Trends and Determinants of Cycling in the Washington, DC Region

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16. Abstract

This report analyzes cycling trends, policies, and commuting in the Washington, DC area. The analysis is divided into two parts. Part 1 focuses on cycling trends and policies in Washington (DC), Alexandria (VA), Arlington County (VA), Fairfax County (VA), Montgomery County (MD), and Prince George's County (MD) during the last two decades. The goal is to gain a better understanding of variability and determinants of cycling within one metropolitan area. Data on bicycling trends and policies originate from official published documents, unpublished reports, site visits, and in-person, email, or phone interviews with transport planners and experts from municipal governments, regional planning agencies, and bicycling advocacy organizations. Part 2 of the report presents a multiple regression analysis of determinants of bike commuting based on data of 5,091 workers from the Washington, DC region. A series of logit, probit, and relogit (Rare Events Logistic) regressions focus on the role of bike parking, cyclist showers, and free car parking at work as determinants of the decision to cycle to work, while controlling for socio-economic factors, population density, trip distance, bikeway supply, and season of the year. The report finds that cycling levels and cyclist safety have been increasing in the Washington region. However, cycling appears to be spatially concentrated in neighborhoods of the urban core jurisdictions. Compared to national averages for urbanized areas a larger share of bicycle trips in Washington, DC is commute or work related (41% vs. 17%). Area cyclists are predominantly male, between 25 and 40 years old, white, and from higher income groups. Bicycle planning in the region has its roots in the 1970s, experienced a hiatus in the 1980s, but has witnessed a 'renaissance' since the (late) 1990s. Initially bicycle policies focused on the provision of off-street paths—often shared with pedestrians. Since the late 1990s, jurisdictions have greatly expanded their on-street bicycle lanes and implemented other innovative programs. The regression analysis appears to support the expansion of the bike network, since bikeway supply is a significant predictor of bike commuting. Moreover, bike parking and cyclist showers at work are associated with more bike commuting. Free car parking at work is associated with less bike commuting; and transit commuter benefits were not a significant predictor of bike commuting.

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Table of Contents

Executive Summary

This report analyzes cycling trends, policies, and commuting in the Washington, DC area—including the urban core and inner suburban jurisdictions of Washington, DC; Alexandria City, Arlington County, and Fairfax County in Virginia; and Montgomery County and Prince George's County in Maryland. The report is divided into two parts. Part 1 analyses cycling trends and policies during the last two decades. Part 2 presents a multiple regression analysis of determinants of bike commuting in 2007/2008.

The analysis relies on mixed research methods including case studies, personal interviews, and multiple regression analysis. Data on bicycling trends and policies presented in Part 1 were collected from municipal governments, regional planning agencies, and bicycling advocacy organizations. Data originate from official published documents, unpublished reports, site visits, and in-person, email, or phone interviews with transport planners and experts. These data are analyzed in the context of national and regional cycling trends over time based on a comparison of the latest National Household Travel Survey (NHTS) 2008/2009 and the Metropolitan Washington Council of Government (MWCOG) household travel survey of 2007/2008. The multiple regression analysis in Part 2 utilizes individual level data from the MWCOG's regional household travel survey as well as Geographic Information Systems (GIS) data measuring the supply of bike trails and lanes.

Key Findings of Part 1 are:

- *Cycling levels are increasing—but with great spatial variability.* Between 1994 and 2008, cycling levels increased in the Washington, DC area. In both years the urban core jurisdictions of Washington, DC, Arlington, and Alexandria had higher cycling levels than the inner suburbs. However, even within the urban core jurisdictions cycling was spatially concentrated in certain neighborhoods, such as Capitol Hill, Adams Morgan, and Mount Pleasant in Washington, DC, and the Rosslyn-Ballston corridor and parts of Alexandria in Virginia.

- *A large share of bicycle trips in Washington, DC are commute or work related.* In 2008, 41% of all weekday bike trips in the region were commute or work related compared to only 17% in other urbanized areas in the U.S. The high share of utilitarian trip purposes in the region is comparable with bike-friendly cities in Europe, such as Berlin or Amsterdam.

- *Cyclist safety has improved.* As cycling levels have increased, so has cyclist safety. Moreover, in 2008, jurisdictions with more cycling had safer cycling. Washington, DC, Alexandria, Arlington County, and Montgomery County had safer cycling than Prince George's County and Fairfax County.

- *Bicycle planning has its roots in the 1970s and has experienced a 'renaissance' since the late 1990s.* Bike planning in the Washington, DC region has its roots in the 1970s. However, even in the late 1990s only few bike lanes had been built. Bike infrastructure supply was mostly limited to off-street paths that are shared between bicyclists and pedestrians. Since the late 1990s, all jurisdictions have also expanded their networks of on-street bike lanes and signed bike routes. Washington, DC, Arlington, and Alexandria have expanded their

network of on-street lanes more aggressively than suburban Montgomery, Fairfax, and Prince George's counties. Washington, DC has also been the regional leader in experimenting with innovative bicycle infrastructure, such as traffic lights for cyclists, bike boxes, contra-flow bike lanes, cycle tracks, and a state of the art bike parking station at Union Station. Together with Arlington County, Washington, DC launched Capital Bikeshare, the nation's first regional bike sharing program.

- *Programs targeting underrepresented groups could reduce geographic, age, ethnic, and gender disparities among cyclists.* Area cyclists are predominantly male, between 25 and 40 years old, white, and from higher income groups. These statistics resemble characteristics of typical cyclists in the USA. However, in European cities cycling is more equally distributed across all groups of society. In the Washington area, programs targeting underrepresented groups could reduce geographic, age, ethnic, and gender disparities among cyclists. Some efforts are already underway, such as WABA's 2011 outreach plan for under-served areas.

- *Network of bicycle infrastructure should be expanded and integrated.* Fully connecting the network of bike lanes and paths is an important step to encourage cycling among more risk-averse groups. Even though bike lane supply has increased significantly over the last decade, the bike network remains fragmented. This fragmentation often requires cyclists to ride in roads with heavy car traffic. Further expansion of the bike lane network may require taking travel lanes or parking from cars, which will be less politically acceptable than many of the comparatively easier measures implemented so far. Moreover, area wide traffic-calming of residential neighborhood streets could help connect the bike network by enabling cyclists to share neighborhood roads with slow traveling cars.

- *Further improvements of regional trail network.* The region already has an excellent network of separate mixed-use trails. However, especially on weekends, some of these mixed-use trails are crowded with pedestrians, runners, recreational cyclists, and sports cyclists all sharing the same narrow eight foot wide path. Cities like Minneapolis provide extra wide shared use trails with dedicated space for pedestrians and cyclists.

Key Findings Part 2:

- *Bike parking and cyclist showers at work are associated with more bike commuting*. Compared to no trip-end facilities for cyclists at work, both bike parking alone and bike parking combined with showers are related to more bike commuting. Results show that 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.

- *Free car parking at work is associated with less bike commuting. Transit commuter benefits are not a significant predictor of bike commuting.* Employees are less likely to cycle to work if the employer provides free car parking—even after controlling for other factors. Reducing free car parking at work may help increase bicycle commuting—especially for shorter trip distances. The provision of commuter transit benefits neither encourages nor discourages bike commuting.

- *The analysis supports the positive relationship between bikeway supply and bike commuting*. Washington, Arlington, and Alexandria have almost tripled the length of their bicycle networks since 1995. Results of this study indicate that expansion of bikeway networks may help increase the share of bike commuters.

- *Other results of this study may help guide transport policies in the long run*. For example, commuters are more likely to ride their bicycle if trip distances are short. Thus policies that encourage denser development patterns and mixed use development that keep trip distances short may help encourage bike commuting. Moreover, bicycle ownership appears to be an important determinant of bike commuting. Washington, DC and Arlington now provide a public bike sharing system (CaBi) that makes bicycles accessible to a larger group of society—including those who do not own a bike. Easier access to CaBi bicycles may help increase bike commuting.

- *Inclusive programs are needed to encourage bike commuting for all groups.* Significant differences in bike commuting levels by gender, race, and income in the Washington region suggest the need for inclusive programs to encourage bike commuting for all groups. Results of this analysis indicate that a comprehensive package of policies may be most successful in encouraging a larger group of society to cycle. Trip-end facilities at work, less free car parking, and greater bikeway supply appear to be significant parts of this policy package to encourage cycling. Implementing these policies together will likely be most successful in encouraging more bicycling.

PART I: Cycling Trends and Policies in the Washington, DC Region

1. Introduction

Encouraging more bicycling in U.S. metropolitan areas may help alleviate peak hour congestion on roadways and public transport. More daily bicycling can also help reduce CO_2 emissions, local air pollution, oil dependence, and provide health enhancing physical activity as part of the daily routine (Buehler et al., 2011, Heinen et al., 2010, Banister, 2005). For the last 20 years, cycling levels have been increasing in U.S. cities. However, growth in cycling varies widely across and within jurisdictions. Most prior studies on cycling in large cities exclude adjoining suburban jurisdictions (Dill and Carr, 2003, Pucher and Buehler, 2011). This analysis comprises urban core and inner suburban jurisdictions of the Washington, DC area[1] to capture cycling levels beyond the municipal boundaries of Washington, DC. The goal is to gain a better understanding of variability and determinants of cycling within one metropolitan area—controlling for interregional variability in climate, and culture. Data for this analysis originate from the Metropolitan Washington Council of Government (MWCOG) Household Travel Survey 2007/2008, the U.S. Census Bureau, and information obtained directly from local bicycling experts. The qualitative analysis of trends and policies in this part of the report is combined with a series of multiple regression analyses investigating the role of socio-economic factors and bike infrastructure in determining cycling levels and for all trips and the commute in Part 2.

2. Cycling in the Washington, DC Region

2.1 The Study Area: The Washington, DC Region

Table 1 provides an overview of socio-economic and spatial characteristics of the study area. The urban core of the region includes Washington and the two Virginia jurisdictions of Arlington County, and Alexandria City on the western bank of the Potomac (MWCOG, 2009). Suburban jurisdictions included in this study are Fairfax County in Virginia and Montgomery and Prince George's Counties in Maryland bordering Washington to the north and east respectively (for map see Figure 3 below). Together the urban core and inner suburban jurisdictions comprise 3.8 million inhabitants.

Median household incomes in the region are higher than the national average of $50,000 (USDOC, 2010, USDOC, 2011b). Even Prince George's County—the least wealthy jurisdiction in this study—had a median household income that was 40% higher than the national average[2]. However, higher household incomes in the Washington area are partially offset by 40% higher costs of living compared to the national average for urban areas (USDOC, 2011a). With the exception of Arlington County, area jurisdictions have higher shares of minority populations than the national average of 29%. Washington and Prince George's County are majority African American (53% and 64%, respectively).

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[1] The Metropolitan Washington Council of Governments (MWCOG) categorizes Washington, Alexandria City, and Arlington County as part of the *urban core* of the region. Montgomery County, Prince George's County, and Fairfax County (including Falls Church and Fairfax City) are defined as *inner suburbs*.

[2] Municipal averages hide large income discrepancies within jurisdictions. For example, in Washington, DC median household income east of the Anacostia River was only $34,000 in 2010—well below the national median USDOC 2011b. *United States Census,* Washington, DC, United States Department of Commerce, U.S. Census Bureau..

Table 1 also lists population density, share of households without cars, percentage of university and college students in the population, and Metrorail stations per inhabitant for each jurisdiction, since these variables are significant predictors of bicycling and bike commuting (Heinen et al., 2010, Krizek et al., 2009). Higher population density is related to more cycling, because shorter distances between origins and destinations result in trips that are easily covered by bicycle. Washington, Arlington, and Alexandria have three to four times greater population densities than suburban Fairfax, Montgomery, and Prince George's County.

University students have been found to cycle more, but students account for a similar share of the population in all jurisdictions. Individuals in households without automobiles are more likely to cycle. Causation may run both ways, since individuals who prefer cycling may decide not to own an automobile. The share of carless households in Washington, 35%, is eight times greater than in Fairfax County, where 4% of households are carless. In the other jurisdictions roughly 10% of households are carless. The high share of households without cars in Washington may be partially explained by good accessibility provided by Metrorail and bus. In 2009, the Washington region ranked 4th in the U.S. in number of passenger trips and passenger miles of travel by public transport (APTA, 2011).

The connection between public transport access and cycling remains less clear. Some studies point to competition between the two modes, while others identify the bicycle as feeder mode for public transport that enlarges transit's catchment area beyond walking distance. There are Metrorail stations in all jurisdictions of the study area. The majority of residents in Washington, Arlington, and Alexandria have a Metrorail stop within walking or cycling distance from their homes, but many areas of Fairfax, Montgomery, and Prince George's County do not have any access to Metrorail.

Jurisdiction	Population	Land Area (square miles)	Population per Square Mile	Percent of University Students	Percent of Car-free Households	Percent White	Household Median Income	Metro Rail Stops per 100,000 Inhabitants
Washington	600,000	61	9,800	11%	35%	39%	$59,300	6.3
Arlington	217,000	26	8,400	10%	11%	71%	$96,200	5.1
Alexandria	150,000	15	9,900	9%	12%	63%	$77,100	2.7
Fairfax	1,038,000	395	2,600	8%	4%	66%	$102,500	0.5
Montgomery	972,000	495	2,000	9%	8%	58%	$94,400	1.8
Prince George's	835,000	485	1,700	10%	9%	23%	$69,900	1.2

Table 1. Socio-demographic and spatial characteristics of Washington, DC and adjacent jurisdictions. *Sources*: (USDOC, 2010, USDOC, 2011b, MWCOG, 2009).

