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Bike Lanes and Other Determinants of Capital Bikeshare Trips

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ABSTRACT

Bikesharing is a relatively new form of bicycle infrastructure in North America that is theorized to encourage more bicycling trips. (*1*) However, planning bikeshare systems requires determining exactly where to place stations to maximize ridership. This exploratory study analyzes determinants of bikeshare usage of the Capital Bikeshare system in Washington, DC, with a special focus on bicycle lanes and frequency of bikesharing checkouts. It is hypothesized that placing bikesharing stations near bike lanes will increase ridership.

GIS analysis links each bikeshare station with bike lane supply and control variables within a ½ mile area. Bivariate analysis indicates a correlation between bike lane supply and bikesharing usage. The multiple regression analysis finds a statistically significant relationship between number of bikesharing trips and bike lane supply after controlling for population, retail destinations in the vicinity of stations, and the percentage of households without a car.

This study finds a significant correlation between the presence of bicycle lanes and Capital Bikeshare usage, and also highlights the importance of population density and mixed-uses in encouraging ridership. The study also reveals opportunities for further research into car-free households that seem to not use Capital Bikeshare.

INTRODUCTION

Public bikesharing systems are a new form of bicycle infrastructure investment that is theorized to encourage more bicycling. This exploratory study analyzes determinants of bike sharing in Washington, DC with a special focus on the connection of bicycle lanes and bikesharing checkouts.

Washington, DC introduced its Smartbike bikesharing program in 2008, with approximately 100 bicycles dispersed across 10 stations in the downtown area. This small scale pilot system demonstrated sufficient ridership to encourage the District of Columbia Department of Transportation (DDOT), the County of Arlington, VA, and the Metropolitan Washington Council of Governments to implement a regional bikesharing system of 1,000 bicycles at 110 stations. (*2*) For a $75 annual fee, members are able to check out bicycles at one of the stations and return the bike at any other station throughout the regional system at no additional charge for trips shorter than 30 minutes. In addition to the annual membership, monthly, weekly, and daily memberships are also offered to allow visitors to Washington, DC, and those interested in sampling the system, to access the bicycles as well. By making bicycles readily accessible, convenient, and visible to many people, the system operators hope to encourage significant bicycle ridership for transportation.

Planning bikeshare systems requires determining exactly where to place stations to maximize ridership. Station siting is subject to a variety of factors outside the scope of this study, such as rights to land access, line-of-sight requirements of solar panels for electricity supply, citizen preferences, and political considerations. But apart from these practical considerations, there are few resources that directly examine the determinants of bikeshare trip demand to establish or expand bikesharing systems. The Philadelphia region built a bikesharing demand model that assigned bikesharing suitability scores to zones of the city based on a number of environmental factors, but these factors were chosen and weighted by intuition and not based on empirical data (*3*). It is hypothesized that placing bikesharing stations near bicycle paths and lanes, should help increase ridership.

U.S. local governments have installed bicycle lanes and trails to encourage more people to ride bicycles. However, research has given mixed results on whether (*4*) or not (*5*) bicycle lanes actually encourage increased bicycle ridership. A variety of stated preference surveys (*6, 7, 8*), before-and-after studies (*9*) and cross-sectional analysis (*4, 10*) have consistently demonstrated the positive association of bicycle lanes with bicycle ridership. Recently, multiple regression analysis of bicycle lane and trail length for the 90 largest cities in the United States showed a direct and significant relationship between lanes, paths, and bicycle ridership (*11*). However, research has offered few firm estimates of the quantitative impact of bicycle lanes.

This exploratory analysis aims to quantify the relationship between bicycle lanes and the number of check-outs at bike sharing stations in Washington, DC, by examining whether or not Capital Bikeshare ("CaBi") ridership varies with the quantity of bicycle lane supply in the immediate vicinity of the stations.

