BICYCLE BOULEVARDS: STATISTICAL ANALYSIS OF THE PRESENCE OF BICYCLE BOULEVARDS AND THEIR INFLUENCE ON BICYCLE-TO-WORK RATES IN PORTLAND, OREGON

by

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THESIS ABSTRACT

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Title: Bicycle Boulevards: Statistical Analysis of the Presence of Bicycle Boulevards and Their Influence on Bicycle-to-Work Rates in Portland, Oregon

One of the top bicycling cities in the United States, Portland, Oregon has used a mixture of bicycle infrastructure to create a cohesive network for bicyclists. Building on their success, in 2010 Portland set forth on an ambitious path to envision their bicycle network in 2030. The primary goal of this plan is to attract the "Interested but Concerned" demographic of bicyclists through an increase of their bicycle boulevard network from 30 miles to 286 miles. However, there has been no direct link between bicycle boulevards and bicycle rates. Therefore, this study analyzes the influence of bicycle boulevards on bicycle-to-work rates using U.S. Census data with Geographic Information Systems data in concert with both ordinary least squares (OLS) regressions and a fixed effects (FE) regression. The OLS and FE models both indicate that there is a statistically significant relationship between bicycle boulevards and bicycle-to-work rates.

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CHAPTER I

INTRODUCTION

The use of a bicycle as the main means of transportation has historically been low in the United States when compared to many Scandinavian countries in Europe. Historically, countries like Germany, Netherlands and Denmark have rates of bicycling between 10% and 30%, whereas the United States has had a rate below 1% (Pucher and Buehler 2008). However, in the last few decades there has been a slow increase in the rate of bicycling in the United States. Encouraged by additional funding from the Federal government through the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, the Transportation Efficiency Act for Twenty-first Century (TEA21) in 1998, and in 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) municipalities were able to build and add to their bicycle networks (ibid.).

At the same time, as this increase in funding occurred for bicycle facilities there has been an increase in bicycle ridership numbers. Nationally, since 1990, the percentage of bicycle commuters has risen from .4% to .5% in 2010. In Oregon, since 1990 the rate has risen from 1.1% to 2.1% in 2010 and in Portland from 1990 to 2010, the rate has risen from 1.1% to 5.4% (see Table 1).

For cities over 200,000 people, Portland has the highest rate of bicycle commuters in the United States. This distinction has positioned Portland as a leader in bicycle transportation. Many cities across the United States look to Portland for guidance in the implementation of their own bicycle transportation plans because of their high rates of bicycling commuting. Portland's role as a leader in bicycle transportation is also helped by their designation as one of three platinum rated cities for bicycles (League of American Bicyclists 2011).

Table 1 - Bicycle ridership nationally, statewide and Portland

	1990	***%***	***1996***	***%***	***2000***	***%***	***2010***	***%***
National	466,856	0.41%	n/a		488,797	0.38%	716,535	0.51%
Oregon	13,647	1.05%	n/a		17,172	1.07%	35,996	2.09%
Portland	2,453	1.14%	4,900	1.92%	4,775	1.76%	15,871	5.44%

Source: 1996 and 2005-2010 American Community Survey, 1990 and 2000 US Census

By using best practices from around the United States and the world, Portland has been able to demonstrate that the installation of bicycle infrastructure is effective at promoting bicycle use (National Association of City Transportation Officials 2011). Their success, consequently, can be seen in their high numbers of bicycle commuters in 2010, a rate of 5.44% of trips using the bicycle as a means of transportation to work (U.S. Census 2010).

Working on their current successes, in February 2010, Portland set forth on an ambitious path to envision their bicycle network in the year 2030. The Portland Bicycle Plan for 2030 was designed to provide a framework and guidance as Portland expands their bicycle network. The plan also describes the types of infrastructure, education and policy changes that will help Portland meet its goal of 25% of all trips being conducted by bicycle.

One method to reach this goal is the creation of a classification system of bicyclists within the city. Using the work by Roger Geller, the City of Portland Bicycle Coordinator, the categorization of bicyclist into distinct categories helps the City of Portland prioritize the build out of their bicycle infrastructure.