2.2 Trends and Geographic Variability in Cycling Levels

Over the last 20 years cycling levels have been increasing in the Washington area (TPB, 2010a, TPB, 2006, MWCOG, 2010a, USDOC, 1980-2000, USDOC, 2011b). Between 1994 and 2008, the bike share of all trips in the regional core increased from 1.0% in 1994 to 1.5% in 2008. Over the same time period, cycling also increased in the inner suburbs, from 0.4% to 0.7% of all trips (MWCOG, 2010a, TPB, 2010b). Cycling levels in the urban core were twice as high as in suburban jurisdictions.

Both in 1994 and 2008, Washington had the highest share of trips by bike—followed by

Alexandria (Figure 1). The share of bike trips in Washington and Alexandria was twice as high as the inner suburbs of Fairfax, Montgomery, and Prince George's County. Between 1994 and 2008 Alexandria showed the strongest increase in cycling levels from 0.6% to 1.1% of all trips. Cycling levels increased more than 50% in Arlington, Montgomery, and Prince George's County.

Between 1994 and 2008, the share of commutes by bike increased in all jurisdictions. In both years, all jurisdictions had a higher bike share for commutes than for all trip purposes (see Figure 1). For example, in 2008 in Washington cycling accounted for 3.3% of work trips compared to 1.5% of all trips. In Alexandria the share of work trips was almost three times the share for all trips. This is in contrast to national averages for urban areas that show 1.1% bike share for all trips and 0.8% bike share for commuters (Alliance for Biking and Walking, 2010).

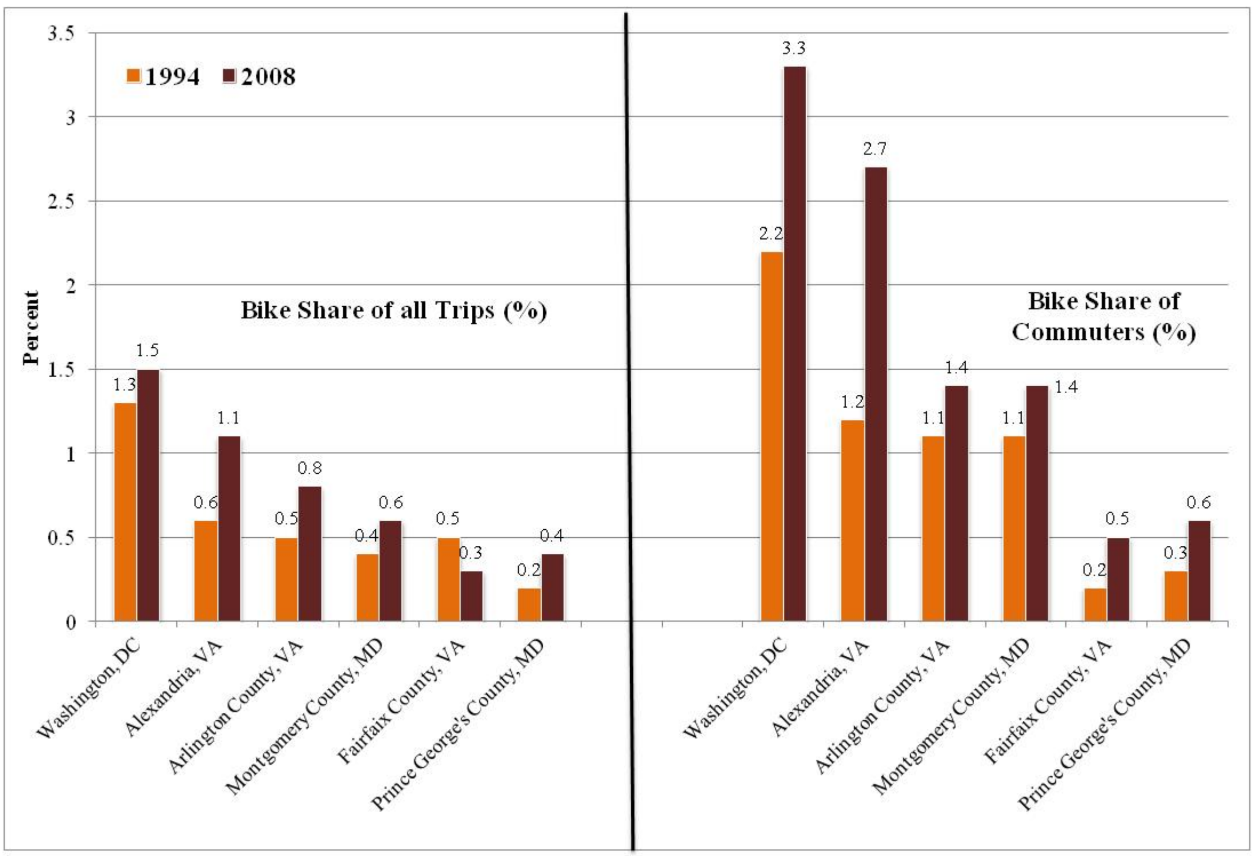

Figure 1. Trend in bike share of all trips and share of commute trips by bicycle in Washington, DC and adjacent jurisdictions, 1994-2008. *Source*: (MWCOG, 2010a)

The U.S. Census Bureau tracks the regular mode of transportation for commuters. Census data support the trends presented above. Between 1990 and 2005-2009 (averaged), the number of daily bike commuters increased almost two-fold in the region—from 6,086 to 11,517 regular bike commuters per day. The number of regular daily bike commuters increased at least twofold in Washington, Alexandria City, Arlington County, and Montgomery County (see Figure 2). Fairfax County had the smallest percentage increase in bike commuting over this time period.

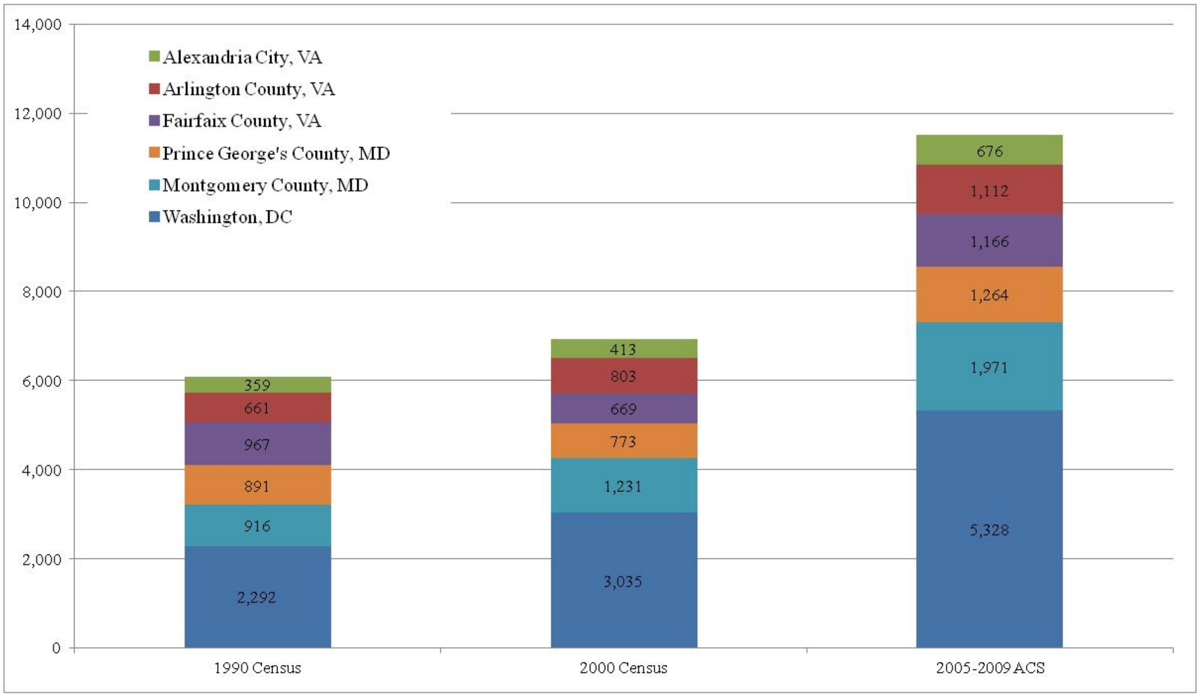

Figure 2. Trend in regular daily bike commuters in Washington, DC and inner ring suburbs, 1990-2009. *Source*: own analysis of (USDOC, 1980-2000, USDOC, 2010, USDOC, 2011b).

Local counts of bicyclists on bridges and trails also support the apparent increase in cycling levels over the last 20 years. Counts of bicyclists entering the core of the metropolitan area show an increase from 800 daily cyclists in 1986 to 1,900 in 2002 (TPB, 2010a, TPB, 2006). Due to a change in methodology this trend cannot be extended beyond 2002. However, a data series relying on a revised count method shows a more than two fold (126%) increase in peak hour cyclists entering Washington between 2004 and 2009 (TPB, 2010a). Local travel surveys also report increases in cycling levels. However, these surveys are often not representative of the population and results are neither comparable over time nor across jurisdictions.

There is considerable variability in bike commute levels within the 5 jurisdictions. Sample size of the MWCOG regional travel survey is not large enough to disaggregate results for all trip purposes below the level of individual jurisdictions. However, disaggregate statistics are available from the U.S. Census Bureau, but only for the commute. Figure 3 displays the bike share of commuters for census tracts in the Washington region. Bike commute levels are highest in census tracts inside the Capital Beltway (Interstate 495). Census tracts in College Park, home to the University of Maryland, and Bethesda have the highest cycling 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 for Northern Virginia. Within Washington cycling commute shares are highest in the Capitol Hill, Georgetown, Adams Morgan, Mount Pleasant, and U-Street neighborhoods. Bike commute levels decrease with distance from the regional core and are lowest in outlying suburban census tracts. However, even within Washington, census tracts east of the Anacostia River have few bike commuters.

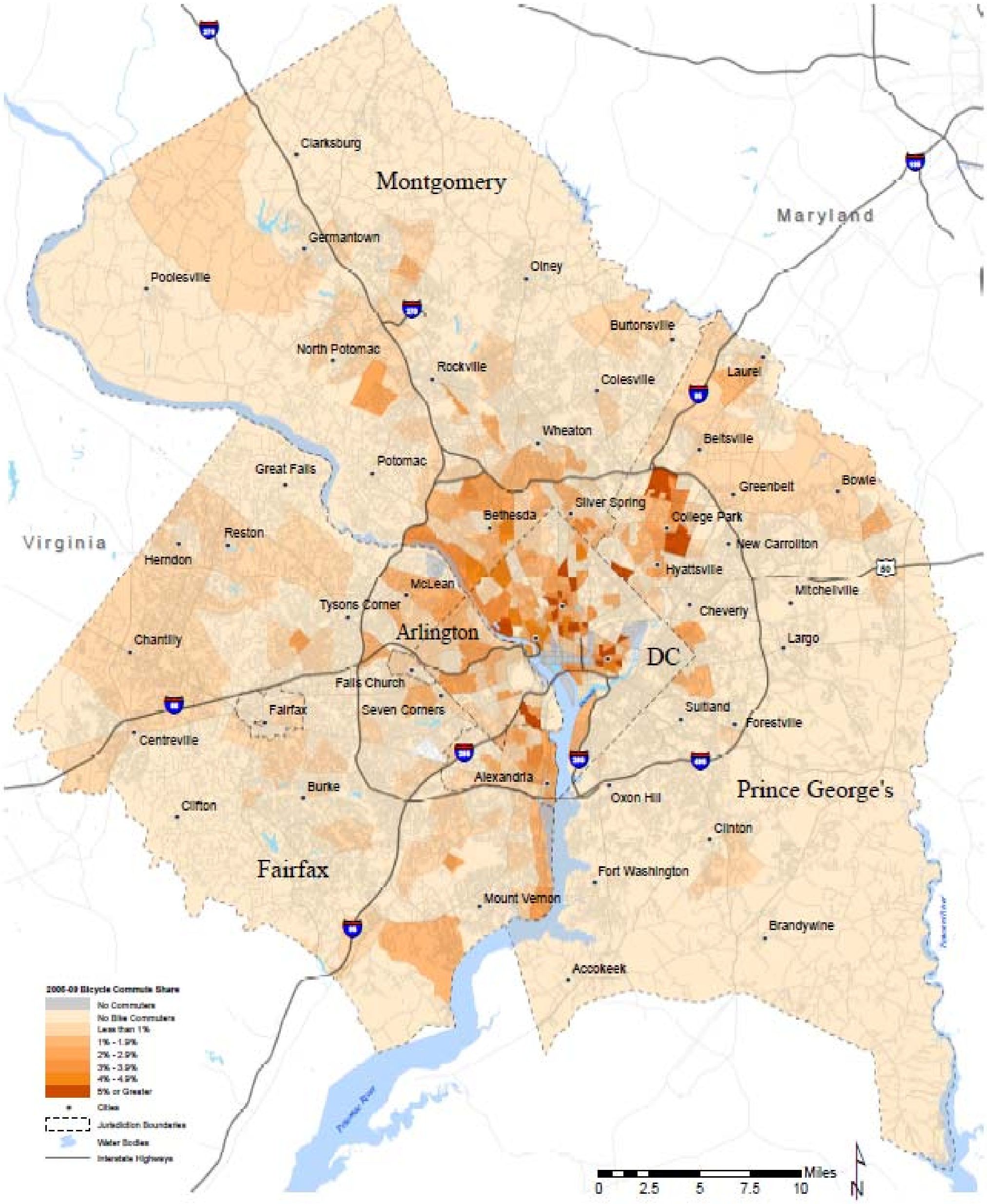

Figure 3. Variation in the share of regular bike commuters in the Washington, DC region.
Source: own analysis of (USDOC, 2010, USDOC, 2011b). *Note: Map created by D. Sonenklar*

2.3 Trip Purpose and Cyclist Demographics

2.3.1 Trip Purpose

Bike commute mode shares presented above suggest that the commute accounts for a large share of bike trips in the Washington area. According to the 2008 MWCOG and 2009 NHTS, Washington's share of weekday bike trips that are work-related (41%) is more than twice the national average for urbanized areas (17%) (Figure 4). By comparison, only 19% of weekday bike trips in Washington, DC are for recreation—compared to 47% in urbanized areas nationally. Together, commute, personal business, and shopping trips account for 60% of weekday bike trips in the Washington region. This level of cycling for transport is far higher than in other U.S. cities and comparable with bike friendly European cities such as Amsterdam, Copenhagen, or Berlin

(Pucher and Buehler, 2008). The sample size of the MWCOG survey does not allow further disaggregation of these results to individual jurisdictions.