DATA

This exploratory analysis uses CaBi usage data for system check-outs from the system's opening in September 2010, through March 23, 2011. Data were obtained from Alta Bicycle Share, the system operator. Average rides per day per station were calculated using the total number of rides originating from each station, divided by the number of days the station was in operation prior to March 23, 2011. Only ride origins were used, as this was the only data obtained from the system operator. Ride information is logged at the system stations, and transmitted in batches to a central usage database in 15-minute time increments.

The resulting average daily ridership was joined with a GIS point file for Washington, DC CaBi stations. Bikeshare stations in Arlington, VA, were excluded due to the lack of comparable information on bicycle facilities, retail locations, and other variables considered for Washington, DC in this analysis. A summary of all data described in this section is provided in Table 1.

TABLE 1 Descriptive Statistics for 0.5 Mile Buffer Areas Around CaBi Stations

Variable	Mean	Median	Std. Dev.	Min	Max
Dependent variable					
Average daily bikeshare check-outs	14.65	12.89	11.16	0.03	51.77
Independent variables, within 1/2 mile of bikesharing stations					
Total population*	11784	9595	6768	957	29102
Weighted average bicycle modeshare*	2.03%	2.06%	1.24%	0.00%	4.20%
Weighted average percentage of households with no access to an automobile*	34.39%	35.10%	13.51%	0.00%	62.12%
Weighted average median annual household income*	$ 41,135	$38,906	$ 15,609	$1,120	$78,581
Number of ABRA liquor license holders#	68.34	45.00	61.59	2.00	229.00
Intersections#	265.66	268.00	78.66	109.00	452.00
Bike lane supply (km)#	2.23	1.80	1.94	0.00	8.61
Bike trail supply (km)#	0.32	0.15	0.42	0.00	1.94
Independent variables, proximity to nearest bikesharing stations					
Nearest Metrorail station (km)#	1.35	1.00	1.28	0.00	5.00
Nearest grocery store (km)#	1.55	1.00	1.32	0.00	6.00
Independent variables, dummy	**Cases**				
Bikeshare station within Central Employment Area#	26				
Bikeshare station east of Anacostia River#	9				

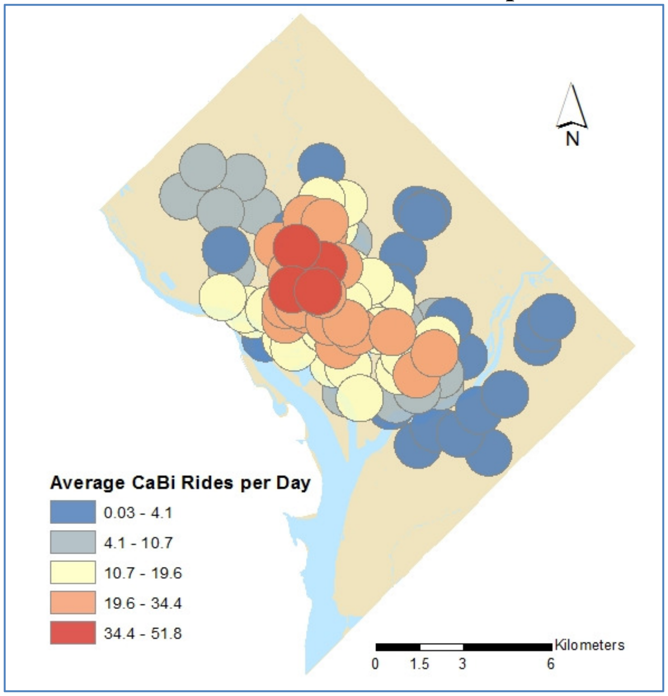
*Calculated using data from the American Community Survey (ACS) 5-year average 2005-2009, by block group
#Calculated using GIS files posted online by Washington DC Office of Chief Technology Officer, accessed April 3, 2011. http://data.dc.gov/

Figure 1 shows that the average number of trips per day is generally higher for stations in denser, more central locations in Washington, DC. Usage varies widely, with a station in the dense centrally-located neighborhood of Dupont Circle averaging over 51 trips a day, down to .03 trips per day at a station in the less dense outer neighborhoods east of the Anacostia River.

