourly Average Trip Duration

Variable	(4) Avg trip duration		(5) Avg trip duration to/from Metro		(6) Avg trip duration to/from no Metro		Z value difference between β(2) and β(3)
	Coefficients	t-statistic	Coefficients	t-statistic	Coefficients	t-statistic	
Temp - 10s (ºF)^	-8.465**	(-2.69)	-10.49*	(-2.55)	-9.792	(-1.81)	-0.102
Temp - 20s (ºF)	-4.563***	(-4.26)	-5.026***	(-4.01)	-5.904***	(-3.56)	0.422
Temp - 30s (ºF)	-3.451***	(-5.23)	-2.554***	(-3.34)	-4.674***	(-4.64)	1.676
Temp - 40s (ºF)	-1.185*	(-2.20)	-1.602**	(-2.67)	-2.792***	(-3.53)	1.198
Temp - 60s (ºF)	1.036	(1.85)	1.686**	(2.70)	3.049***	(3.71)	-1.321
Temp - 70s (ºF)	3.676***	(5.29)	4.465***	(5.75)	5.203***	(5.09)	-0.574
Temp - 80s (ºF)	3.991***	(4.52)	5.539***	(5.70)	3.905**	(3.05)	1.016
Temp - 90s (ºF)	2.179	(1.69)	3.478*	(2.54)	0.523	(0.29)	1.306
Temp - 100s (ºF)	-0.805	(-0.20)	-2.045	(-0.51)	-3.640	(-0.68)	0.239
Relative Humidity	-0.0568***	(-5.77)	-0.0916***	(-8.45)	-0.0905***	(-6.34)	-0.061
Wind Speed (MPH)	-0.134***	(-4.18)	-0.122***	(-3.49)	-0.0740	(-1.60)	-0.835
Fog	2.167	(0.59)	-1.825	(-0.39)	-0.153	(-0.02)	-0.208
Rain	-2.771***	(-4.19)	-2.495***	(-3.29)	-2.496*	(-2.50)	0.001
Thunderstorm	0.461	(0.24)	-3.108	(-1.45)	-1.605	(-0.57)	-0.424
Snow	2.682	(1.55)	0.969	(0.47)	7.139*	(2.57)	-1.788
Dark	-3.127***	(8.74)	-5.400***	(13.63)	-5.878***	(11.25)	0.730
November 2010^^	-3.861***	(-3.39)	-8.719***	(-6.93)	-0.310	(-0.19)	-4.036***
December 2010	-6.947***	(-5.25)	-11.73***	(-7.95)	-1.984	(-1.02)	-3.985***
January 2011	-7.707***	(-5.82)	-12.68***	(-8.60)	-2.945	(-1.52)	-3.992***
February 2011	-8.005***	(-6.33)	-13.53***	(-9.66)	-1.723	(-0.93)	-5.098***
March 2011	-4.233***	(-3.46)	-6.821***	(-5.03)	1.363	(0.76)	-3.653***
April 2011	-2.580*	(-2.02)	-6.560***	(-4.63)	4.828**	(2.59)	-4.862***
May 2011	-1.154	(-0.68)	-9.645***	(-5.06)	8.737***	(3.49)	-5.842***
June 2011	-4.945**	(-2.68)	-13.68***	(-6.62)	4.258	(1.57)	-5.257***
July 2011	-5.104**	(-2.71)	-12.16***	(-5.77)	6.572*	(2.37)	-5.385***
August 2011	-5.731**	(-3.09)	-13.48***	(-6.50)	6.510*	(2.39)	-5.840***
September 2011	-5.951**	(-3.16)	-12.99***	(-6.19)	5.290	(1.92)	-5.276***
October 2011	-4.915*	(-2.57)	-13.79***	(-6.47)	7.771**	(2.78)	-6.132***
November 2011	-5.565**	(-2.71)	-14.60***	(-6.36)	7.562*	(2.51)	-5.857***
December 2011	-5.497*	(-2.06)	-16.87***	(-5.66)	12.08**	(3.09)	-5.892***
No. of Stations	-0.183	(-1.82)	0.265*	(2.33)	-0.906***	(-6.13)	6.280***
Peak Travel Hours	-3.131***	(-8.67)	-3.873***	(-10.42)	-3.467***	(-7.08)	-0.661
Weekends/Holidays	5.433***	(16.82)	9.714***	(26.99)	5.701***	(12.02)	6.741***
Constant	32.63***	(10.96)	22.39***	(6.67)	53.67***	(12.30)	-5.681***
Observations	10,737		8,693		8,661		
R-squared	0.108		0.190		0.104		
Adjusted R-squared	0.106		0.187		0.101		
F	39.38		61.52		30.34		

t statistics in parentheses * $p<0.05$ ** $p<0.01$ *** $p<0.001$

^Equivalent temperature ranges in Celsius begin at about -12.2º C and ranges are about 5.55º C for each bin. "Temp – 50s (ºF)" served as a reference group for temperature bin dummy variables.

^^"October 2010" served as a reference group for month dummy variables.

Coefficients represent the change in mean trip duration for each unit of increase of that variable, holding all other variables constant. As most variables are dummies, the coefficient is the effect on the mean when the variable is true (i.e. equals 1). For example, average trips in the rain are 2.77 minutes shorter, *ceteris paribus*.

Table 4: Elasticity Estimates – Trip counts, negative binomial model estimates

Variable	(1) Trips Elasticity	(2) Trips to/from Metro Elasticity	(3) Trips no Metro Elasticity
Temp - 10s (F)*	-5.59954	-4.80082	-2.93535
Temp - 20s (F)	-1.92414	-1.42784	-1.10223
Temp - 30s (F)	-1.0401	-0.82577	-0.70745
Temp - 40s (F)	-0.31521	-0.30474	-0.27252
Temp - 60s (F)	0.183722	0.175518	0.158862
Temp - 70s (F)	0.368716	0.302324	0.285377
Temp - 80s (F)	0.489824	0.391038	0.382453
Temp - 90s (F)	0.355319	0.21964	0.238907
Temp - 100s (F)	-0.01877	-0.29693	-0.21288
Relative Humidity (mean elasticity)	-0.94513	-0.728	-0.6833
Wind Speed (MPH)	-0.00704	-0.0087	-0.00556
Fog	-0.07358	0.155491	0.227405
Rain	-0.75067	-1.04214	-0.71772
Thunderstorm	0.066207	-0.0349	0.049341
Snow	-0.0694	-0.43764	-0.36206
Dark	-1.00371	-0.7665	-0.21531
Peak Travel Hours	0.478476	0.398904	0.303021
Weekends/Holidays	-0.01461	-0.13769	0.193459

*Equivalent temperature ranges in Celsius begin at about -12.2º C and ranges are about 5.55º C for each bin.

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