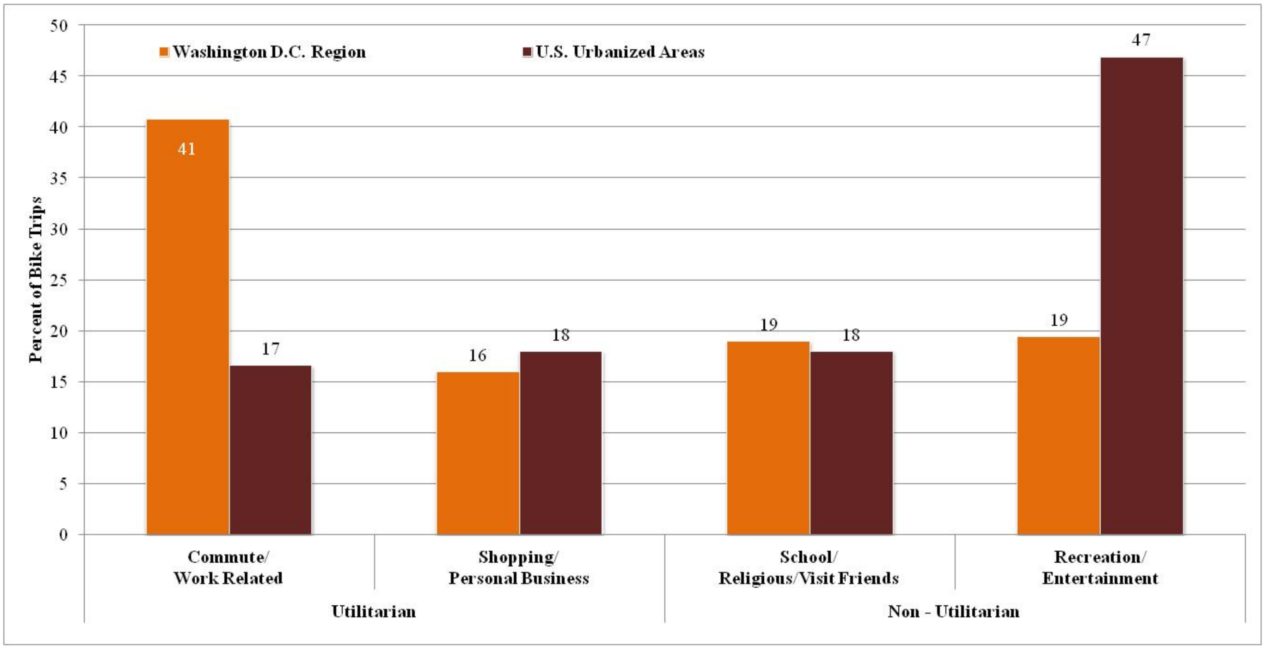

Figure 4. Share of weekday bicycle trips by trip purpose in the Washington, D.C. region compared to U.S. national averages for urbanized areas, 2008/2009. *Source*: own analysis of (USDOT, 2010, MWCOG, 2010a).

2.3.2 Cyclist Demographics

Figure 5 shows that bicycling in Washington is less male dominated than in other urbanized areas in the U.S.: 33% of bike trips in the Washington area are by women compared to 25% nationally. The age of cyclists also differs. Nationally, almost 50% of bike trips are made by individuals between 5 and 24 years old. In Washington the majority of bike trips (70%) are made by 25 to 65 year olds. Compared to other urbanized areas, cyclists in Washington also own fewer cars. Forty-two percent of bike trips are made by individuals living in car-free or one-car households in the Washington area. Nationally individuals in carless or one car households only account for 33% of bike trips. Cyclists in Washington are also wealthier than the national average—even when controlling for differences in local and national income distributions. The wealthiest 25% of the population accounts for 41% of bike trips in Washington compared to 26% nationally. Lastly, cycling in the Washington region is dominated by whites, who accounted for 88% of all bike trips in 2008 (vs. 82% nationally).

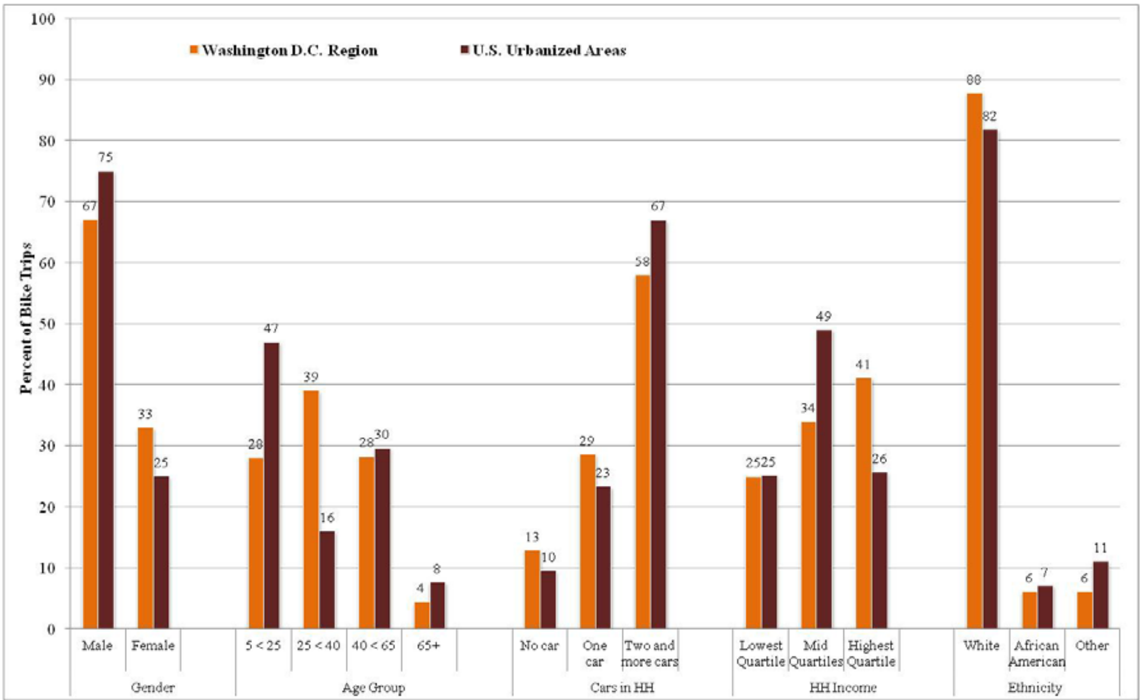

Figure 5. Share of bike trips by socio-demographic indicators in the Washington, D.C. region compared to the U.S. national averages for urbanized areas, 2008/2009. *Source*: own analysis of (USDOT, 2010, MWCOG, 2010a).

2.4 State of Cyclist Safety

Available statistics indicate stagnating cyclist fatality and injury levels in spite of increasing cycling levels. Between 1998 and 2009, regional cyclist fatalities per year fluctuated widely from lows of 1 and 3 in 2003 and 2006 to highs of 10 and 13 fatalities in 2001 and 2005—but without any clear upward or downward trend (MWCOG, 2010a). Reported cyclist injuries were stable between 1998 (657 injuries) and 2009 (653 injuries) (MWCOG, 2010a). A two-fold increase in cycling during the same time period suggests significant improvements in cyclist safety per bicycle trip. For example, the annual cyclist fatality rate per 1 million regular bike commuters declined from 2.88 in 1998-2001 to 1.13 in 2006-2009 (averaged). Similarly, rates of serious cyclist injuries per 100,000 bike commuters per year declined from 2.66 to 1.55 over the same time period (MWCOG, 2010a, USDOC, 2010). These statistics can only serve as a rough proxy for safety trends, since cyclist fatalities in the numerator originate from all bike trips and the denominator only accounts for regular bike commuters. However, commute levels are the only available data for cycling levels for this time frame.

The theory of 'safety in numbers' suggests that some of the improvements in cyclist safety in the Washington area may be related to the increase in cycling levels (Jacobsen, 2003). Causation likely runs both ways. Safe cycling conditions encourage more individuals to cycle, while higher cycling levels contribute to a safer cycling environment. The theory suggests that higher cycling volumes increase cyclist visibility and driver awareness (i.e. greater awareness of cyclists when making turns and entering roadways). A higher share of trips by bike also increases the likelihood that drivers themselves may be bicyclists for other trips and thus can better anticipate the movements and safety needs of cyclists in traffic. Moreover, communities with more cycling typically have better and safer bike infrastructure (Heinen et al., 2010).

Figure 5 presents the relationship between annual cyclist fatality rates and cycling levels across jurisdictions in the Washington area. Fatality data are averaged for the years 2006-2009 to account for annual fluctuations in cyclist fatalities. Figure 6 plots annual bicycle trips per capita on the vertical axis and average yearly cyclist fatality rates on the horizontal axis. In 2006-2009, Alexandria had the safest cycling followed by Washington, Arlington, and Montgomery County. By comparison, cyclist fatality rates were 2 to 4 times greater in Fairfax and Prince George's County. Figure 6 supports the theory of safety in numbers within the Washington area, since jurisdictions with higher cycling levels have lower cyclist fatality rates. Moreover and as discussed further below, localities with safer cycling also provide more separate facilities for cyclists, such as bike lanes and paths. There are no comparable data on cyclist injuries across jurisdictions, since Maryland statistics do not distinguish between injured motorists and injured cyclists in crashes that involve cars and bicycle.

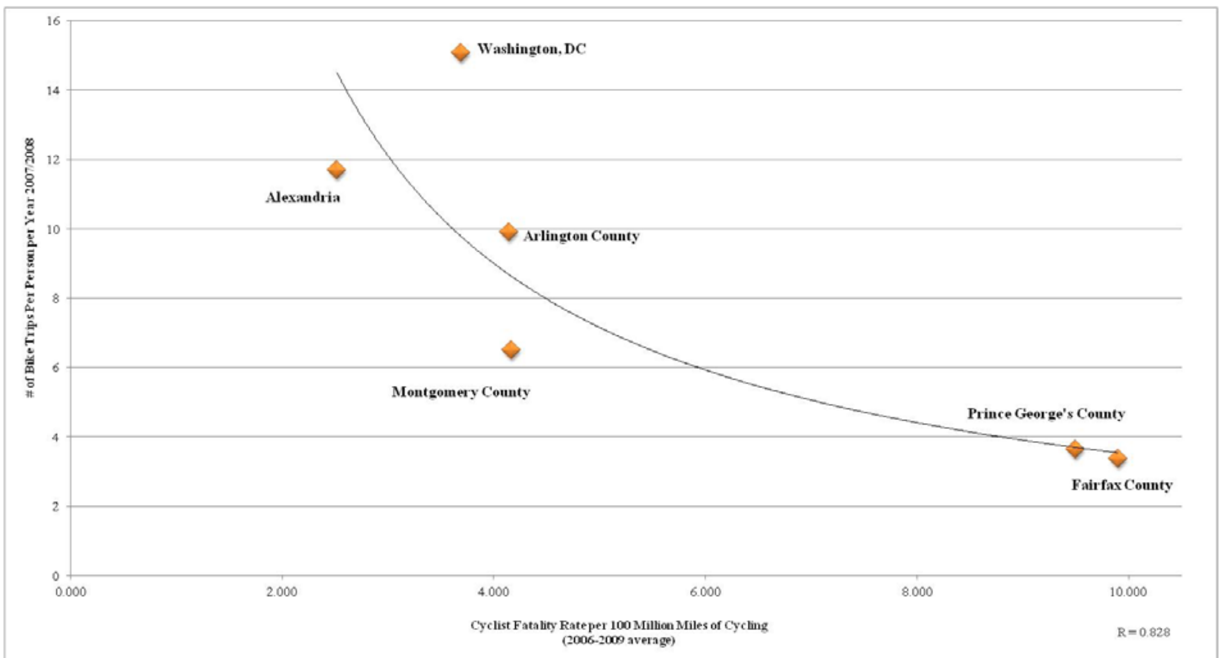

Figure 6. Relationship between annual cyclist fatality rates and bike trips per person per year in Washington, D.C. and adjacent jurisdictions (2006-2009 averages). *Source*: own calculations based on (MWCOG, 2010a, TPB, 2010a) and data collected from jurisdictions.