The next step in the analysis was to determine the most appropriate distance for the buffer around CaBi stations. No information was available on how far users will travel to obtain a bicycle, so a crow's flight radius of 0.5 miles (804 meters) was used. DDOT used this distance to examine the attributes of potential sites in their original station planning, and continues to use this distance in assessing sites for system expansion. Crow's flight distance was used to create the buffer, rather than network distance, in order to provide a uniform area around each station for easier interpretation of the analysis. Within these uniform buffer areas, ArcGIS software was used to associate the spatial data described below with each CaBi station.

Currently, there is no strong theory on determinants of bikesharing usage, mainly because it is a recent phenomenon in North America. Thus, the selection of candidate explanatory variables was guided by available research results on determinants of bicycle use (*11, 12, 13, 14*).

FIGURE 1 Distribution of bikeshare trips.



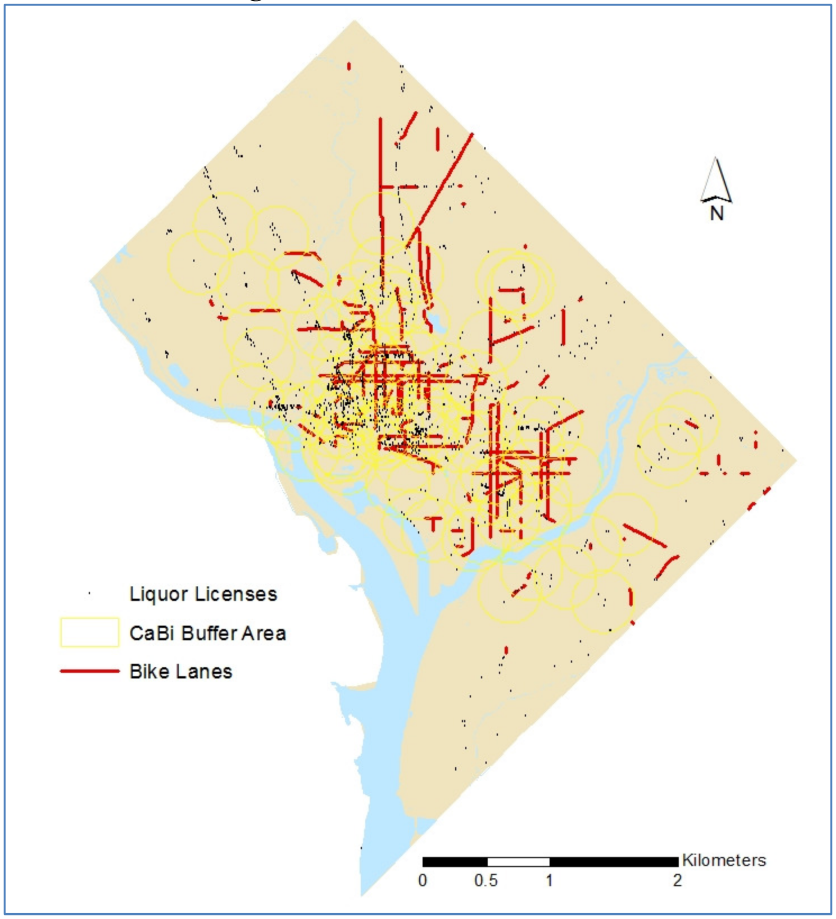
Bicycle Lanes and Trails

Official Washington DC GIS files for bicycle lanes and trails had to be edited to exclude lanes that had not yet been installed—but were already included in the file. Streets with shared-lane markings ("sharrows"), signed bike routes, and shared bus-bike lanes were included in the official DC data, but were also excluded from this analysis, under the assumption that these types of facilities are not sufficiently sheltered from automotive traffic to encourage additional ridership. On-street bicycle facilities with greater protection from traffic than traditional bike lanes, such as cycletracks and buffered bike lanes, are thought to encourage even greater levels of cycling (*15*). However, these facilities are not installed in sufficient quantity in Washington, DC to permit separate analysis, and were treated the same as all other bicycle lanes in this analysis. The total distance of bike lanes and trails within the buffer zone was then calculated for each bikeshare station. Additionally, the crow's-flight proximity of each station point to the nearest bike lane or bike trail was calculated to test whether there is a significant ridership benefit to being comparatively closer to a bicycle facility, as has been indicated by a previous travel behavior survey (*16*).

