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Determinants of bicycle commuting in the Washington, DC region: The role of bicycle parking, cyclist showers, and free car parking at work

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ABSTRACT

This article examines the role of bicycle parking, cyclist showers, free car parking and transit benefits as determinants of cycling to work. The analysis is based on commute data of workers in the Washington, DC area. Results of rare events logistic regressions indicate that bicycle parking and cyclist showers are related to higher levels of bicycle commuting—even when controlling for other explanatory variables. The odds for cycling to work are greater for employees with access to both cyclist showers and bike parking at work compared to those with just bike parking, but no showers at work. Free car parking at work is associated with 70% smaller odds for bike commuting. Employer provided transit commuter benefits appear to be unrelated to bike commuting. Regression coefficients for control variables have expected signs, but not all are statistically significant.

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1. Introduction

Over the last decades US cities have increasingly promoted bicycle commuting to reduce local and global air pollution, combat peak hour traffic congestion, and achieve health benefits from physical activity (Alliance for Biking and Walking, 2012). In large US cities bicycling accounts for 0.8% of commutes to work, compared to 10–37% in large bike-friendly cities in the Netherlands, Denmark, and Germany (Pucher and Buehler, 2012).

Bicycling can replace short automobile commutes of less than 3 miles that are disproportionately energy and emission intensive for cars due to cold starts and hot soaks (US Department of Transportation, Federal Highway Administration, 1993). More commutes by bicycle and fewer commutes by single occupancy vehicle in congested areas can additionally reduce fuel consumption and emissions from energy and emission intensive re-accelerations in peak hour traffic. Bicycling may also help ease urban traffic congestion in downtowns, because bicycles require less road space than automobiles. In some downtowns of US cities, such as on Washington, DC's L, K, and 14th streets, car traffic speeds during peak commute hours in the peak direction are between 6 and 12 km/h (Metropolitan Washington Council of Governments, 2011) – well below the 16 km/h median cycling speed for commute trips (US Department of Transportation, Federal Highway Administration, 2010).

Environmental benefits of more bike commuting depend on the substitution of car for bike trips. Between 25% and 86% of current bike commuters report that they would drive if it was not possible to cycle to work (Krizek et al., 2011). Cyclists are also more likely than pedestrians to have switched from single occupancy vehicles (Thakuriah et al., 2012). European countries, such as the Netherlands, Denmark, and Germany, with more commutes by bicycle and fewer commutes by automobile report much lower CO_2 emissions per capita from road passenger transport than the US (1900 versus 4500 kg of CO_2 emissions per capita) (International Energy Agency, 2011).

Seeing the potential benefits of more bicycle commuting, an increasing number of US cities has adopted zoning ordinances that require new office buildings to provide more bike parking and cyclist showers and less car parking, with the goal

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Table 1
Socio-demographic and spatial characteristics of Washington, DC and adjacent jurisdictions. *Sources*: MWCOG (2010) and US Census Bureau (2010).

Jurisdiction	Washington, DC	Arlington County, VA	City of Alexandria, VA	Fairfax County, VA	Montgomery County, MD	Prince George's County, MD
Population	600,000	217,000	150,000	1,038,000	972,000	835,000
Land area (Square Miles)	61	26	15	395	495	485
Population per square mile	9800	8400	9900	2600	2000	1700
Percent of university students	10.5%	10.0%	8.5%	8.2%	8.5%	9.6%
Percent of car-free households	35.2%	10.9%	11.9%	3.7%	8.4%	9.3%
Percent white	38.7%	70.5%	63.2%	66.2%	58.1%	23.4%
Household median income (US $)	59,300	96,200	77,100	102,500	94,400	69,900
Metrorail stops per 100,000 inhabitants	6.3	5.1	2.7	0.5	1.8	1.2
Bike share of all trips (2007/2008)	1.5%	0.8%	1.1%	0.3%	0.6%	0.4%
Bike share of commutes (2007/2008)	3.3%	1.4%	2.7%	0.5%	1.4%	0.6%

to encourage bicycling to work (Alliance for Biking and Walking, 2012). Only few studies have investigated the relationship between bike commuting and trip-end facilities at work (Heinen et al., 2010) and results are mixed; but a majority find a positive relationship between trip-end facilities and bike commuting. Almost all studies have relied on samples of cyclists and exclude non-cyclists. Most studies do not employ data on observed behavior, but use stated-preference surveys that report cyclists' choice between hypothetical commutes. The differential influence of various types of trip-end facilities remains unclear and most studies fail to control for free car parking at work and commuter transit benefits.