In his research, Geller ultimately classifies four different types of bicyclists:

- Strong and Fearless
- Enthused and Confident
- Interested but Concerned
- No way, No how

He noted that each of the different groups require different bicycle facilities to make them feel safe while bicycling. The "Strong and Fearless" and "Enthused and Confident" bicyclists are already comfortable being mixed with automobile traffic and are more willing to travel on roads with bicycle lanes. The "Interested but Concerned" group is markedly different. Their different requirements create the condition where Geller argues, "that in order to meet the, "Interested but Concerned" needs you must plan for people who are not riding bicycles already" (City of Portland Bureau of Transportation 2011). This group of individuals, he notes:

> Would like to ride more, but are afraid because they do not feel safe near fast-moving traffic on busy streets, even when bike lanes exist. They would ride if they felt more comfortable on the roadways due to fewer and slower-moving cars or if more car-free alternatives were available (ibid).

It is because of this fact, Portland is adding an additional 367 miles of separated or traffic calmed bicycle facilities in addition to 490 separated in-roadway treatments which include bicycle lanes, buffered bicycle lanes, and cycle tracks (see Table 2).

Combined that adds 681 miles or increases the amount of bikeways by 242% when compared to the already existing facilities in 2010. More importantly, the city is focusing on the importance of bicycle boulevards to attract the "Interested but Concerned" demographic of bicyclist.

Table 2 – Infrastructure goals of the bicycle plan for 2030

	2010 (mi)	***% total system***	***2030 (mi)***	***% of total system***	***Miles Added***	***% Change***
Trails	75	27%	139	14%	64	72%
Separated In-roadway facilities	176	63%	490	51%	314	178%
Bicycle boulevards	30	11%	286	30%	256	853%
Enhanced Shared Roadways	0	0%	47	5%	47	100%
Total	281		962		681	242%

Source: (City of Portland Bureau of Transportation 2011)

With the bicycle boulevard network growing from 8.64 miles in 1990 to now presently at 29.85 miles, the network has grown by 194%. By 2030, the goal is to increase the bicycle boulevard network to 286 miles, which is an increase in 858% from the current installed infrastructure in 2010 (see Table 3).

The importance of bicycle boulevards highlighted by the 853% increase from 2012 to 2030 is mainly because this type of infrastructure is:

> Low-volume and low-speed streets that have been optimized for bicycle travel through treatments such as traffic calming and traffic reduction, signage and pavement markings, and intersection crossing treatments (Walker, Tresidder, and Birk 2011).

Additionally:

> Bicycle boulevards, in particular, have proven to attract high numbers of riders due to the level of comfort they provide, the mobility function they serve and their proximity to where people live and travel. Indeed, bicycle boulevards have become among the city's most popular bikeways (City of Portland Bureau of Transportation 2011).

Table 3 – Bicycle boulevards compared to bicycle network over time (1990-2030)

	Bicycle Boulevard (mi)	***Bicycle Network (mi)***	***% of total system***	***Change (mi)***	***% change***
1990	8.64	75.04	11.51%		
1996	8.64	112.68	0.08%	0	0%
2000	25.42	216.13	11.76%	16.78	194%
2010	29.85	283.17	10.54%	4.43	17%
2030	286	962	29.73%	256	858%

Source: (City of Portland Bureau of Transportation 2011)

Through anecdotal evidence, the city's claim of bicycle boulevards as being the most popular bikeways is possible, however there has been very little done to study their association with bicycle ridership. With an increase from 286 miles in 2010 to 962 miles, an 858% increase, bicycle boulevards will provide the skeleton that is the bicycle network in Portland and therefore it is critical to understand their effect on bicycle commuting rates.

Research Question

This study seeks to look at the effect of bicycle boulevards on the bicycling rates in Portland, Oregon. By looking at one particular type of bicycle facility, conclusions can be drawn to see if bicycle boulevards have a relationship with bicycle rates. This thesis will look at one primary research question:

- Does the presence of a bicycle boulevard have a statistically significant effect on the bicycle-to-work commute rate in Portland?