Like CaBi usage patterns, the presence of bike lanes also follows a spatial pattern of centrality (shown in Figure 2), with the majority of bike lanes lying in the densest central portions of the city. Bike lanes outside the downtown core are often short, and isolated from the remainder of the bicycle network.

GIS buffer analysis was also used to find the total quantity of street intersection points within the bikeshare station buffer. Higher quantities of intersections around bikeshare stations are indicative of a connected street grid, which is supportive of bicycling as it allows for more direct routes (*17*).

FIGURE 2 Washington DC bike lanes and the location of bikesharing stations.



Surrounding Community Amenities

Numerous studies have demonstrated the effect that destinations and a mixture of uses can have on generating and attracting bicycle trips (*12*). To control for this, a point file of Washington DC Alcohol Beverage Regulation Administration (ABRA) licenses is used to approximate the density of bars and restaurants within the buffer zone of each bikeshare station. The majority of these ABRA license holders are restaurants, and it is assumed that restaurants are co-located with other retail establishments. Thus, the density of ABRA license points is intended as a rough proxy for more general retail destinations. Each CaBi station's crow's flight proximity to grocery stores and Metrorail stations was also calculated, to determine if the presence of these facilities encouraged ridership.

Geographic Variability: Control for City Sector

This analysis tested two controls for sectors of Washington DC that may capture variability in ridership levels not measured by other explanatory variables. The first sector is the DC Office of Planning's designated Central Employment Area. Detailed spatial data on the location of employment centers was not available for this analysis, so the city's defined employment district is included to control for whether or not people will initiate bikesharing trips from their places of work. Furthermore, controlling for bikesharing station buffers intersecting with the boundary of this sector will also test whether centrality is a significant motivation for ridership, outside of the other independent variables examined.

The other sector tested is the area of Washington, DC located to the east of the Anacostia River. This sector has experienced exceptionally low usage of the CaBi system. The purpose of this dummy variable is to determine if bikesharing is lower east of the Anacostia even when controlling for other variables in this model. Reasons for lower bikesharing rates east of the Anacostia may include the sub-standard bicycle facilities on the bridges crossing the Anacostia River into the western portions of Washington, DC, prevalence of bus transit use, or a negative image of bicycling in this part of the city.

Population and Demographics

This analysis uses 2009 US Census block groups for Washington, DC, rather than the slightly revised boundaries of the more recent 2010 block groups. This permits US Census American Community Survey (ACS) data for 2005-2009 to be incorporated directly into the analysis. ACS block group bike to work trip data is used to test whether the presence of greater or fewer numbers of regular bike commuters has a significant impact on CaBi use, with all other variables held constant. Median household income data is used not only to control for any impact that income might have on bicycling directly, but also to control for any differences in ridership that may be related to the CaBi system requirement to pay with a credit card. Block group population was used to account for population density in the area in the immediate vicinity of the CaBi station. Because the buffer area around each station is uniform, the estimated population lying inside this area approximates residential density. Data on floor area ratios, or other measures of the built environment were not available. The proportion of households with no access to a vehicle was included to account for car-free households that are more likely to cycle (*11*). All of these independent variables were compiled for each Washington DC, block group, and joined with a GIS shape file of the 2009 block groups.