Unlike previous studies, this analysis uses revealed preference travel data of commuters, including cyclists and non-cyclists; distinguishes between bike parking, clothes lockers, and cyclist showers at work; and includes variables indicating if employers provide free automobile parking and transit benefits. A series of rare events logistic (relogit) models controls for other determinants of bike commuting, such as socio-economic factors, population density, trip distance, bikeway supply, and season of the year.

2. Data sources and variables

Data for the analysis originate from the Metropolitan Washington Council of Governments' (2010) regional household travel survey 2007/2008. Households were contacted based on a random sample of residential postal addresses stratified by geographic area. Participating households received a 1-day travel diary to record purpose, mode of transport, distance, and duration of each trip during an assigned weekday between February 2007 and May 2008.

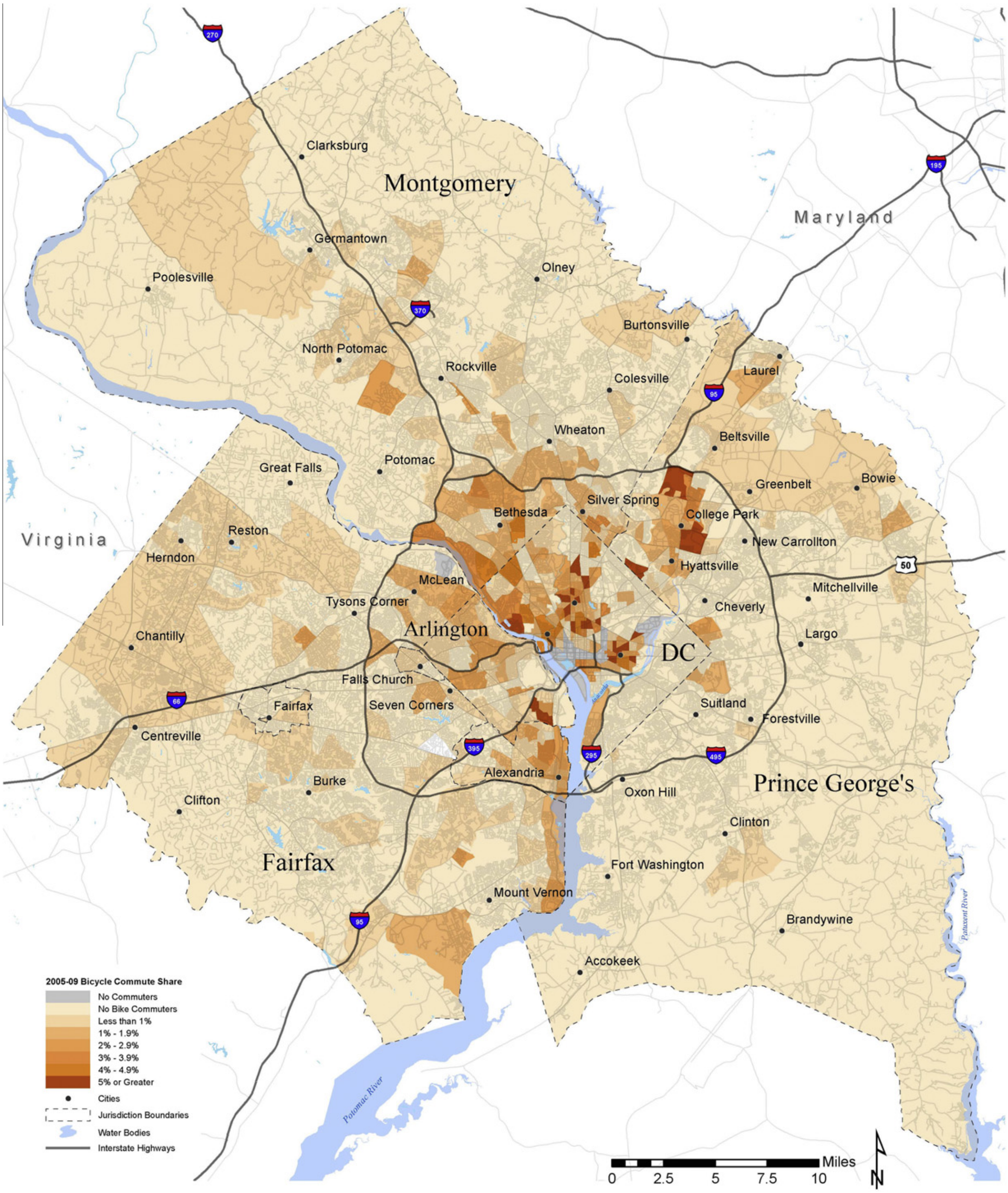
One day after the travel day had passed, the survey team gathered travel data using a computer aided telephone interview with each household member. During the interview respondents relied on their travel diary as a tool to jog their memory. The final sample included 4711 households with 5091 daily commuters from Washington, Arlington County, Alexandria City, Fairfax County, Montgomery County, and Prince George's County; reaching target participation rates in each geographic area. For this analysis, data on bikeway supply, population, and land area were collected and merged with the dataset using 2155 traffic analysis zone (TAZ) identifiers for households.