2.4.1 Laws and Regulations that Influence Cyclist Safety

Laws requiring bike helmet use are similar in all jurisdictions and cannot explain the difference in cycling safety (WABA, 2011a). None of the jurisdiction requires bike helmets for adults and all jurisdictions mandate bike helmets for children[3]. Moreover, all jurisdictions require front bike lights and rear reflectors or lights when riding in the dark. Washington, DC additionally requires bells on bikes. Texting while driving is not allowed in the entire region. However, Virginia allows talking on a mobile phone while driving. Washington, Maryland, and Virginia include bicyclist's rights in their driver's education manuals and in questions on driver's tests.

[3] Washington, DC and Maryland require that children and teenagers younger than 16 wear bike helmets. The State of Virginia does not require bike helmets for children, but local ordinances in Alexandria, Arlington County, and Fairfax County require children younger than 14 to wear a bike helmet.

3. Cycling Policy in the Washington, DC Area

3.1 A Brief History of Bicycle Planning

A detailed description of the history of bike planning in Washington area jurisdictions is beyond the scope of this paper. The following provides a brief overview of the early developments of bike planning in the 1970s, the relative lack of planning in the 1980s and early 1990s, and the renewed focus on bike planning since the mid 1990s.

Planning for bicycling in the Washington region dates to the 1970s. In 1972 the Washington Area Bicycle Association (WABA), the region's largest pro-bicycling lobbying organization, was formed (Hanson and Young, 2008, WABA, 2010b). Local jurisdictions and the regional planning board published their initial bicycle plans in subsequent years: Alexandria City and Arlington County in 1974; Washington and Montgomery County in 1978, and the regional Transportation Planning Board (TPB) in 1977 (DDOT, 2005, DDOT, 2010a, Bike Arlington, 2011, Fairfax County, 2011, Montgomery County, 2008, Prince George's County, 2011, City of Alexandria, 2011a, TPB, 2010a). Bicycle plans of the 1970s were often limited to specific corridors or were part of other planning documents, such as comprehensive plans or transportation master plans. Bike plans typically called for the construction of on-street and off-street bikeways. Prince George's County's plan (1975) was an exception, since it focused on the construction of a shared-use trail network only.

The implementation of most of these initial plans was limited to the construction of off-street bike trails and paths. There were only a few new pro-bike initiatives in the 1980s, such as the inclusion of bicycling in Arlington County's transportation master plan and Alexandria's new bicycle map. In the 1990s, interest in bicycle planning reemerged at regional and local levels. Bicycling became part of the TPB's regional long-range transportation plan in 1991 and the TPB published its regional vision for bicycling in 1998 (TPB, 2006, TPB, 2001). Arlington County updated its transportation master plan with an expanded bicycling section in 1994 (Hanson and Young, 2008). Alexandria established a bicycle study committee in 1992 and published a bicycle transportation and multi-use trail master plan in 1998. Montgomery County adopted its Countywide Park Trails plan in 1998 and Prince George's County created a bicycle trails advisory group. Washington did not have a dedicated bike planner during the decade.

Building on the progress of the 1990s, bicycle planning experienced a renaissance in the 2000s. The TPB published its regional bicycle priorities plan in 2001 and authored and updated its regional bicycle plan in 2006 and 2010. Washington hired a full time bicycle planner in 2001 and released its bicycle master plan in 2005. Arlington included bicycling into the goals and policies section of its transportation master plan in 2007. Alexandria hired its first bicycle planner in 2004, adopted a bicycle mobility plan in 2008, and updated its bicycle map in 2009. In Maryland, Montgomery and Prince George's Counties adopted bicycle master plans in 2005 and 2009, respectively. Fairfax County adopted a comprehensive bicycle initiative in 2006 and published a county bicycle map in 2009. As of 2011 all jurisdictions, the MWCOG, and Metro have staff dedicated to bicycle planning[4] (TPB, 2010a).

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[4] Washington, DC had 2 full time equivalent (FTE) staff working on bicycling and 1 staff working on planning for trails. Arlington had 1 staff and Alexandria 0.5 dedicated personnel for bicycling. Fairfax County employed 1 staff for bicycling and 2 for trails. Montgomery County had 1 staff for trails and 0.33 persons working for bicycling. Prince George's County employed 1 staff for trail planning. Additionally, the TBP and Metro, the regional transit

3.2 Off-Street Paths and Shared-Use Trails

Between the 1970s and 2000 most jurisdictions focused on building off-street trails and shared-use paths—often with planning and financial support from the National Park Service (NPS, 1990). In 2010, there were 490 miles of trails and shared use-paths connecting the entire region (TPB, 2010a). Trails are typically shared between cyclists and other non-motorized users and are either paved or made of compacted gravel. The late1970s saw the opening of several trails such as Rock Creek Park trail in Washington and regional trails, such as the Cleveland and Ohio (C&O) towpath between Washington and Cumberland, MD (1971), the Mount Vernon Trail connecting Arlington, Washington, Alexandria, and Fairfax County (1973), and the Washington and Old Dominion (W & OD) trail connecting Arlington County, Fairfax County, and Purcellville in Loudon County, Virginia (1974) (NPS, 1990).

Today, roughly 190 miles of the regional shared-use trail network are entirely separated from roadways, often following old railway lines or canals, such as the W & OD trail or the Capital Crescent Trail between Georgetown in Washington and Silver Spring in Montgomery County that opened in 1986 (NPS, 1990, TPB, 2010a). About 300 miles of trails run adjacent to roadways. For example, Arlington County's Custis Trail that opened in 1982 and connects to both the Mount Vernon and W & OD trails, mainly follows the Interstate 66 corridor (Hanson and Young, 2008).

Compared to the 1970s and 1980s, new construction of regional trails has slowed since the year 2000, though, but new stretches of regional trails continue to be built (TPB, 2010a). For example, the City of Rockville in Montgomery County built 20 miles of trails between 1998 and 2005 (City of Rockville, 2011a). Similarly, between 2000 and 2010 Washington added 10 miles of trails to increase total trail mileage to 50 miles[5] (DDOT, 2010a). While bike commuting on trails has been increasing, the majority of shared-use paths are most heavily used on weekends for recreation. For example, counts by the National Park Service indicate that 75% of bike trips on the Mount Vernon Trail are for recreation and only 25% are for transportation (NPS, 2011).

The region has also made progress in widening sidewalks and including bicycle and pedestrian facilities on new bridges to provide important connections for cyclists. For example, the newly rebuilt Woodrow Wilson Bridge crossing the Potomac River between Alexandria City and Prince George's County includes an improved shared-use bike path providing a safe connection for cyclists between the Mount Vernon Trail in Virginia and connecting routes in Maryland (TPB, 2010a). There are also shared-use sidewalks (some separated from traffic) on all but one bridge crossing the Potomac and Anacostia Rivers (DDOT, 2010a). Nevertheless, while the region has improved a number of important bridge connections, many shared-use paths on bridges remain narrow, crowded, and insufficiently separated from car traffic. This is especially the case for those bridges crossing the Anacostia River.

3.3 On-Street Bike Lanes, Innovative Bike Infrastructure, and Signed Bike Routes

In contrast to the expansion of trails, few bike lanes had been built by the late 1990s. For

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provider, each employed 0.5 staff working specifically on bicycling. The Virginia Department of Transportation also employed 1 staff for bicycle planning in their Northern Virginia offices TPB 2010a. *Bicycle and Pedestrian Plan for the National Capital Region,* Washington, DC, Transportation Planning Board, MWCOG..

[5] One of these trails was a stretch of the Metropolitan Branch Trail (MTB) that opened in 2010 connecting Union Station in Washington, DC and Silver Spring, MD (DDOT, 2011).

example, Arlington County had only 3 miles of bike lanes in 1995 (Bike Arlington, 2011, TPB, 2010a). In 2001 Washington had only 3.2 miles of bike lanes, even though the city's 1978 plan called for 17 miles of on-street lanes (DDOT, 2010a). Since then local jurisdictions have significantly expanded their supply of on-road bike lanes. Table 2 compares the supply of bike lanes and paved off-street trails for the year 2011. Washington's supply of bike lanes was 15 times greater than the supply of lanes in Montgomery County. Fairfax County had over 200 miles of paved off-street trails—almost twenty times more than Alexandria City.

The comparison of total miles of bike paths and lanes hides variability in geographic size of the jurisdictions. Figure 7 compares bike path and lane supply adjusting for land area. The core jurisdictions have the greatest supply of bike lanes and paths per square mile[6]. Compared to suburban counties, bike path supply was .5 to 9 times greater in core jurisdictions. The greatest difference was in bike lane supply per land area, which was more than 14 times greater in the core jurisdictions.

Jurisdiction	On-Street Lanes (miles)	Paved Off-Street Trails (miles)	On-Street Lanes and Off-Street Trails (miles)
Washington, DC	60	50	110
Arlington County	29	48	77
Alexandria City	13	13	26
Fairfax County	22	200	222
Montgomery County	17	146	163
Prince George's County	4	90	94

Table 2. Supply of bike lanes and paved off-street paths and trails, 2011 *(measured as centerline miles) Source:* Data collected directly from bicycle planners in each jurisdiction.

[6] Adjusting for population size, core jurisdictions also had a 4 to 20 times greater supply of bike lanes than suburban counties.

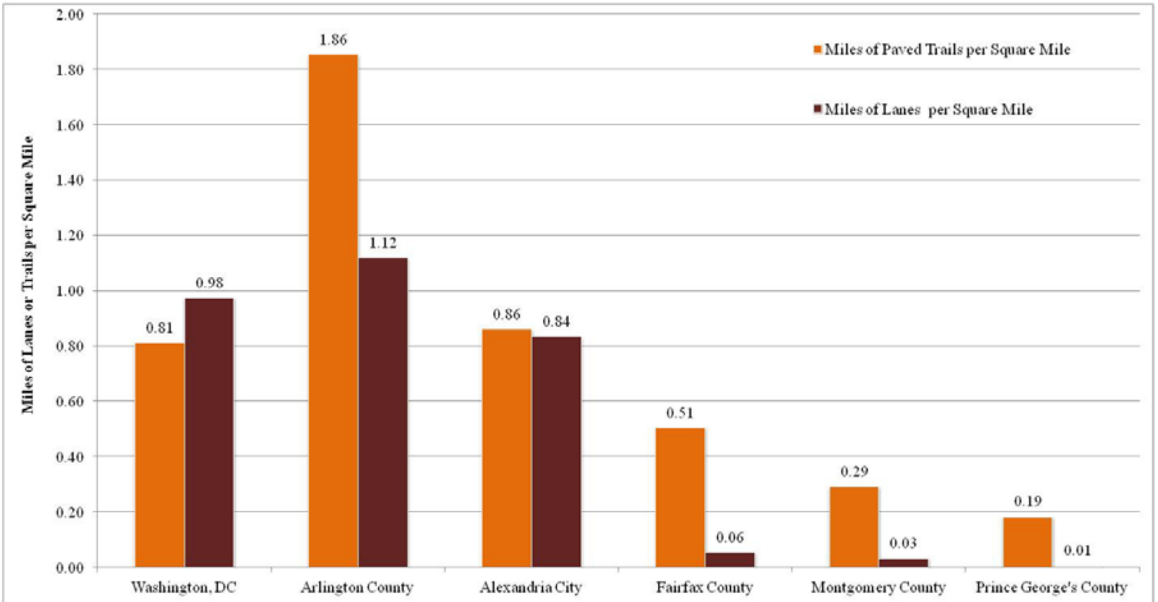

Figure 7. Supply of bike lanes and off-street paths per square mile land area, 2011.
Source: Data collected directly from bicycle planners in each jurisdiction.

Alexandria, Arlington, and Washington have been building bike lanes at a much faster rate than surrounding jurisdictions. For example, bike lane supply in Washington increased 20 fold from 3 miles in 2001 to 60 miles in 2011. Similarly, bike lane supply in Arlington increased ten-fold from 3 miles in 1995 to 29 miles in 2011. Many of the bike lanes were installed on roadways that previously had extra wide car travel lanes or parking lanes with excess width. One example of this was 15th Street NW in Washington, DC, which had relatively low car traffic volumes.

Figure 8 compares the spatial distribution of the construction of new bike lanes in Washington between the early 2000s and 2009. The city focused its new bike lanes in neighborhoods, such as Capitol Hill, Mount Pleasant, Adams Morgan, and U-Street that had some of the city's highest cycling levels in the early 2000s. As the network of bike lanes expanded in these neighborhoods, cycling commute levels increased as well. Causation may run both ways. High levels of cycling in the early 2000s may have increased demand for bike lanes in these neighborhoods. More bike lanes in turn likely encouraged more commuters to ride their bicycles. However, the construction of bicycle lanes was not uncontroversial. In some neighborhoods bike lanes have become associated with redevelopment, rising property values, and resulting economic pressure on poorer households.