The Census block group files were linked to the CaBi station buffer areas. Because the CaBi station buffer areas do not closely match the shapes of the Census block groups, a GIS function called a 'union' was used to measure the proportion of each block group's area that falls within each CaBi station buffer. This proportional area for each block group was then used to give a weight to that Census block group's data, and the product was combined with data for other block groups lying wholly or partially within the CaBi station buffer area. The result is a weighted average (or in the case of population, a total) of Census block group data for each CaBi station buffer area.

ANALYSIS

Bivariate Correlations

Bivariate correlation analysis shows that most independent variables have the expected relationship with bike sharing (see Table 2). The first exception is bicycle trail length within the buffer zone, which shows a negative correlation with bike sharing. This is likely due to the location of bicycle trails inside Washington, DC, which are located on the outskirts of the densely populated areas of the city, or on National Park Service property, away from CaBi stations. The second exception is proximity to Metrorail stations and grocery stores, where it was assumed that an inverse relationship would be observed, but each variable is positively associated with CaBi ridership.

When analyzed via bivariate regression, many of the variables exhibit a statistically significant relationship with CaBi ridership. However, visual inspection of the spatial distribution of many of the independent variables also exhibit similar patterns, which may lead to multicollinearity when used simultaneously in a multiple regression analysis. For example, bicycle commute share and bicycle lane kilometers exhibit a strongly positive bivariate Pearson's correlation of 0.6449.

TABLE 2 Bivariate Correlation with Average Bikeshare Check-outs Per Day

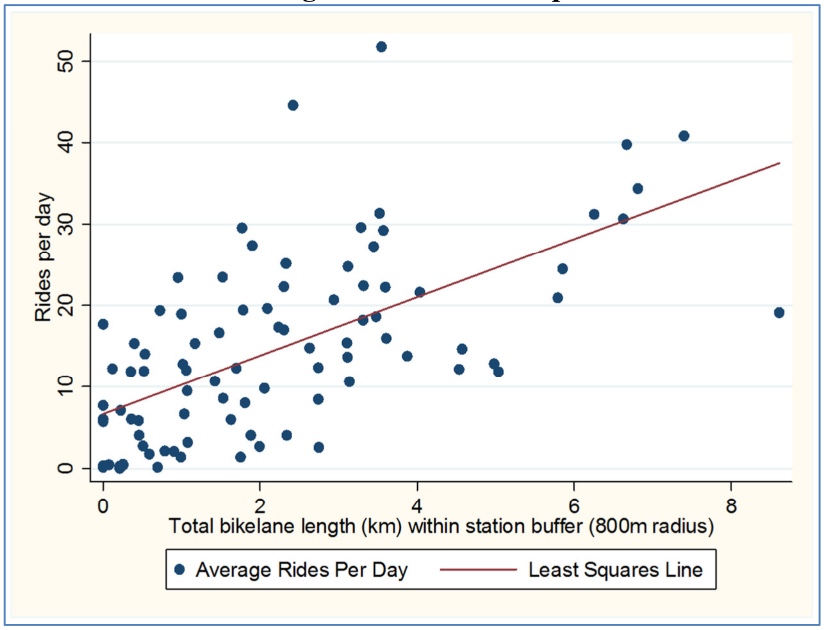
Variable	Correlation
Independent variables, within 1/2 mile of bikesharing stations	
Total population	0.57**
Weighted average bicycle modeshare	0.49**
Weighted average percentage of households with no access to an automobile	0.15
Weighted average median household income	0.3**
Number of ABRA liquor license holders	0.72**
Intersections	0.42**
Bike lane supply (km)	0.62**
Bike trail supply (feet)	-.23*
Independent variables, proximity to nearest bikesharing stations	
Nearest Metrorail station (km)	0.27**
Nearest grocery store (km)	0.41**
Independent variables, dummy	
Bikeshare station within Central Employment Area	0.26
Bikeshare station east of Anacostia River	-0.43**

***Significant at the 99% level*
**Significant at the 95% level*

Bivariate Regression

An initial bivariate regression was performed to test the relationship between kilometers of bike lanes within the buffer area (x) and average bikeshare rides per station (y). The scatterplot and output of this simple regression is shown in Figure 3, and suggests a positive correlation between the two variables. The regression output predicts that each additional kilometer (0.62 miles) of bike lane within the half-mile (804m) buffer around a CaBi station is related to an additional 3.58 rides perday . The *t statistic* indicates that the slope coefficient is statistically significant at the 99% level. Bike lane supply helps explain 39% of the variability in CaBi ridership. However, the inclusion of other independent variables may help to more fully explain the determinants of CaBi ridership.