Washington, Arlington County, and Alexandria City form the high density-urbanized core of the Washington, DC region (Table 1). Fairfax, Montgomery, and Prince George's Counties are lower density, inner suburban jurisdictions bordering the urban core. Median annual household incomes in the region are higher (about $85,000) than the national average of $50,000.[1] With the exception of Arlington County, area jurisdictions have higher shares of minority populations than the US average of 29%. The share of carless households in Washington is eight times greater than in Fairfax County; a difference partially explained by high levels of Metrorail and bus ridership in Washington.

Cycling levels are higher in the urban core than in the inner suburbs. In all jurisdictions, the bicycle shares of commute trips are greater than the shares for all trip purposes. For example, in Washington the share of commutes by bicycle was 3.3%, while the bike share of all trips was 1.5%. This contrasts with national averages for urbanized areas, where in 2009 the bike share of commutes was lower than the bike share of all trips (Alliance for Biking and Walking, 2012). Bicycling in the Washington, DC region is more commute oriented than in other urbanized areas in the US with 41% of cycling trips in the Washington region in 2008 being commute related, compared to only 17% in other urbanized areas in the country.

There is considerable variability in bike commuting within jurisdictions (Fig. 1). Bicycle commuting levels are highest in census tracts inside the Washington Capital Beltway. Census tracts in College Park and Bethesda have the highest cycling

[1] Municipal averages hide income discrepancies within jurisdictions. For example, in Washington, DC median household income east of the Anacostia River was only $34,000, well below the national median.



Data source: US Census Bureau, (2010).
Note: Map created by D. Sonenklar

Fig. 1. Variation in the share of regular bike commuters in the Washington, DC region.

commute levels of the Maryland suburbs. Old Town Alexandria and Arlington County's Crystal City and Rosslyn–Ballston Corridor have the highest bike commute shares in Virginia. Within Washington, cycling commute shares are highest in the Capitol Hill, Georgetown, Adams Morgan, Mount Pleasant, and U-Street neighborhoods. In general bike commuting

Table 2
Variable names, definitions, descriptive statistics, and bivariate association with bike commuting.