Overview of Thesis

Chapter II is a literature review that looks at bicycle infrastructure and how bicycle infrastructure changes perceptions of safety. Chapter III describes the data and methods. Chapter IV details the findings and chapter V discusses the findings, suggest possible implications and draw attention to future studies.

CHAPTER II

LITERATURE REVIEW

Role of Bicycle Facilities in Promoting Bicycling

The literature on the topic of bicycles can be summed into three distinct methodological categories. Stated preference survey, revealed preference observation and state or citywide aggregated-level studies are the main methods that have been used to look at the topic of bicycles. Each of these types of methods has added to the growing body of literature; however, there still exists a gap when looking at specific types of bicycle infrastructure at smaller geographic scales. By using an aggregated-level study at the census tract level, this analysis can provide insight into specific gap within the literature.

As it stands, within the current wider transportation paradigm there are many who will continue to doubt the ability for bicycle use to be a major component within transportation planning. It can be argued that the reason that many individuals doubt the ability for bicycle commuting to play an important role in wider transportation policy is because there is not enough data demonstrating the effectiveness of bicycle infrastructure on commute patterns. These doubters equate bicycle projects to beautification projects that do not deserve dedicated funds (Tracy 2011). Additionally with the budgetary climate of the great recession, extra scrutiny is applied to bicycle infrastructure projects as funding sources continue to dwindle (Lowy 2011). Even with the progress that has been made, there is a renewed push, as seen in the most recent transportation bill that was signed by President Obama to strip dedicated funds from bicycle infrastructure and encouragement programs. The new bill, Moving Ahead for Progress in the 21st Century (MAP-21) is estimated to cut or reduce funding sources for bicycle infrastructure by upwards of 70% as bicycle projects are scored against road projects (America Bikes 2012). Therefore, bicycle advocates will need to be able to show the effectiveness of adding bicycle infrastructure to the overall network and that the value of the infrastructure is worth the money spent.

The Research

The research that has been done, both on a macro and micro scale, has been effective at demonstrating that the creation of bicycle facilities creates conditions that are more favorable for individuals to bicycle. The improvement of already existing bicycle facilities also has positive effects on creating conditions for people to cycle.

Aggregated Cross Sectional Methodology

On a macro scale, the role of bicycle facilities and infrastructure in promoting bicycle use has been thoroughly studied using both statewide and citywide aggregated data. The use of large aggregated datasets has suggested that there is a correlation between the amount of bicycle facilities and the rate of bicycle ridership. One of the first types of this type of study, conducted by Arthur Nelson and David Allen (1997) used a before and after analysis of 18 cities to look at the relationship between the installation of bicycle facilities and their effect on bicycle commuting. They also looked at a myriad of other variables including mean temperature, number of rainy days, percent of students and number of bicycle pathways against bicycle commute rates. Their results found that, "each mile of bikeway per 100,000 residents is associated with a 0.069 percent increase in commuters using bicycles, holding other factors constant" (Nelson and Allen 1997).

Similar findings were seen in a two later studies done by Jennifer Dill and Theresa Carr (2003) and Ralph Buehler and John Pucher (2011). In both studies, they used larger samples to look at the relationship between the rate of bicycle commuting and the amount of bicycle lanes and paths. In the Dill and Carr study, they used the 35 largest cities, excluding “college towns” in the United States. Using a regression analysis, they found that there was a strong correlation between commute rates and the amount of bicycle lanes and paths that were built (Dill and Carr 2003).

In the more recent study using similar data, Buehler and Pucher expanded the dataset to include the largest 90 cities in the United States. Using similar methods, they found similar results, which confirmed that there was a similar correlation between the presence of bicycle lanes and paths and the percentage of individuals who bicycle to work (Buehler and Pucher 2011).

At a less aggregated level, Kevin Krizek, et al (2009) studied the bicycle facilities in Minneapolis/St. Paul by using U.S. census data. They analyzed the change in commuting patterns in 1990 and 2000 based on the installation of bicycle infrastructure. Their analysis suggested that individuals near bicycling facilities showed a significant increase in bicycle mode share. During that same study, they also looked to see if there were any changes in travel behavior. However they were unable to answer whether the addition of facilities changed commuting patterns of the surrounding areas as individuals chose streets that had bicycle facilities (Krizek, Barnes, and Thompson 2009).