FIGURE 3 Bivariate regression and scatterplot of bike lanes and CaBi trips.



$$y(\text{average CaBi rides per day}) = 3.58(\text{bike lanes}) + 6.68$$

Independent variables	**Coefficient**	*t*
Bike lane supply (km) within 1/2 mile of bikesharing stations	3.58	7.49**
Constant	6.68	4.75**
Observations	91	
Adjusted R^2	0.38	
F-statistic	56.07**	

***Significant at the 99% level*

Multiple Regression Results and Discussion

An initial multiple regression analysis was performed with total bike lane supply population, and ABRA liquor licenses as explanatory variables. These three variables showed the highest bivariate correlations with average CaBi trips per day, and the correlations between dependent and independent variables for all three of these explanatory variables were significant at the 99% level.

The result of this initial multiple regression (shown in Table 3) suggests a correlation between CaBi usage and total length of bike lanes within the buffer area ($p=.062$), even when controlling for population density within the buffer area ($p=.001$), and the number of liquor license holders within the buffer area ($p=.0000$). The resulting multiple regression equation has an adjusted R^2 value of 0.62, and predicts that one additional kilometer (0.62 miles) of bike lane within a ½ mile buffer of a bike sharing station is related to 0.97 additional CaBi check-outs per day.

TABLE 3 Initial Multiple Regression

$$y(\text{average CaBi rides per day}) = 0.00045(\text{population}) + 0.093(\text{liquor license holders}) + 0.97(\text{bike lanes}) + 0.80$$

Independent variables, within 1/2 mile of bikesharing stations	**Coefficient**	*t*
Total population	0.00045	3.45**
Number of ABRA liquor license holders	0.093	6.43**
Bike lane supply (km)	0.97	1.89*
Constant	0.80	0.54
Observations	91	
Adjusted R^2	0.62	
F-statistic	49.76**	

***Significant at the 99% level*
**Significant at the 90% level*

There was no strong theory or empirical guidance from other studies about variables that determine bike share usage. Thus in a second analysis, a stepwise regression was performed in STATA. This analysis starts with a full model including all control variables listed in Table 1 and then excludes variables that were not significant at the 90% level.

The result of the stepwise regression (shown in Table 4) shows a correlation between CaBi usage and three of the independent variables previously tested -- total length of bike lanes within the buffer area ($p=.084$), population densitywithin the buffer area ($p=.0000$), and the number of liquor license holders within the buffer area ($p=.0000$). The stepwise regression added the proportion of households within the buffer area with no access to a car ($p=.001$). The resulting multiple regression equation has an adjusted R^2 value of 0.67, and predicts that one additional kilometer (0.62 miles) of bike lane within a ½ mile buffer of a bike sharing station is related to 0.855 additional CaBi check-outs per day at every station which contains that one-kilometer section of bike lane.

TABLE 4 Revised Multiple Regression

y(average CaBi rides per day) = 0.00054*(population)* + 0.11*(liquor license holders)* + 0.86*(bike lanes)* - 0.19*(% car-free households)* + 5.78

Independent variables, within 1/2 mile of bikesharing stations	**Coefficient**	*t*
Total population	0.00054	4.29**
Number of ABRA liquor license holders	0.11	7.48**
Bike lane supply (km)	0.86	1.75*
Weighted average percentage of households with no access to an automobile	-0.19	-3.32**
Constant	5.78	2.81**
Observations	91	
Adjusted R^2	0.66	
F-statistic	44.39**	

***Significant at the 99% level*
**Significant at the 90% level*

The majority of the independent variables in this multiple regression showed the theoretically expected signs. Population within the CaBi buffer areas is positively and significantly related to usage, with every additional 1,000 people related to an additional 0.5 rides per day. The seemingly low magnitude of the coefficient is partially explained by the offsetting impact of high levels of CaBi ridership at several of the core downtown stations surrounded predominantly by office and retail space.