Variable name	Measurement/description	Descriptive statistics	Significant bi-variate association with bike commuting
Bike parking and showers/ lockers	Nominal variable. Value of 1 if workplace provides bike parking and showers/lockers; 0 if not	11.1% have workplaces with showers, lockers, and bike parking	$P < 0.05$ (Chi-square test)
Bike parking, no showers/ lockers	Nominal variable. Value 1 if workplace provides bike parking, but not showers/lockers; 0 if not	38.2% have workplaces with bike parking, but no showers and lockers	$P < 0.05$ (Chi-square test)
Free car parking	Nominal variable. Value of 1 if workplace provides 'free car parking'; 0 if not	46.8% have free car parking at work	$P < 0.05$ (Chi-square test)
Transit benefits	Nominal variable. Value of 1 if workplace provides 'transit benefits'; 0 if not	26.9% have employers that provide transit commuter benefits	$P < 0.05$ (Chi-square test)
Race/ethnicity	Nominal variable. Value 1 if respondent is white; 0 if other	68.8% white	$P < 0.05$ (Chi-square test)
Gender	Nominal variable. Value 1 if respondent is male; 0 if female	49.1% male	$P < 0.05$ (Chi-square test)
Age	Nominal variable.Value 1 if respondent is between 25 and 40 years old; 0 if other.	22.9% between 25 and 40 years old	$P < 0.05$ (Chi-square test)
Income	Nominal variable. Value 1 if respondent lives in wealthiest 25% (quartile) of households; 0 if other	35.1% in highest income quartile	$P < 0.05$ (Chi-square test)
Car access	Ratio variable. Cars per household member	Mean: 0.800 cars per household member (St.Dev.: 0.446)	$P < 0.05$ (t-test)
Bicycle access	Ratio variable. Bicycles per household member	Mean: 0.534 bicycles per household member (StDev: 0.619)	$P < 0.05$ (t-test)
Trip distance	Nominal variable. Value 1 if the trip was shorter than 3 miles (the average bike commute distance in 2007/08); 0 if longer	23.0% commute less than 3 miles	$P < 0.05$ (Chi-square test)
Population density	Ratio variable. Persons per acre of land area in home TAZ	Mean: 15.8 people per acre (StDev: 16.7)	$P < 0.05$ (t-test)
Urban core	Nominal variable. Value of 1 if respondent lives in Washington, Arlington, or Alexandria; 0 if not	36.5% live in urban core	$P < 0.05$ (Chi-square test)
Bikeway supply	Centerline miles of bike lanes and paths per 1000 persons in home TAZ	Mean: 0.0965 miles of bikeways per 1000 persons (StDev: 0.921)	$P < 0.05$ (t-test)
Season	Nominal variable. Value of 1 if travel day was between May and October; 0 if other	57.8% of individuals were interviewed between May and October	$P < 0.05$ (Chi-square test)
Biked to work	Nominal variable. Value of 1 if individual commuted by bicycle; 0 if other	1.7% of respondents cycled to work	n.a.

decreases with distance from the regional core; though some census tracts east of the Anacostia River in Washington have low bike commute levels.

The presence of trip-end facilities at work was measured with two dummy variables reflecting workplaces with bicycle parking, but no cyclist showers or clothes lockers; and workplaces with bike parking, cyclist showers, and clothes lockers. In 2007/2008, 11.1% of commuters reported to have bike parking, clothes lockers, and cyclist showers at work and another 38.2% had bike parking, but no showers or lockers (Table 2). Almost half of the commuters reported free car parking at work and 26.9% had access to employer subsidies for commuting by public transport.[2]

It was not possible to control for some other factors that influence cycling levels, such as topography, bike parking at home, bike-transit integration, bikesharing programs, cycling culture, cyclist safety, and educational events. Compared to suburban counties, however, the urban core jurisdictions of Washington, Arlington, and Alexandria, have safer cycling, more active cycling advocates, and have implemented more programs to encourage cycling (Buehler et al., 2012). Some of these differences across jurisdictions are captured with a dummy variable flagging 36.5% of respondents living in urban core jurisdictions.

3. Results

Table 2 presents bivariate tests analyzing the relationship between independent variables and bike commuting. Chi-square tests indicate that significantly more individuals commute by bike if employers provide cyclist showers, bike lockers, and bike parking. Free car parking at work is associated with less bike commuting and employer transit benefits are positively related to cycling to work. Bike commuting is more common for whites, males, individuals in the top income quartile, trips shorter than 3 miles, and in households with more bicycles. Individuals in households with more cars are less likely to commute by bike. The share of bike commuters is greater in the urban core, at higher population densities, and in areas with more bike paths and lanes. Lastly, more individuals commute by bike during the warmer summer months.

[2] Table 2 also lists control variables for other determinants of cycling commonly found in other studies (Heinen et al., 2010).