Stated Preference Methodology

The use of stated preference surveys is another method that can be used to look at bicycle commuting ridership. Designed primarily using surveys, researchers are able to investigate individual behavior by looking at preferences. By asking survey participants specific questions regarding their choice and behavior, stated preference surveys can look into individual behavior to see what types of bicycle infrastructure is needed to create more bicycle commuters. However, this methodology can be problematic since individuals are able to state one preference and elect to do another.

While this is the case, Emond, et al (2009) found in a study that gender has an effect on facility preference and the overall likelihood of bicycle use. In this case, men preferred to live in communities where bicycle facilities already exist while women preferred to live in communities that they felt safe. This conclusion manifested itself when individual factors including safety, physical limitations, and attitudes towards bicycle commuting determined the likelihood of bicycle use (Emond, Tang, and Handy 2009).

Furthermore, a study done by Nebiyou Tilahun, David Levinson, Kevin J. Krizek found that individuals were willing to choose different types of infrastructure at a cost of travel time. By having survey participants choose their preferences from a set of pictures with and without bicycle lanes, the researchers found that individuals were willing to add additional travel time to use off-road bicycle facilities in comparison to un-marked streets with on-street parking (Tilahun, Levinson, and Krizek 2007).

Revealed Preference Methodology

The use of stated preference however, can be problematic since actual behavior can be different from individual stated preferences. To correct for this revealed preference methodology is used. Revealed preference methodology utilizes a system of tracking or monitoring individuals to look at actual individual behavior. At the least aggregated level, the use of monitoring can look at individual behavior to see if individuals are actually using installed bicycle infrastructure. This methodology has unfortunately been unsuccessful at showing a relationship between bicycle use rates and bicycle facilities being present.

The research has shown that the presence of facilities does have an effect on individual behavior and route choice. In 2008, Jennifer Dill and John Gliebe looked at bicycle use by using global position system (GPS) technology to track individual travel behavior. Their goal was to look at the effect of different types of infrastructure on individual preference of routes in Portland, Oregon. In their analysis, a sample of 164 adults showed that individuals placed a high importance on directness of their route and avoiding streets with heavy vehicular traffic. In some cases, the study participants would go out of their way to utilize low traffic streets over higher trafficked streets with bicycle lanes, which supports the Krizek study (2009). Additionally, there was a clear difference between route choice and gender, which supports the findings that Emond, et al (2009) found in their stated preference study.

These two factors are important to consider since individual preference can be based partly on perceived and actual safety. The lower trafficked, lower speed streets in Portland play an important role in promoting both actual and perceived safety. It is shown that streets that have had their speeds reduced to less than 20 mph have fewer injuries than streets that have not had their speeds reduced (Grundy et al. 2009). Coincidently, these low speed streets are the same streets that Dill and Gliebe highlight as preferred by cyclists.

More importantly, they found that there is a contradiction in revealed preference in regards to directness and avoiding high traffic streets. In many cases, the bicycle network is designed that these two preferences are not aligned. Therefore, individuals will have to choose between traveling on high trafficked streets with bicycle lanes, which are direct, or traveling on streets with no facilities that are not direct but have less traffic. In the Dill and Gliebe study, it showed that individuals were more willing go against their stated preference by traveling out of their way to avoid unfavorable facilities. Ultimately, this change was at a cost to directness of route (Dill and Gliebe 2008).

Determinants of Cycling: The Role of Low Speed, Low Volume Streets

The results from the reveled preference study by Dill and Gliebe are important to consider if cities like Portland are going to be able to increase their bicycle ridership rates. To meet their goal of reaching 25% of all trips being made by bicycle, the Bicycle Plan for 2030 highlighted the need to capture the "Interested but Concerned" bicyclists. This category is about half of the potential bicycle riders in Portland.