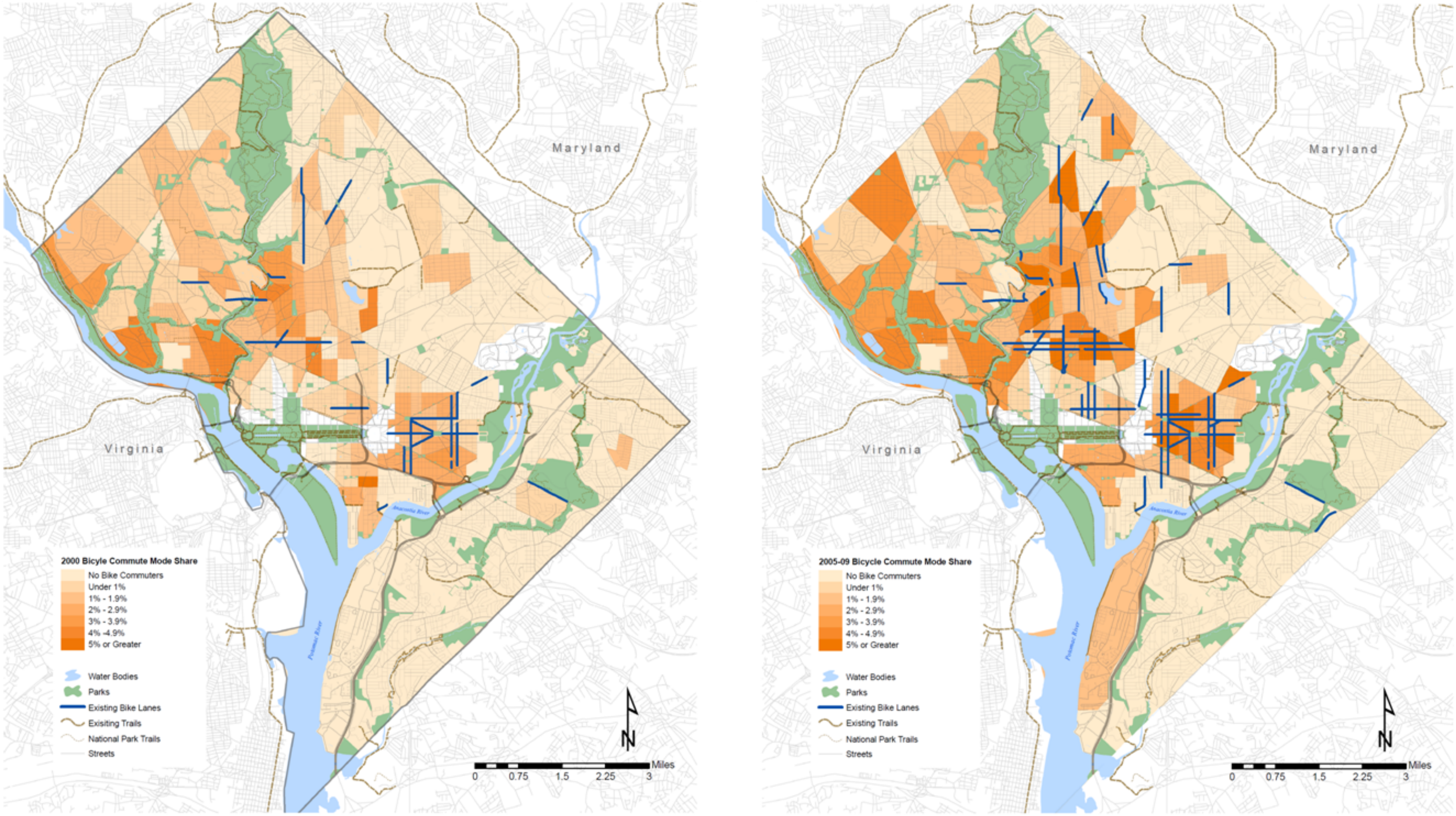

Figure 8. Supply of bike lanes and paths and cycling commute levels in Washington, DC, early 2000-2003 (left) and 2007-2009 (right). (USDOC, 1980-2000, USDOC, 2010, USDOC, 2011b) *Source: Map created by Dan Sonenklar*

The core jurisdictions have also led the region in experimenting with innovative bicycle infrastructure measures. Washington installed bike boxes at select intersections, such as New Hampshire Avenue. Alexandria painted its first bike box on Commonwealth Avenue. Bike boxes give bicycles an advanced stop line in front of automobiles. Bike boxes increase cyclist visibility for motorists and also allow cyclists to pass-by traffic congestion and wait in front of the queue, away from tailpipe emissions.

Washington also installed the region's first bicycle activated traffic light at the intersection of 16th Street, NW, U-Street, NW, and New Hampshire Avenue, NW. Moreover, Washington, DC was first in the region to install contra-flow bicycle lanes. The lanes run along 15th Street, NW and New Hampshire Avenue, NW—restricting car traffic to one direction only, but allowing cyclists to ride in either direction. Washington also built bi-directional bike lanes in the median on the portion of Pennsylvania Avenue, NW that runs between the U.S. Capitol and the White House. Special striping on the roadway provides a 10 inch buffer between cyclists and car traffic. There are protected cycle tracks on South Dakota Avenue, NW and along 15th Street, NW in Washington. In contrast to buffered bike lanes, cycle tracks provide additional vertical physical barriers to protect cyclists from car traffic.

Figure 9. Bike commuters on the bi-directional bike lanes on Pennsylvania Avenue between the White House and the Capitol. *Photo: Ralph Buehler*

Figure 10. Bi-directional cycle tracks on 15th Street, NW separate cyclist from car traffic and provide extra security. *Photo: Ralph Buehler*

Alexandria City painted extra wide 'climbing' bike lanes on Braddock Road to give cyclists extra space for horizontal movement when cycling up the steep hill (City of Alexandria, 2011a). Washington used dashed lines to extend bike lanes through intersections to guide cyclists and alert drivers, such as at the intersection of R Street, NW and Connecticut Avenue. While this is new in the region, other North American cities use more advanced measures to guide cyclists through intersections. For example, New York City and Portland, are experimenting with colored bike lanes to increase driver awareness for cyclists at dangerous crossings or intersections (Pucher et al., 2011b).

Most area jurisdictions have marked road surfaces with 'sharrows'—featuring two chevrons and a drawing of a bicyclist—reminding car drivers to share the road with cyclists. All jurisdictions have expanded their network of signed bike routes. These bike routes sometimes overlap with bike lanes and paths, but typically guide cyclists on 'sharrowed' roads and streets with low car traffic volumes. In 2009, Washington had 64 miles of signed bike routes and Alexandria had 60 miles (City of Alexandria, 2011a, DDOT, 2010a). Bike route signs and 'sharrows' do not require extra space on roadways and are easier to implement than separate bike paths and lanes that require dedicated space for cyclists. However, signed routes do not separate cyclists from car traffic and thus may discourage more risk-averse groups from cycling. In the context of the region's relative lack of use of traffic calming measures, this may be particularly problematic.

Indeed, in European cities, such as Berlin and Amsterdam, and other North American cities, such as Vancouver and Portland, traffic calming is an integral part of the bike network (Pucher and Buehler, 2008, Pucher et al., 2011b, City of Portland, 2010, City of Vancouver, 2010). Traffic calming combines low speed limits with physical alterations of the road surface designed to slow or divert car traffic. Measures include speed bumps, humps, chicanes, median islands, raised crosswalks, curb extensions, street closures, and special pavement. Low speed limits and limited car traffic allow cyclists and motorists to share the road. Traffic-calmed neighborhood streets can often provide crucial connections between otherwise disjointed bike paths or lanes.

Responses to the MWCOG 2008 survey confirm that risk-averse groups prefer separate cycling facilities. According to the survey results, 29% of area cyclists typically cycled on off-street trails; 37% rode predominantly in bicycle lanes or on streets with traffic; and 34% cycled equally on trails and roads. However, women, who have been shown to be more risk averse (Garrard et al., 2008), accounted for over 40% of cyclists typically riding on trails, compared to only 30% cycling in the street or bike lanes.

Laws for cycling on sidewalks and requirements for the use of bike lanes and paths vary by state and jurisdiction (WABA, 2011a). Maryland requires cyclists to ride on bike paths and lanes, where they are present. Cyclists in Washington and Virginia can choose where to ride, even if bike paths and lanes are present. The two states and Washington allow cycling on sidewalks unless prohibited by local ordinance. Alexandria and Montgomery County prohibit cycling on certain sidewalks by ordinance. Similarly, in Washington cycling on sidewalks is prohibited in the central business district. Given the heavy congestion in Washington both during the week as well as on weekends, the prohibition from cycling on sidewalks in downtown DC may be especially discouraging to those riders unwilling to ride with car traffic.

3.4 Bike-Transit Integration, Bike Sharing, and Bike Parking in Buildings

Integrating bicycles with public transportation may be mutually beneficial for both modes (Martens, 2007, Brons et al., 2009). Bike parking at transit stops and dedicated space for bikes on trains and buses can enlarge the catchment area of public transport beyond typical walking distances. Cyclists can ride their bikes to and from transit stops and make longer trips than would be otherwise possible just by bike. Public transport also provides an alternative when regular cyclists experience inclement weather or mechanical failure. In 2007, only 0.64% of passengers rode their bicycles to Metrorail stations (WMATA, 2010). However, between 2002 and 2007 daily Metrorail access trips by bike increased from 965 in 2002 to 1,550 in 2007 according to the WMATA passenger survey (WMATA, 2010). The busiest bike access stations in the region were Union Station in Washington, Hyattsville in Maryland, and Pentagon City and East Falls Church in Virginia (NVTC, 2011). Statistics about bikes on buses were only available from Metrobus. Of the roughly 400,000 daily passenger trips on Metrobus, only 650 were made by passengers with bicycles (WMATA, 2010).

3.4.1 Bikes on Buses and Trains

With the exceptions of DASH bus in Alexandria[7] and Prince George's County's bus system, all buses had front-mounted bike racks with space for up to two bicycles in 2011 (WABA, 2010a). Transit systems do not charge for transporting bikes on racks on buses. Cyclists can also bring their bikes on Metrorail for free, but only four bicycles are allowed per car and only outside of peak commute hours (7-10am and 4-7pm). All Metrorail stations are equipped with elevators and cyclists are required to use elevators, since bikes are not allowed on escalators (WABA, 2010a).

[7] DASH has obtained funding to equip buses with bike racks, as early as 2012.

Maryland's MARC commuter rail, serving the northern suburbs, does not allow any full-size bikes on its trains. VRE, Virginia's regional rail system, allows bicycles on midday trains, but bans bikes from early inbound trains during the morning and early outbound trains during the afternoon rush hour. MARC, VRE, and Metro allow folding bicycles on their trains at all times (WABA, 2010a).

Jurisdiction	Racks	Lockers	Sum Racks and Lockers	Racks per Station	Lockers per Station	Racks and Lockers per Station
Washington, DC	333	200	533	8.8	5.3	14.0
Arlington County, VA	256	102	358	22.8	8.7	31.6
Alexandria City, VA	130	44	174	27.5	11.0	38.5
Fairfax County, VA	258	164	422	26.8	24.8	51.6
Montgomery County, MD	567	394	961	47.3	32.8	80.1
Prince George's County, MD	392	352	744	26.1	23.5	49.6

Table 3. Bike parking supply at Metrorail and regional rail stations, 2011. *Source:* Data collected directly from bicycle planners in each jurisdiction.

3.4.2 Bike Parking at Train Stations

There are about 1,900 bike rack spaces and 1,300 bike lockers available at transit stations and park and ride lots in the Washington region (WABA, 2010a, NVTC, 2011, WMATA, 2010). Spaces in bike racks are available on a first-come first-serve basis and free of charge. Table 3 shows that Montgomery County had the largest average number of bike racks per Metrorail station. Suburban Metrorail stations have more bike lockers per station than Metrorail stations in the urban core. Lockers protect bicycles from weather and theft and can be rented on a yearly basis. Fairfax County charges $60 per year for bike locker rentals at park and ride parking lots with bus access. In 2010, the cost to rent a bike locker at a Metrorail station increased from $70 to $200 per year—the first increase since the early 1980s (NVTC, 2011). Use of bike lockers varies by station. Overall, about half of all lockers at Metrorail stations were rented in 2011—down from about 2/3 before the price increase in 2010.

Metrorail and local jurisdictions have plans to expand the number of bike parking spaces at transit stops in the future. For example, regional and local transport plans propose bicycle cages at five Metrorail stations and two bike stations holding 150 bicycles each. Metrorail and the City of Alexandria intend to double the number of bike parking spaces at the King Street station (from 34 to 68). Metrorail is also updating existing facilities, replacing old bike racks with new state of the art U-shaped bike racks at many stations (NVTC, 2011).

In 2009, Washington's first full service bike station opened next to Union Station. The bike station provides indoor, secure parking spaces for 140 bikes. Cyclists can park their bikes for $1 per day, $12 per month, or $96 per year (WABA, 2010a, NVTC, 2011). The station also offers bike repair, bike lockers, and changing rooms, but does not provide showers. Station staff is present from 7am to 7pm on weekdays and from 9am to 5pm on weekends and bike station members can access the station with a key card at any time. Due to its proximity to historic Union Station and the Old Post Office, the bike station had to adhere to special design standards, which raised construction costs to about $4.5 million. The city is planning to provide less expensive bike stations or bike cages at other key transit hubs in the region (DDOT, 2010b).

Figure 11. The bicycle station at Union Station provides secure and sheltered parking for 140 bicycles, bike repair service, and bike rentals. *Photo: Ralph Buehler*

3.4.3 Bike Sharing

Washington was the first area in North America to experiment with third generation bike sharing systems—consisting of bicycles, docking stations, and computerized kiosks for self-service bike rental with credit or debit cards (CaBi, 2011, Shaheen et al., 2010, DeMaio, 2009). In 2008, Smart Bike opened a small pilot project with 120 bikes and 10 kiosks in Washington DC (SmartBike DC, 2010). In September 2010, Smart Bikes was replaced with Capital Bikeshare (CaBi). CaBi is the first regional bikesharing system in North America. It is jointly operated by Arlington County and Washington, DC. CaBi is 10 times larger than Smart Bikes with 1,100 bikes and 116 stations in 2011.