The multiple regression analyses presented in Table 3 examine the relationship of bike commuting, employer incentives, and trip-end facilities at work, while controlling for other factors. Bicyclists only account for 1.7% of commuters in the region and therefore the dependent variable contains many more non-bike commuters than bicycle commuters. In such cases, maximum likelihood estimation can result in biased coefficients that underestimate probabilities for bike commuting.

Rare events logistic (relogit) estimation computes unbiased estimates for logit models with rare events. Relogit relies on maximum likelihood estimation akin to a standard logit model, but produces corrected estimators with lower mean square errors than the standard model. Corrections are most important for samples of less than 500, but have been shown to improve estimators even in samples of over 20,000 with a small percentage of events ($Y = 1$) (even below 0.15%) (King and Zeng, 2001).

Model 1 in Table 3 presents results of a relogit estimation including all available variables that are theoretically relevant.[3] Available statistics indicate that the model is a good fit. Pseudo R-square (McFadden) is 30.0%, and Chi-square distributed likelihood ratio tests show that the independent variables have joint significance. Tolerance and variance inflation factor statistics suggest no problem with multicollinearity among independent variables. To account for potential spatial auto-correlation, due to individuals living in the same household or the same TAZ, robust standard errors are estimated using household and TAZ as clusters.

Coefficients in model 1 in Table 3 were transformed ($e^{(\beta)}$) and can be interpreted as adjusted odds ratios (AOR), representing a respondent's likelihood of cycling to work relative to a specific reference group[4], while controlling for other variables. Trip-end facilities at work appear to be significant determinants of cycling to work. Compared to individuals without any bicycle facilities at work, commuters with cyclist showers, clothes lockers, and bike parking at work are associated with a 4.86 greater likelihood to commute by bicycle. Individuals with bike parking, but no showers and lockers at the workplace, are associated with 1.78 times greater odds to cycle to work than those without trip-end facilities. By contrast free car parking at the workplace is associated with 70% smaller odds for cycling to work. Commuter transit benefits are not significantly related to bike commuting.

Coefficients for control variables are consistent with relationships reported in most other studies, but not all AORs are statistically significant. Whites are associated with 3.43 times greater odds to cycle to work than non-whites. Similarly, compared to women, men are associated with a 2.65 greater likelihood to cycle to work. One more car per household member is associated with 77% smaller odds for cycling to work. More bicycles per household member are related to a greater likelihood to cycle to work. One additional mile of bikeways per 1000 inhabitants is related to an 11% greater likelihood of cycling to work. Short work-trips of under 3 miles are associated with more bike commuting compared to longer trips. The coefficients for household location in the urban core and population density are not statistically significant in the full model. Finally, respondents with travel days between May and October are more likely to commute by bike than those traveling during other months.

To test the robustness of the results, a series of relogit regressions was estimated testing for the influence of individual groups of variables and controlling for potential multicollinearity and endogeneity (models 2–6 in Table 3). Coefficients of individual explanatory variables have comparable statistical significance, magnitude, and direction in the full and reduced models. In all models, the coefficients of trip-end facilities at work and free car parking remain significant and transit commuter benefits are not significant. Model 1 is the preferred specification because it includes all available variables that are theoretically relevant. Model 2 only includes variables capturing trip-end facilities, free car parking at work, and transit commuter benefits. The variables account for 9.0% of the variability in bike commuting. Statistical significance and direction of coefficients are comparable with the full model.[5]

Individuals who wish to cycle more may own fewer cars and more bicycles. Similarly, cyclists may live in denser urban neighborhoods with more bikeway supply. Models 3 through 5 test for these potential distorting effects due to simultaneous equations bias and multicollinearity. Model 3 omits car and bicycle ownership and models 4 and 5 omit land-use variables and bikeway supply. Most coefficients in the reduced models are not significantly different from the full model at the 5% level. In model 3, the coefficient for white is larger than in the full model, likely related to higher rates of bike ownership among whites. Moreover, the lower R^2 for model 3 compared to the full model suggests an important contribution of bike and car ownership towards explaining bicycle commuting.