ABRA liquor licenses suggest an effect of retail destinations on CaBi trip generation. The significant relationship between these variables suggests that a significant proportion of CaBi rides are for the purpose of utilitarian trips to retail destinations, consistent with the growth trend in bicycling for transportation instead of purely recreational purposes (*18*).

The exception is the number of households with no access to a car. This variable shows a negative correlation, with each percentage point increase in households without access to a car correlated with a 0.19 decrease in average CaBi rides per day. Previous studies have shown the opposite relationship between access to automobiles and bicycle ridership (*11*).

There are a number of possible explanations for this counter-intuitive result. The highest proportion of households without access to a car are east of the Anacostia River, which is also the area with the least supply of bike lanes, among the least dense neighborhoods, and the lowest levels of CaBi usage. Finally, it is possible that requiring a credit card for membership is a significant barrier for car-free households as well.

Suggestions for Further Research

As with any study of cross-sectional data, one cannot determine causality from this analysis. For instance, bike lanes may have originally been sited where ridership was already high. Thus, it is possible that CaBi ridership may have been higher in these areas without the presence of bike lanes. A before/after study of CaBi station activity where new bicycle facilities are installed would provide a quasi-experimental test of the conclusions of this analysis that better documents the effect of bicycle infrastructure interventions (*19*).

No strong guidance was available on the selection of variables, and a number of variables that might have enhanced this analysis were not included due to a lack of available data. Automobile volume on individual street segments has been cited as a deterrent to cycling (*6*), but data could not be obtained for average daily trips on individual road segments. Similarly, data that would have provided a more precise spatial representation of job density was not accessible. Other variables to be considered for inclusion in a subsequent analysis are distance to next CaBi station, bicycle availability at stations, information on the location of student populations, and more detail on the built environment surrounding the CaBi stations.

This analysis only includes usage data for the first six months of the system operation. Trip volumes increased subsequent to the end-date of this dataset, and a much fuller dataset might provide new and/or stronger insights into the determinants of bikeshare demand.

The size of the buffer analysis zone used in this analysis was chosen based on the practice of DDOT. However, other studies referenced here use buffer radii for bicycling analyses that vary widely, depending on the variable being tested. Further experimentation with buffer radii for different independent variables might help to refine this analysis. This endeavor would be helped greatly by information on how far people are travelling to use a bikeshare station, and more reliable results might be obtained by using actual walking network distance to define the buffer analysis zone, as opposed to crow's-flight radii.

Finally, a closer examination is warranted of the factors leading to low usage of CaBi east of the Anacostia River, and by extension, low bicycle modeshare generally in this region of the city. Ridership in this sector is notably lower, and while this is partially explained by the variables in this analysis, consideration of other factors specific to this area might lend some insight into this phenomenon. In particular, the paradox of low levels of bicycling and CaBi ridership despite the high proportion of households without access to an automobile highlights the need for further research.

CONCLUSION

Capital Bikeshare data reveals a significant and positive relationship between bike lane supply near Capital Bikeshare stations and the number of trips originating from those stations. For planners of nascent bikeshare systems, this analysis suggests that locating new bikesharing stations close to bike lane networks may help increase ridership.

The results of this analysis suggest that CaBi operating agencies can encourage ridership at their existing underperforming stations by installing more bike lanes in their immediate vicinity. For expanding the system, CaBi operating agencies may get a higher ridership "return" on their station investment by siting those additional stations in locations with a higher density of population, retail destinations, and bike lanes.

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