Sixty additional CaBi stations are currently planned for an expansion of the system within Washington and Arlington (CaBi, 2011). Rockville, MD and Alexandria also have plans to join the system (City of Rockville, 2011b, City of Alexandria, 2011b). Alexandria will launch a small extension of the CaBi system in spring 2012 comprising six stations and 54 bicycles in the Old Town and Carlyle neighborhoods. Rockville's CaBi extension will include 200 bicycles and 20 stations.

Figure 12. Third generation bike sharing systems, such as Capital Bikeshare, consist of automated kiosks, docking stations, and specially branded bicycles. *Photo: Ralph Buehler*

Funding for Washington's share of CaBi ($6 million) came from federal Congestion Mitigation and Air Quality (CMAQ) funds and a 20% local match. Arlington County's funds ($835,000) originated from the Virginia Department of Transportation and other local moneys (DDOT, 2010a). Similar to Washington, the City of Alexandria will use CMAQ funds to pay for the installation of CaBi (City of Alexandria, 2011b). Rockville was able to obtain Job Access Reverse Commute (JARC) funds from the Federal Transit Administration (City of Rockville, 2011b). Due to JARC requirements the city will distribute free CaBi memberships to qualifying low income residents.

CaBi has been successful during its first year of operation. Its 17,000 members made over 1 million trips between September 2010 and September 2011 (CaBi, 2011). The greatest challenge for the system is balancing bicycles between stations during the morning and afternoon commutes. In the morning, demand for bikes is highest in residential neighborhoods, while demand for bike parking is greatest in downtown locations. Commuter movements from residential neighborhoods to workplaces downtown in the morning result in 'empty' kiosks without bikes in residential neighborhoods and 'full' kiosks without available bike parking spaces in downtown. During the first year, bicycle theft and vandalism have been minimal. Only 45 bikes had to be repaired because of vandalism and only 6 bikes were stolen. Bike theft may be minimal, because the design of CaBi bikes is unique and bikes are built with special parts that cannot be used on other bikes and need special tools to be disassembled (CaBi, 2011).

3.4.5 Bike Parking in Buildings and Public Spaces

Parking for bicycles at trip origins and destinations is as important for cyclists as car parking is for drivers. Ordinances in all jurisdictions require some form of bicycle parking—typically depending on office space or retail floor area, number of units in residential buildings, or number of car parking spaces provided. Arlington County and Montgomery County additionally require showers and changing facilities for bicyclists in buildings larger than 50,000 and 100,000 square feet respectively (MWCOG, 2011). Washington mandates bicycle parking in off-street car parking garages (DDOT, 2010a). Prince George's County's bike parking requirements are limited to special transit-oriented developments in the county. In Fairfax County commercial developments may be required to provide bike parking and showers when requesting a variance or special use permit.

Area jurisdictions do not systematically track the number of bike parking spaces. Washington estimates that in 2011, about 2/3 of car parking garages in the city provided bike parking (DDOT, 2010a). Arlington County estimates that 4,000 to 6,000 secure bike parking spaces have been built since requiring bike parking in 1990 (Bike Arlington, 2011). Some data are available on the number of bike racks supplied in public spaces, such as on sidewalks or in public squares. Between 2002 and 2009, Washington installed 1,162 bike racks. Arlington County provides 600 public short-term bicycle racks, including a covered bike parking shelter close to a public transport hub. Arlington plans to install 50-70 new bicycle racks per year. Alexandria has been installing about 100 new bicycle parking spaces each year (City of Alexandria, 2011a). Washington, Arlington, Alexandria, and Montgomery County have a bicycle rack request program that allows businesses and citizen to request bike rack installation. DDOT pays for bicycle racks if employers cover the cost of installation.

3.5 Promotion, Information, Incentives, and Education

There are many bike promotion events and educational programs in the Washington region. Some programs are provided region-wide while others are local initiatives only. The following briefly summarizes key initiatives (WABA, 2010b).

3.5.1 Cyclist Education

Similar to other regions in North America, the Washington region offers bike education courses for adults and children. WABA's Confident City Cycling course provides a refresher in riding skills for interested adults. Together with local and state governments WABA also provides cycling courses for children. Washington's week-long Street Smarts for Kids program offers cycling classes for children in grades 3 through 5. The class instruction focuses on cycling safety. DDOT estimates that in 2009 and 2010 an average of 4,000 children participated in youth bicycles education courses (Alliance for Biking and Walking, 2010).

Rockville, MD was the first city in Maryland to develop and implement a comprehensive K-5 grade pedestrian and bicycle safety education program for children. In 2011, Fairfax County's first Braddock Bike Day safety event provided cycling education and bike rodeos for 75 participants. Moreover, in collaboration with WABA, local jurisdictions participate in the federally funded Safe Route to Schools (SRTS) program—offering financial and planning support for schools that wish to improve safety for walking and cycling to school.

3.5.2 Driver Education and Enforcement

Educating motorists and enforcing the rules of the road are important to increase cyclist safety. Driver training in all jurisdictions includes information about non-motorized road users. Additionally, DDOT conducted training for 2,000 bus drivers on how to protect cyclists. Since 2005, Washington has also trained 400 of its police officers in pedestrian and bicyclist issues—alerting police officers to the specific needs of pedestrians and cyclists (DDOT, 2005, DDOT, 2010a).

Since 2002, the TPB has coordinated the annual Street Smart program, including a public awareness campaign about road safety with advertisements at transit stops, on the radio, and in the print media. The program is geared to foster behavioral change and intends to improve safety for cyclists and pedestrians. The campaign also includes a temporary surge in traffic safety enforcement with increased citations and warnings for motorists, pedestrians, and cyclists. During the fall of 2009 and the spring of 2010, police issued 30,221 citations and 7,804 warnings to motorists, pedestrians, and cyclists.

3.5.3 Bike Promotion and Incentives

All jurisdictions participate in the national Bike to Work day. Between 2002 and 2011, the number of participating cyclists in the 6 jurisdictions increased fivefold from 2,035 in 2002 to 10,992 in 2011 (WABA, 2011b). There are other annual bike ride events, such as Bike DC, which had 3,000 participants in 2008, the annual 50 States and 13 Colonies Ride, and the Vasa Ride in March organized by WABA and the Swedish Embassy. More frequent bike events include the City Bikes Ladies rides on Sundays organized by City Bikes and Critical Mass rides on the first Friday of every month. There are also regular bike clinics and co-ops in many jurisdictions—such as Phoenix Bikes in Arlington, VeloCity in Alexandria, and the Bike House in Washington. These organizations hold community events and other educational opportunities for youth as we as adults to learn about bicycling and bicycle repair. Bike clinics and co-ops also provide a venue for cyclists to interact and share experiences. BicycleSpace, a new bicycle shop also organizes group rides and other events for cyclists.

WABA's Bicycle Ambassadors attend public events and engage in one on one consultation about cycling and cyclist safety. Alexandria, WABA, and the National Park Service also partnered to sponsor a similar ambassador program to promote non-automobile travel in Alexandria. At some large events, such as the Cherry Blossom festival in Washington in the spring, WABA volunteers provide valet parking for bikes. There is no charge for cyclists, but event organizers pay a fee to WABA. When using the bike valet parking, cyclists leave their bikes at a guarded WABA stand, receive a unique identifying code for their bicycle, and later reclaim their bikes using that identification number.

3.5.4 Information for Cyclists

All jurisdictions provide bicycle maps in print and online. Maryland and Virginia also provide statewide maps of facilities for bicyclists. 'Google Maps' and 'Ride the City' provide online bicycle trip planning tools that allow cyclists to find the best route between trip origins and destinations. 'Ride the City' allows cyclists to distinguish between the safest route, following bike lanes and paths as closely as possible, and the most direct route for those cyclists who are comfortable cycling in traffic. Cyclists can also access 'Ride the City' on their smart phones while en route. All jurisdictions have made progress in providing signage for cyclist. The regional trail networks are particularly well signed, and some local bike route networks, such as the network in Alexandria, have improved their signage as well.

3.5.5 Incentives

The MWCOG offers a guaranteed-ride-home program for workers who commute to work by bike, transit, or on foot at least two days per week (MWCOG, 2011). Once signed up, the program guarantees up to four free rides home per year in case of emergency. The program intends to remove the uncertainty and increase flexibility for non-automobile commuters. The MWCOG's Commuter Connections program also provides detailed information about bike commuting for individuals and employers. Information for employers comprises local initiatives, as well as federal programs, such as the pre-tax parking cash-out and the $20 bicycle transportation fringe benefit.

In 2011, the Fairfax County Department of Transportation offered a Bike Benefit Match Program to employers who provided the $20 federal bicycle transportation fringe benefit (Fairfax County, 2011). For qualified employers, the county matched 50% of the total amount in fringe benefits. Matching funds could be used by employers to purchase bike racks, lockers, or marketing materials. Arlington County offers an innovative incentive for its employees to cycle to work (Bike Arlington, 2011). County employees, who cycle for at least half of their commutes, receive $35 per month. Moreover, Arlington's car-free-diet program offers online resources for commuters to compare differences in costs as well as emissions between commuting by car and bike. Individuals can also make an online pledge to drive less and cycle more.

4. Summary of Trends and Policy Recommendations

Between 1994 and 2008, cycling levels increased in the Washington region. In both years the urban core jurisdictions of Washington, Arlington, and Alexandria had higher cycling levels than the inner suburbs. However, even within the urban core cycling is spatially concentrated in certain neighborhoods, such as Capitol Hill, Adams Morgan, and Mount Pleasant in Washington, DC, and the Rosslyn-Ballston corridor and Old Town Alexandria in Virginia. In 2008, 41% of all weekday bike trips in the region were commute related compared to only 17% in other urbanized areas in the U.S. The high share of utilitarian trip purposes in the region is comparable with bike-friendly cities in Europe, such as Berlin or Amsterdam. Bike commuting in the region may be influenced both by the region's high level of congestion as well as the WMATA transit system, which is one of the most heavily used systems in the country.

Available statistics indicate that cycling has gotten safer over the last decade. In 2008, Washington, Alexandria, Arlington County, and Montgomery County have safer cycling than Prince George's County and Fairfax County. Safety statistics and trends support the theory of safety in numbers. Cycling has become safer over time with increasing cycling levels and in 2008 jurisdictions with more cycling had safer cycling. Causality likely flows both ways, since safer cycling also encourages more individuals to cycle.

Bike planning in the Washington region has its roots in the 1970s. However, even by the late 1990s only very few bike lanes had been built and bike infrastructure supply was mostly limited to shared-use off-street bike paths. In 2010, 490 miles of shared-use paths connected the entire region. Since the late 1990s, all jurisdictions have also expanded their networks of on-street bike lanes and signed bike routes. Washington,, Arlington, and Alexandria have expanded their network of on-street lanes more aggressively than suburban Montgomery, Fairfax, and Prince George's counties. Washington has also been the regional leader in experimenting with innovative bicycle infrastructure, such as traffic lights for cyclists, bike boxes, contra-flow bike lanes, cycle tracks, and a state of the art bike parking station at Union Station. Together with Arlington County, Washington launched the nation's first regional bike sharing program.

In spite of the progress documented above, many challenges for cycling remain. For example, area cyclists are still predominantly male, between 25 and 40 years old, white, and from higher income groups. Programs tailored to specific groups could help increase cycling for everyone in Washington including all age groups, all ethnicities, men as well as women, and all geographic areas of the region. Some efforts are already underway, such as WABA's 2011 outreach plan for under-served areas.

Fully connecting the network of bike lanes and bike paths is another important step to encourage cycling among more risk-averse groups. Even though bike lane supply has increased significantly over the last decade, the bike network still remains fragmented often requiring cyclist to ride in roads with heavy car traffic. Further expansion of the bike lane network will require taking travel lanes or parking from cars, which will be less politically acceptable than many of the easier measure implemented so far. Moreover, area wide traffic-calming of residential neighborhood streets should be part of this package to enable cyclists to share these roads with slow traveling cars. Cities like Portland, Seattle, or Vancouver have created bike boulevards—traffic-calmed residential streets that prioritize cycling over car travel.

The region already has an excellent network of separate bike paths. However, especially on weekends, some of these mixed-use trails are crowded with pedestrians, runners, recreational cyclists, and sports cyclists sharing the same narrow eight feet wide path. Cities like Minneapolis provide extra wide shared use trails with dedicated space for pedestrians and cyclists. Sometimes pedestrians and cyclists in Minneapolis are separated by a solid line painted on the path. Other times the city provides physically separated bike paths and walkways.

PART II: Bicycle Commuting in the Washington, DC Region

1. Introduction

This part of the report examines the role of bike parking, cyclist showers, and free car parking at work as determinants of the decision to cycle to work. The analysis is based on commute data of 5,091 workers from the Washington, DC region, where commuting accounts for 41% of all bike trips (MWCOG, 2010a). A series of *logit*, *probit*, and *relogit (Rare Events Logistic)* regressions also controls for other determinants of bike commuting, such as socio-economic factors, population density, trip distance, bikeway supply, and season of the year (Heinen et al., 2010).

2. Determinants of Bike Commuting: The Role of Trip-End Facilities, Free Car Parking, and Transit Commuter Benefits at Work

Socio-economic and demographic factors, land use, bikeway supply, topography, and climate have been identified as significant determinants of bike commuting (Heinen et al., 2010). Few studies control for trip-end facilities at work, such as bike parking and cyclist showers. Most of those studies rely on stated preference surveys (SPS) that require cyclists to choose between hypothetical scenarios. Studies on trip-end facilities rarely include non-cyclists or use revealed preference data based on actual commute trips (Noland and Kunreuther, 1995, Moritz, 1997, Dickinson et al., 2003).