Individuals who wish to cycle to work may seek an employer that provides bike parking, showers, and clothes lockers. Similarly, individuals who wish to drive may seek an employer with free car parking. Model 6 tests for potential endogeneity between bike commuting and trip-end facilities and parking at work. Coefficients are not significantly different from the full model in column 1. Another potential solution to modeling simultaneous dependencies is an instrumental variable regression that could help control for endogeneity. None of the variables in the data set were sufficiently exogenous to serve as a strong instrumental variable.[6]

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[3] Direction and statistical significance of the coefficients of the relogit model in column 1 of Table 3 are comparable to results of probit and logit models. Relogit estimation is, however, theoretically preferable. 'Scobit' would be an alternative estimation technique, but for this sample scobit does not converge.

[4] Reference group is assigned the base value 1.00.

[5] Model 2 likely suffers from omitted variables bias, thus producing more extreme AORs for trip-end facilities and free car parking than the full model.

[6] The omission of a variable directly measuring cyclist safety may be problematic for the analysis. The main difference in cyclist safety, however, is between safer cycling in the urban core jurisdictions and more dangerous cycling in suburban jurisdictions. Thus, the urban core dummy variable likely picks-up part of the variability in cyclist safety.

Table 3
Adjusted odds ratios (AORs) after relogit for the decision to commute to work by bicycle.

	Adjusted odds ratios (AOR) after relogit for the decision to commute by bicycle (1 = yes; 0 = no)					
	Full Model 1	Reduced Model 2	Reduced Model 3	Reduced Model 4	Reduced Model 5	Reduced Model 6
Workplace provides bike parking, showers, and lockers (1 = yes; 0 = no)	4.86***	6.81***	4.99***	5.26***	4.76***	
Workplace provides bike parking but not showers/lockers (1 = yes; 0 = no)	1.78*	1.97**	1.71*	1.83*	1.69*	
Workplace provides free car parking (1 = yes; 0 = no)	0.30***	0.23***	0.26***	0.29***	0.30***	
Workplace provides transit commuter subsidies (1 = yes; 0 = no)	0.73	0.91	0.85	0.74	0.75	
Respondent is white (1 = yes; 0 = no)	3.43***		4.02***	3.72***	3.58***	3.86***
Respondent is male (1 = yes; 0 = no)	2.65***		2.86***	2.55***	2.72***	2.89***
Respondent is between 25 and 40 years old (1 = yes; 0 = no)	1.27		1.28	1.37	1.27	1.30
Respondent's household is in highest income quartile (1 = yes; 0 = no)	1.83***		1.64**	1.83***	1.74***	1.86***
Cars per household member	0.23***			0.19***	0.23***	0.18***
Bicycles per household member	3.94***			4.13***	3.95***	4.06***
Trip distance of commute shorter than 3 miles (1 = yes; 0 = no)	2.37**		2.96***		2.31**	2.58***
Population density (in 1000 persons per acre)	1.00		1.00		1.00	1.00
Residence in 'Urban Core' jurisdiction (1 = yes; 0 = no)	1.28		1.48		1.40	1.60
Miles of bike lanes and paths per 1000 population	1.11***		1.14***	1.11***		1.08***
Summer months	1.73***		1.44***	1.77***	1.71***	1.80***
Pseudo R-squared (McFadden)	0.30	0.09	0.18	0.29	0.29	0.25
Prob > LR (Chi-Squared)	0.00	0.00	0.00	0.00	0.00	0.00
LL (intercept)	−444.3	−444.3	−444.3	−444.3	−444.3	−444.3
LL (full)	−313.4	−411.8	−366.5	−319.1	−317.9	−334.2
Observations	5091	5091	5091	5091	5091	5091

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

4. Conclusions

Over the past decades, American local governments have changed local zoning ordinances to encourage bicycle parking and cyclist showers in new large office buildings with the goal to increase bicycle commuting. The results of this analysis of commuters in the Washington region indicate that bike parking and cyclist showers at work are associated with more bike commuting—even after controlling for other determinants of cycling to work. The combined supply of bike parking, clothes lockers, and cyclist showers has a statistically stronger influence on bike commuting than the provision of bike parking only. Compared to no trip-end facilities for cyclists, both, bike parking and showers combined and bike parking alone are related to more bike commuting. Results also indicate that free car parking at work is associated with less bike commuting; and that workplace commuter transit benefits are not related to bike commuting.

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