In creating these types of facilities, it would support both the revealed and stated preference results. To support this fact, Portland highlights the need to create a cohesive network of low-stress bikeways. One method to create this network is through the creation and expansion of bicycle boulevards. These boulevards are highlighted as a critical component in the Portland plan due to their ability to provide a level of perceived safety that is not found on streets with automobile traffic and bicycle lanes (City of Portland Bureau of Transportation 2011). Additionally, Geller argues that bicycle boulevards provide a middle way between bicycle lanes, which are easy to implement and provide great proximity to places individuals what want to travel, and cycle tracks, which are both close to places individuals want to travel and provide separation to traffic but are hard to implement. Bicycle boulevards, however are a good midway point that provides users separation and easy implementation at the cost of being close to places people want to travel (ibid).

Even with the associated benefits of bicycle boulevards, there has been very little work in researching them further. In an international review of the peer reviewed literature, Pucher, Dill and Handy found only minor references to bicycle boulevards (Pucher, Dill, and Handy 2010). Outside of academic journals, there exist a few reports done by the Federal Highway Administration or other similar bodies that look into the design and best practices (Association of Pedestrian and Bicycle Professionals and Rails-to-Trails Conservancy 1998; National Association of City Transportation Officials 2011; Walker, Tresidder, and Birk 2011). The reason for the lack of research into bicycle boulevards could be partly due to the small sample of cities that use the designation of bicycle boulevards. As of 2010, only Portland, Oregon, Palo Alto and Berkeley in California use the bicycle boulevard name as an official designation in their network classification and planning documents. Another reason for the lack of research could be that bicycle boulevards use simple traffic calming measures to prioritize bicycle riders on the street. In the Pucher, Dill and Handy study, they found that of the research done, traffic-calmed streets have a positive effect on for bicycle ridership. They state, "of the six studies on traffic calming, all but one found positive results, though none rigorously measured the effects on the amount of bicycling" (Pucher, Dill, and Handy 2010).

Therefore, the research conducted in this thesis will address the gap within existing literature by measuring the effects of this specific type of bicycle infrastructure on bicycling rates in Portland, Oregon.

CHAPTER III

DATA AND METHODOLOGY

Using similar methods as previous studies, this analysis will look at a statistical relationship between U.S. Census bicycle-to-work data and various independent variables. More specifically, this study seeks to build upon the work done by Mauricio Leclerc. In his research, he compared the miles of bicycle facilities, transportation factors and socioeconomic factors to bicycle-to-work rates (Leclerc 2002). For this analysis, the focus is further narrowed to look at the possible relationship between the presence of bicycle boulevards and the bicycle-to-work commute rate. Regression analysis utilizing ordinary least squares (OLS) will be used with Geographic Information Systems (GIS) software to look at this possible relationship. Building upon the OLS regression, a fixed effects (FE) regression will also be conducted look at the relationship between bicycle boulevards and bicycle-to-work commute rates over time.

Data

The data for this analysis will be from the City of Portland, Metro and U.S. Census data from the 1990 Census, 1996 American Community Survey, 2000 Census and the 2010 American Community Survey five-year average. From Metro through their Regional Land Information System (RLIS) the data shows the Portland city boundary and between 141 and 145 census tracts depending on the specific year and U.S. Census bureau dataset. Dependent on the year, the decennial census and ACS data can be disaggregated to match the census boundaries within the Metro GIS data to visualize the bicycle-to-work variable. The Census data also contains other socioeconomic and population variables that could be used to look at possible correlations. The GIS data obtained from the City of Portland describes the location, classification of different bicycle infrastructure and the year each bicycle network segment was built (see Table 4).

Table 4 – Variables and data sources

Variables	***Source***
Bicycle-to-Work Rates	
Bicycle to Work (1990)	1990 Census STF 3
Bicycle to Work (1996)	1996 American Community Survey
Bicycle to Work (2000)	2000 Census STF 2
Bicycle to Work (2010)	2006-2010 American Community Survey 5-year estimates
Bicycle Network in Portland	
Bicycle Boulevard (feet)	City of Portland
Bicycle Network (feet)	City of Portland

Variables

To look at the relationships, this analysis will use a regression analysis to look at the effects of the installation of bicycle boulevards in the transportation system. Using a regression analysis will demonstrate if there is a possible relationship between the independent and dependent variables. The dependent variable will be the bicycle-to-work commute rate in each U.S. Census dataset. This variable is obtained in 1990 by Summary Tape File 3 (STF3), in 1996 by American Community Survey (ACS), in 2000 by Summary Tape File 2 (STF2) and in 2010 by the ACS five-year average