Most studies conclude that bike parking at work encourages bike commuting (Heinen et al., 2010). The differential impact of various trip-end facilities remains ambiguous. Some studies find that cyclist showers increase the likelihood to commute by bike, while other studies indicate that they do not (Stinson and Bhat, 2004, Taylor and Mahmassani, 1996). Wardman et al.(2007) report that bike commuters in three British cities were willing to trade-off longer commute times for trip-end facilities at work: 2.5 to 4.3 additional minutes for bike parking and 6.0 more minutes for showers or changing facilities. Two SPS studies from Canada find that cyclists value bike parking more than cyclist showers (Abraham et al., 2002, Hunt and Abraham, 2007). A web-based SPS of Texan cyclists found that bike commuters value bicycle racks and cyclist showers equally (Sener et al., 2009).

The studies listed above include only cyclists. Few studies also include non-cyclists. For example, responding to a SPS 2,065 British commuters indicated that improved changing facilities at work may increase cycling to work for non-cyclists (Dickinson et al., 2003). A survey of 354 cyclists and non-cyclist in Philadelphia finds that bike parking is positively related to the likelihood of bike commuting (Noland and Kunreuther, 1995).

Some studies also include other employer incentives. For example, a SPS by Wardman et al. (2007) suggests that monetary payments to cyclists may encourage bike commuting—especially when payments are designed to offset the benefit of free automobile parking at work. Others speculate that free car parking may discourage cycling to work, but do not control for parking in the analysis (Stinson and Bhat, 2004, Noland and Kunreuther, 1995, Dickinson et al., 2003, Taylor and Mahmassani, 1996). Several studies on commuting find that free car parking is an incentive for driving to work and thus discourages bicycle commuting (Shoup, 2005, Shoup, 1999).

No recent study has investigated the connection of employer provided transit commuter benefits and cycling to work. Evidence on the relationship of transit ridership and cycling for all trip purposes is contradictory. Some studies indicate that the two modes are competing for passengers, while others report that transit and bicycling are complementary (Schwanen, 2002, Pucher and Buehler, 2009).

In summary, most studies conclude that bike parking is positively related to bike commuting. The differential influence of various types of trip-end facilities remains unclear. There are no studies that additionally control for the relationship of free car parking at the workplace or commuter transit benefits. Most studies are SPS of cyclists, thus excluding non-bicyclists and not capturing actual observed behavior.

This analysis uses (revealed preference) travel data of commuters as reported by cyclists and non-cyclists in the Washington regional travel survey. The analysis distinguishes between bike parking, clothes lockers, and cyclist showers at work, and includes variables indicating if employers provide free automobile parking and transit benefits. Control variables capture socio-demographic characteristics of respondents, land-use, season of the year, and bikeway supply.

3. Data Sources and Variables

3.1 The MWCOG Travel Survey 2007/2008

Data for this analysis originate from the MWCOG regional household travel survey 2007/2008 (MWCOG, 2010a, MWCOG, 2010b). Households were contacted based on a random sample of residential postal addresses stratified by geographic area. An introductory letter invited households to participate and to complete a short questionnaire. Participating households received a one-day travel diary to record each household member's travel during an assigned weekday between February 2007 and May 2008. In the diary respondents recorded purpose, mode of transport, distance, and duration of each trip.

One day after the travel day had passed, the survey team gathered travel data using a computer aided telephone interview (CATI) with each household member. During the interview respondents relied on their travel diary as 'memory jogger'. The final sample includes 4,711 households with 5,091 daily commuters from Washington, Arlington, Alexandria, Fairfax County, Montgomery County, and Prince George's County—reaching target participation rates in each geographic area. The location of households was geo-coded for 2,155 Traffic Analysis Zones (TAZ). Data on bikeway supply, population, and land area were merged to the dataset using TAZ identifiers (MWCOG, 2010b).

3.2 Variables Measuring Trip-End Facilities, Car Parking, and Transit Benefits

Two dummy variables measure trip-end facilities at work: (1) workplaces with bike parking, but no cyclist showers or clothes lockers and (2) 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. Another 38.2% of commuters had bike parking at work, but no showers or lockers. Nearly half of the respondents (47.8%) had no cyclist facilities at work (see Table 2). Almost half of the commuters (46.8%) reported free car parking at work and 26.9% had access to employer subsidies for commuting by public transport.

3.3 Control Variables

This analysis controls for other determinants of cycling commonly cited in the literature. Three demographic variables capture cyclist gender, race/ethnicity, and age. Previous studies show that bike commuters in the U.S. are more likely male, white, and younger than 25 years old (Buehler and Pucher, 2011, Dill and Carr, 2003). In this sample 68.8% of respondents are white, 49.1% are male, and 22.9% are between 25 and 40 years old.

Two socioeconomic variables measure household income and automobile access. Previous studies find that individuals in households with more cars are less likely to cycle (Heinen et al., 2010, Krizek et al., 2009). Moreover, results from the latest NHTS suggest higher income groups cycle more than poorer groups (Pucher et al., 2011a). Commuters in this sample live in households with 0.8 cars per household member and 35.1% live in the highest income quartile of households.

Previous studies have shown that cycling levels are higher in dense, mixed-use developments with short trip distances and proximity of households to destinations such as offices, stores, and restaurants (Baltes, 1997, Ewing and Cervero, 2010). In this study, the influence of the built environment is approximated with three variables: population density per land area in the TAZ of residence, reported distance of the work trip, and an indicator if a respondent lives in an urban core or suburban jurisdiction. On average respondents lived in TAZs with 15.8 people per acre. Twenty-three percent had commutes shorter than 3 miles—a distance easily covered by bicycle. Moreover, 36.5% live in Washington, Alexandria, and Arlington—the urban core jurisdictions. Several studies find a positive relationship of bikeway supply and cycling levels (Parkin et al., 2008, Dill and Carr, 2003). This study measures bikeway supply as combined centerline miles of off-street bike paths and on-street bike lanes per 1,000 inhabitants at the TAZ level. The average commuter in this sample lived in a TAZ with 0.1 miles of bikeways per 1,000 inhabitants.

Several studies find that cycling is deterred by rainy, cold, or hot weather (Heinen et al., 2010, Stinson and Bhat, 2003). This analysis includes a dummy variable flagging months with temperate weather (April-October). Almost two thirds of all bike trips are made during those months.

This study cannot control for some other factors that influence cycling levels, such as topography, bike parking at home, bike racks on buses, bike sharing programs, cycling training courses, media campaigns, and educational events (ABW, 2010, Fietsberaad, 2010). Moreover, the analysis cannot control cyclist safety (Jacobsen, 2003). Comparable data for topography, bicycle policies, and cyclist safety are not available at the individual, household, or TAZ level. However, compared to suburban counties, the urban core jurisdictions of Washington, Arlington, and Alexandria, have safer cycling and have implemented more programs to encourage cycling (TPB, 2010a). Thus, the urban core dummy variable in this analysis will likely capture some of these differences across jurisdictions.

Variable Name	Measurement/Description	Descriptive Statistics	Significant Bi-variate Association with Bike Commuting
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 (StDev: 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)
Bikeway Supply	Center line miles of bike lanes and paths per 1,000 persons in home TAZ.	Mean: 0.0965 miles of bikeways per 1,000 persons (StDev: 0.921)	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 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)
Bike Parking & 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 other.	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 other.	26.9% have employers that provide transit commuter benefits	P<0.05 (Chi-square test)
Season	Nominal variable. Value of 1 if travel day was between May and October; 0 if other.	57.8% of indivudals were interviewed in the summer months	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

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

4. Analysis and Results

4.1 Bivariate Relationships

Chi-square tests indicate that bike commuting is more common for whites, males, the top income quartile, trip distances shorter than 3 miles, and households in the urban core of the region (last column, Table 2). Moreover, t-tests show that individuals in households with more cars are less likely to commute by bike and persons in households with more bicycles have a greater likelihood to cycle to work. Another set of t-tests indicates that the share of bike commuters is greater at higher population densities and in areas with greater supply of bike paths and lanes. Significantly more individuals commute by bike if employers provide cyclist showers, bike lockers, and bike parking. Free car parking at work is associated with a lower share of bike commuters and employer transit benefits are positively related to bike commuting. Lastly, more individuals commute by bike during the warmer summer months.

4.2 Modeling Approach

Bivariate tests analyze relationships between bike commuting and independent variables one at a time. Multiple regressions examine the relationship of bike commuting, employer incentives, and trip-end facilities at work, while controlling for other factors. Models 1 and 2 in Table 2 present results of probit and logistic regressions—two techniques commonly used to estimate models for binary outcome variables. Bike commuters only account for 1.7% of respondents in this sample and the population. Thus, the dependent variable contains many more 'zeros' ('non-events' or non-bike commuters) than 'ones' ('events' or bike commuters). In such cases, maximum likelihood estimation has been shown to result in biased coefficients that favor non-event (Y=0) outcomes over events (Y=1). Moreover, biased-coefficients underestimate relative risks and probabilities for rare events (King and Zeng, 2001a, King and Zeng, 2001b).

King and Zeng developed a software called relogit—Rare Events Logistic Regression—that computes unbiased estimates for rare events logit regression (King and Zeng, 1999, Tomz et al., 2003). This estimation technique relies on maximum likelihood estimation akin to the standard logit regression, but produces corrected estimators with lower mean square errors than the standard logit model. Relogit corrections are most important for small samples (n<500), but have been shown to improve estimators even in large samples (n>20,000) with a small percentage of events (Y=1) (as small as <0.15%) (King and Zeng, 2001a, King and Zeng, 2001b). A mathematical proof for the relogit correction can be found in King and Zeng (2001a, 2001b). Applications of relogit can be found in the political science and applied economics literature (Martin, 2005, Wagner, 2006, Smith and Ziegler, 2008, Temple, 2008).

4.3 Probit, Logit, and Relogit Regression Results

Model 3 in Table 3 presents results of a regression with bias-corrected coefficients based on relogit estimation. Direction and statistical significance of the coefficients of probit, logit, and relogit models in Table 3 are comparable. Because of different distributions of errors, the magnitude of coefficients in the logit regressions is about 1.8-2.0 times greater than for the probit model (Freese and Long, 2006). Pseudo R-squares (McFadden) are comparable across models (~30%). Chi-square distributed likelihood ratio (LR) tests show that the independent variables have joint significance. Tolerance and Variance Inflation Factor (VIF) statistics indicate no problem with multicollinearity among independent variables in this sample. To account for potential spatial auto-correlation, due to individuals living in the same household or the same

TAZ, robust standard errors were estimated using household and TAZ as clusters. Even though the difference between logit and relogit coefficients is small, the latter is the theoretically preferable estimation technique, since it provides bias-corrected coefficients for rare events[8]. Transforming regression coefficients presented in Table 3 into adjusted odds ratios (AORs) allows for a more intuitive interpretation. Column 1 in Table 4 presents AOR transformed coefficients ($e^{(\beta)}$) for the 'full model'. AORs represent the individual's likelihood of cycling to work relative to a specific reference group assigned the base value 1.00, while controlling for other variables in the analysis. Coefficients of all models in Table 4 are consistent with relationships reported in most other studies, but not all are statistically significant.

Controlling for other variables in the regression whites are associated with 3.428 times greater odds to cycle to work than non-whites. Similarly, compared to women, men are associated with a 2.646 greater likelihood to cycle to work. One more car per household member is associated with 76.8% smaller odds for cycling to work. Similarly, more bicycles per household member are related to a greater likelihood to cycle to work (AOR 3.943). One additional mile of bikeways per 1,000 inhabitants in a TAZ is related to an 11.1% greater likelihood to cycle to work. Short work trips distances (<3miles) are associated with more bike commuting than trips longer than 3 miles (AOR 2.366). The coefficients for household location in the urban core and population density are not statistically significant in the full model.

Trip-end facilities at work are 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 4.860 greater likelihood to commute by bike. Similarly, individuals with bike parking, but no showers and lockers at the workplace, are associated with 1.782 times greater odds to cycle to work than those without trip-end facilities. In contrast, free car parking at the workplace is associated with 69.7% smaller odds for cycling to work. Commuter transit benefits are not significantly related to bike commuting. Finally, respondents with travel days during the summer months are more likely to commute by bike than those traveling during winter months (AOR 1.732).

[8] *Scobit* would be an alternative estimation technique, but for this sample scobit does not converge. This is not an uncommon problem. The Stata handbook warns that "in many cases, the ancillary parameter alpha can be highly collinear with the other parameters in the model (i.e., the coefficients). This will lead to a singular variance-covariance matrix (i.e., missing values for one or more standard errors). In these cases, other models may be more appropriate for the data."(STATA 2007. *STATA Handbook Scobit* College Station, TX, STATA Press.)