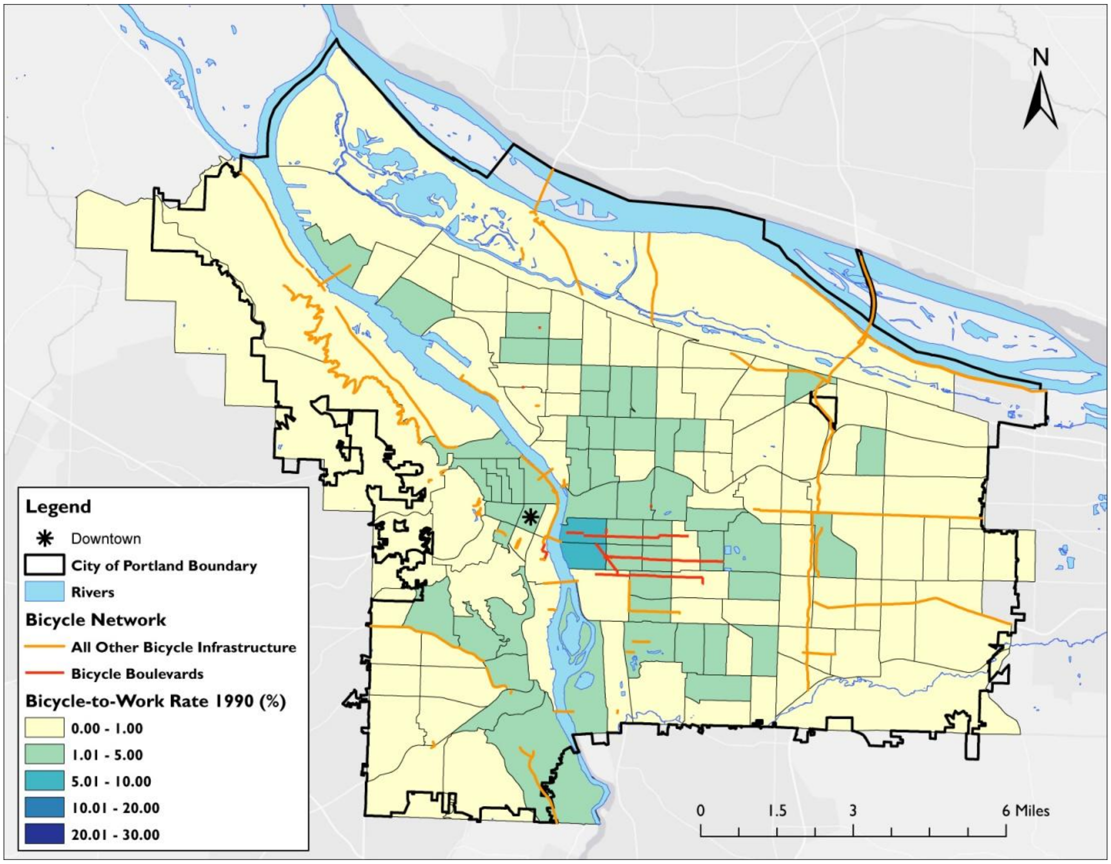
The independent variable will be the bicycle network. The GIS data of Portland's bicycle network is comprised of bicycle lanes, paths and bicycle boulevards. Additionally the total amount of bicycle boulevard miles will be calculated based on the year of completion of each network segment that is recorded within the data. The total footage of bicycle boulevards will be normalized by dividing the bicycle infrastructure and the area of the census tract. Using only segments completed by 1989, 1995, 1999 and 2004; each of these periods can be looked to see if they have an effect of the bicycle-to-work commute rates.

These variables were mapped out using ESRI's ArcGIS ArcMap software. Map 1, 2, 3 and 4 show the percentage of bicycle-to-work commuters and both the bicycle network and bicycle boulevards for 1990, 1996, 2000 and 2010. Map 5 shows a bivariate map comparing the percent change between 1990 and 2010 and Map 6 shows a similar map looking at the actual change from 1990 to 2010.