	Commute by Bike (1=yes; 0=no)		
	Model 1 (Probit)	**Model 2 (Logit)**	**Model 3 (Relogit)**
Respondent is white (1=yes; 0=no)	**1.318** (2.86)***	**1.232** (2.68)***	**0.539** (3.01)***
Respondent is male (1=yes; 0=no)	**1.009** (4.01)***	**0.973** (3.87)***	**0.491** (4.69)***
Respondent is between 25 and 40 years old (1=yes; 0=no)	0.242 (0.84)	0.238 (0.82)	0.137 (1.09)
Respondent's household is in highest income quartile (1=yes; 0=no)	**0.615** (2.37)**	**0.603** (2.33)**	**0.289** (2.50)**
Cars per household member	**-1.482** (3.64)***	**-1.451** (3.57)***	**-0.634** (3.67)***
Bicycles per household member	**1.399** (9.97)***	**1.372** (9.81)***	**0.710** (10.84)***
Trip distance shorter than 3 miles (1=yes; 0=no)	**0.894** (2.34)**	**0.861** (2.26)**	**0.380** (2.35)**
Population density (in persons per acre)	-0.005 (0.72)	-0.004 (0.59)	-0.001 (0.44)
Urban Core Jurisdiction(1=yes; 0=no)	0.249 (0.82)	0.243 (0.81)	0.147 (1.12)
Miles of bike lanes and paths per 1,000 population	**0.096** (3.16)***	**0.105** (3.47)***	**0.052** (3.02)***
Workplace provides bike parking, showers, and lockers (1=yes; 0=no)	**1.620** (4.80)***	**1.581** (4.70)***	**0.709** (4.88)***
Workplace provides bike parking but not showers/lockers (1=yes; 0=no)	**0.597** (1.93)*	**0.578** (1.88)*	**0.245** (1.94)*
Workplace provides free car parking (1=yes; 0=no)	**-1.241** (3.95)***	**-1.194** (3.81)***	**-0.588** (4.57)***
Workplace provides transit subsidies (1=yes; 0=no)	-0.308 (1.11)	-0.304 (1.10)	-0.121 (1.00)
Summer months (1=yes; 0=no)	**0.569** (2.10)**	**0.549** (2.04)**	**0.264** (2.28)**
Constant	**-7.196** (11.86)***	**-6.969** (11.52)***	**-3.614** (14.68)***
Pseudo R-Squared (McFadden)	0.306	0.295	0.295
LL (intercept)	-444.3	-444.3	-444.3
LL (full)	-308.2	-313.4	-313.4
Observations	5,091	5,091	5,091

Robust z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3. Results of Probit, Logit, and Relogit Regressions of the Choice to Commute to Work by Bike

4.4 Reduced Models and Limitations of the Analysis

Reduced models 2 through 6 in Table 4 present relogit regression results testing for the influence of individual groups of variables and controlling for potential multicollinearity and endogeneity. In the full and all reduced models in Table 4 coefficients of individual explanatory variables have comparable statistical significance, magnitude, and direction.

Reduced model 2 only includes variables capturing trip-end facilities, free parking at work, and employer provided transit commuter benefits. Together these variables account for 9.0% of the variability in bike commuting (McFadden R^2). Statistical significance and direction of coefficients are comparable with the full model. The magnitude of coefficients for trip-end facilities is larger than in the full model. Similarly, the magnitude of the 'free parking' coefficient is smaller than in the full model. Reduced model 2 is underspecified and likely suffers from omitted variables bias—thus producing more extreme AORs compared to AORs in the full model.

Including car access, bike access, bikeway supply, population density, and the urban core dummy variable may introduce bias into the full model. Studies suggest that individuals who wish to cycle more are less likely to own an automobile and more likely to own bicycles (Dill and Voros, 2007, Stinson and Bhat, 2003). Similarly, those who wish to cycle more may move into denser urban neighborhoods with more bikeway supply (Krizek et al., 2009). Inclusion of these variables may cause simultaneous equations bias, since bike commuting may affect the choice of car and bike ownership and the decision to live in a compact neighborhood with bike lanes. Additionally, car and bike ownership may be correlated with each other and the land-use variables. Studies show that individuals living in denser neighborhoods and close to bikeways own fewer cars and more bikes (Cervero, 2003, Ewing et al., 2008, Ewing and Cervero, 2010).

	Adjusted Odds Ratios (AOR) after Relogit for the Decision to Commute by Bike (1=yes; 0=no)						
	Model 1 'Full Model'	**Reduced Model 2**	**Reduced Model 3**	**Reduced Model 4**	**Reduced Model 5**	**Reduced Model 6**	**Reduced Model 7**
Respondent is white (1=yes; 0=no)	**3.428** (2.68)***		**4.023** (3.21)***	**3.717** (2.90)***	**3.575** (2.76)***	**3.857** (2.87)***	**3.367** (2.67)***
Respondent is male (1=yes; 0=no)	**2.646** (3.87)***		**2.861** (4.32)***	**2.550** (3.75)***	**2.724** (4.02)***	**2.892** (4.17)***	**2.617** (3.84)***
Respondent is between 25 and 40 years old (1=yes; 0=no)	1.269 (0.82)		1.284 (0.98)	1.368 (1.13)	1.271 (0.85)	1.298 (0.92)	1.239 (0.74)
Respondent's household is in highest income quartile (1=yes; 0=no)	**1.828** (2.33)**		**1.639** (2.05)**	**1.828** (2.32)**	**1.737** (2.15)**	**1.855** (2.46)**	**1.802** (2.27)**
Cars per household member	**0.234** (3.57)***			**0.186** (4.32)***	**0.232** (3.66)***	**0.175** (4.32)***	**0.242** (3.58)***
Bicycles per household member	**3.943** (9.81)***			**4.129** (9.63)***	**3.951** (9.90)***	**4.059** (11.07)***	**3.857** (9.98)***
Trip distance shorter than 3 miles (1=yes; 0=no)	**2.366** (2.26)**		**2.959** (3.16)***		**2.305** (2.22)**	**2.575** (2.64)***	**2.433** (2.37)**
Population density (in 1,000 persons per acre)	1.00 (0.59)		1.00 (0.73)		0.99 (0.79)	1.00 (0.38)	1.00 (0.55)
Residence in Urban Core Jurisdiction (1=yes; 0=no)	1.28 (0.81)		1.48 (1.42)		1.40 (1.12)	1.60 (1.63)	1.26 (0.78)
Miles of bike lanes and paths per 1,000 population	**1.111** (3.47)***		**1.140** (3.89)***	**1.108** (3.83)***		**1.083** (4.26)***	**1.120** (3.60)***
Workplace provides bike parking, showers, and lockers (1=yes; 0=no)	**4.860** (4.70)***	**6.807** (6.38)***	**4.988** (5.13)***	**5.259** (5.06)***	**4.764** (4.76)***		**4.894** (4.78)***
Workplace provides bike parking but not showers/lockers (1=yes; 0=no)	**1.782** (1.88)*	**1.974** (2.54)**	**1.709** (1.92)*	**1.826** (1.95)*	**1.690** (1.75)*		**1.728** (1.78)*
Workplace provides free car parking (1=yes; 0=no)	**0.303** (3.81)***	**0.234** (5.17)***	**0.264** (4.61)***	**0.288** (4.06)***	**0.298** (3.90)***		**0.299** (3.88)***
Workplace provides transit commuter subsidies (1=yes; 0=no)	0.74 (1.10)	0.91 (0.37)	0.85 (0.66)	0.74 (1.12)	0.75 (1.07)		0.75 (1.06)
Summer months	**1.732** (2.04)**		**1.464** (1.65)*	**1.770** (2.14)**	**1.709** (2.01)**	**1.797** (2.22)**	
Pseudo R-Squared (McFadden)	0.295	0.090	0.175	0.289	0.291	0.248	0.289
Prob > LR (Chi-Squared)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LL (intercept)	-444.3	-444.3	-444.3	-444.3	-444.3	-444.3	-444.3
LL (full)	-313.4	-411.8	-366.47	-319.1	-317.9	-334.2	-316.1
Observations	5,091	5,091	5,091	5,091	5,091	5,091	5,091

Robust z-statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4. Adjusted Odds Ratios (AORs) after relogit for the Decision to Commute to Work by Bike

Reduced Models 3, 4, and 5 test for potential distorting effects of simultaneous equations bias and multicollinearity of these variables. Reduced Model 3 omits car and bike ownership. Most coefficients in Model 3 are comparable to the full model ($P<0.05$). However, the coefficient for white is larger than in the full model ($P<0.05$)—likely related to higher rates of bike ownership among whites. Moreover, McFadden's Pseudo R^2 is only 17.7% for this model compared to 29.5% for the full model—indicating the important contribution of bike and car ownership towards explaining bike commuting. Reduced Models 4 and 5 omit land-use variables and bikeway supply. In each model coefficients for the remaining variables are not significantly different from the full model ($P<0.05$). Goodness of fit measures indicate a fit similar to the full model.

There may also be endogeneity between bike commuting and trip-end facilities at work. Individuals who wish to cycle to work may choose an employer that provides bike parking, showers, and clothes lockers. Similarly, individuals who wish to drive may choose an employer with free car parking. Model 5 excludes the trip-end facility, car parking, and transit benefit variables. Coefficients for other variables do not change significantly from the full model. One potential solution to modeling simultaneous dependencies is an instrumental variable regression that can help control for endogeneity. However, none of the variables in the data set was sufficiently exogenous to serve as a strong instrumental variable.

The omission of a variable directly measuring cyclist safety may be another problem for the analysis. However, the main difference in cyclist safety is between safer cycling in the urban core jurisdictions and more dangerous cycling in suburban jurisdictions (TPB, 2010a). Cyclist safety is also correlated with the supply of bike paths and lanes (Lusk et al., 2011, Jacobsen, 2003). Thus, the variables on bikeway supply and the urban core dummy variable may pick-up part of the variability in cyclist safety.

In summary, significance, magnitude, and direction of coefficients for the reduced models 2 to 6 are very similar to the full model. The coefficients of trip-end facilities at work and free car parking remain significant across the models. Transit commuter benefits are not significant in predicting the likelihood to commute by bike. Model 1—the full model—in Table 4 is the preferred model, since it includes all available theoretically relevant variables. All other models likely suffer from omitted variables bias, since theoretically necessary variables are excluded. This study relies on information about commuters in the Washington, DC region, which is not typical for the United States as a whole. For example, Washington, DC is home to the U.S. government and many government contractors. The area population is younger and wealthier than the U.S. average. Moreover, the area is home to one of the largest public transport systems in the United States. For these and other reasons one should be careful when generalizing from this sample to the entire population of the United States. Studies based on regional travel surveys from other cities may help confirm or refute results of this analysis. Alternatively, the next National Household Travel Survey (NHTS) could include questions about trip-end facilities at work. This would facilitate a nationwide analysis for the role of trip-end facilities on bike commuting.

Moreover, as in all cross-sectional analysis, this study cannot claim causality. A different study design with information about changes over time in commuting and in the provision of trip-end facilities would be a way forward—ideally in form of a before and after study with control groups. However, the relationships measured in this study are consistent with the hypothesis. Moreover, in contrast to analysis based on SPS, this study includes information about actual commutes by cyclists and non-cyclists.

5. Discussion and Conclusion

Results of this analysis of commuters in the Washington DC 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. These findings are consistent with other studies that report a positive relationship between trip-end facilities at work and bike commuting (Wardman et al., 2007, Abraham et al., 2002, Hunt and Abraham, 2007, Dickinson et al., 2003, Taylor and Mahmassani, 1996, Noland and Kunreuther, 1995).

This study adds important evidence about the role of different types of trip-end facilities. Most prior studies indicate that bike parking is positively related to bike commuting. Results about the differential role of trip-end facilities are ambiguous and rely on hypothetical stated preference surveys of cyclists. This study uses observed commute data of cyclists and non-cyclists—thus also controlling for trip-end facilities at work for those who commute by car, public transport, or on foot. Results show that 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 ($P<0.05$). 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 indicate that free car parking at work is associated with less bike commuting. Previous studies did not explicitly control for the role of free car parking and trip-end facilities for cyclists in determining the likelihood of bike commuting. For example, Taylor and Mahmassani (1996) did not control for free car parking and found lower cycling levels at workplaces with cyclist showers. The authors speculate that the provision of showers may be correlated with free car parking—thus explaining the negative relationship between showers and cycling. This study shows that cyclist showers are positively related to bike commuting after controlling for free car parking.

This study confirms findings from a previous SPS that indicated that commuters were more likely to make a hypothetical commute by bike if cyclists received a monetary payment that offsets the benefits of free car parking (Wardman et al. 2007). Results of this study show that car parking is associated with less bike commuting. Lastly, results indicate that recent efforts by American municipalities to reduce car parking in new developments and limit free car parking may help encourage more commuting by bicycle.

Transit commuter benefits were not a significant predictor of bike commuting. This result adds to the ambiguous evidence about the connection of cycling and public transport—which are alternatively viewed as competitors or as complements. Results of this study indicate that the provision of commuter transit benefits appear to neither encourage nor discourage bike commuting.

Even though not the focus of this study, the analysis supports the positive relationship between bikeway supply and bike commuting—even after controlling for trip-end facilities and free car parking. During the last decades many American municipalities have greatly expanded their bikeway networks. For example, Washington, Arlington, and Alexandria have almost tripled the length of their bicycle networks since 1995. Results of this study indicate that expansion of bikeway networks may help increase the share of bike commuters.

Other results of this study may help guide transport policies in the long run. For example, commuters are more likely to ride their bicycle if trip distances are short. Thus policies that encourage denser development patterns and mixed use development that keep trip distances short may help encourage bike commuting. Moreover, bicycle ownership appears to be an important determinant of bike commuting. Cities like Minneapolis, Montreal, and Washington now provide public bike sharing systems that make bicycles accessible to a large group of society—including those who do not own a bike. It remains to be seen if easier access to bikesharing bicycles can help increase bike commuting.

Lastly, significant discrepancies in bike commuting levels by gender, race, and income in the Washington region suggest the need for inclusive programs to encourage bike commuting for all groups. Results of this analysis indicate that a comprehensive package of policies may be most successful in encouraging a larger group of society to cycle. Trip-end facilities at work, less free car parking, and greater bikeway supply are a significant part of this policy package to encourage cycling and reduce CO_2 emissions, local air pollution, oil dependence, peak hour congestion on roadways and public transportation.

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