Casually looking at the maps in 1990, there seems to be higher amounts of bicycle-to-work commuters that are commuting from census tracts closer to the downtown core. It can be seen in 1990 the highest rates, between 5.01% and 10% are closest to downtown and the lowest rates are in eastern Portland. There are only three bicycle boulevard routes, each of them traveling east/west towards downtown. Additionally there are only two bicycle lane routes in the eastern portions of Portland (see Map 1).

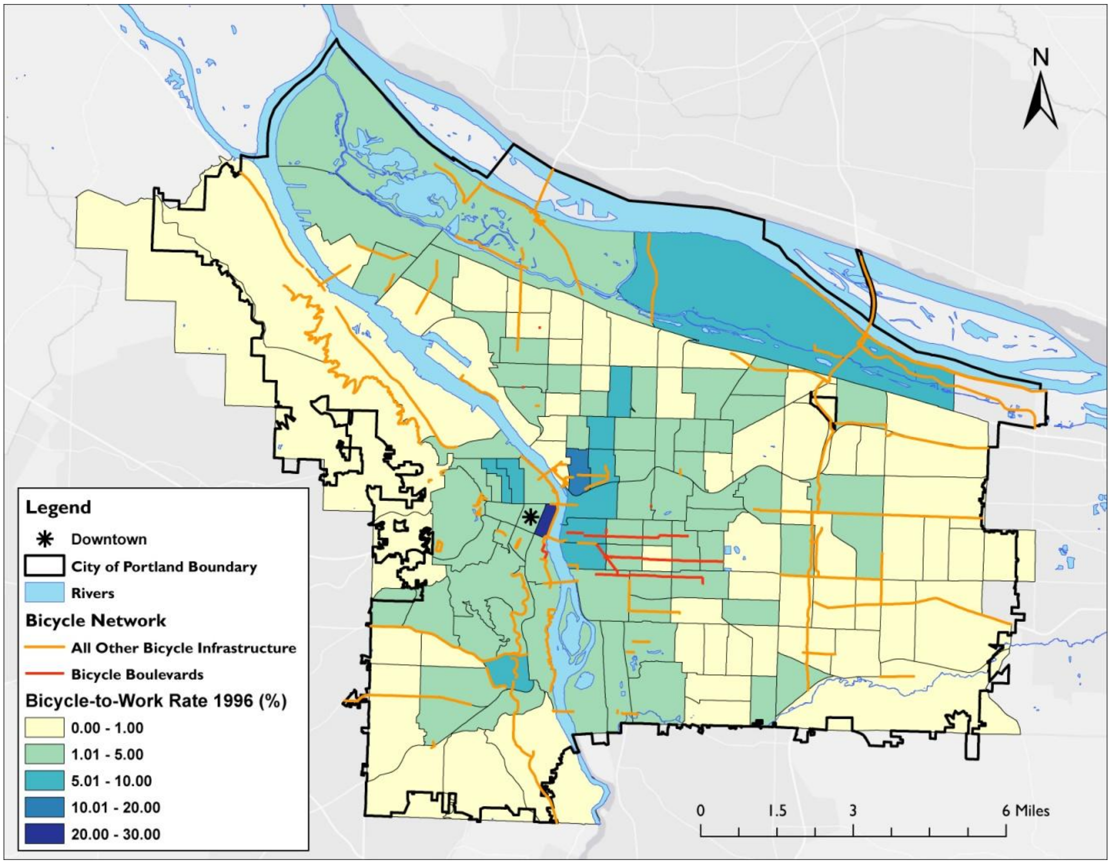
By 1996, additional bicycle infrastructure is installed throughout the city. The addition of bicycle lanes to the north and east across the river from downtown saw increases in bicycle-to-work commuting. At the same time, there was also virtually no expansion of the bicycle boulevard network as there were no bicycle boulevards installed. The eastern sections of Portland furthest from downtown also saw very little infrastructure installed at this time, which could partly be the reason that increases in bicycle rates were very small (see Map 2).

Map 1 – Portland bicycle network and commute-to-work rates in 1990



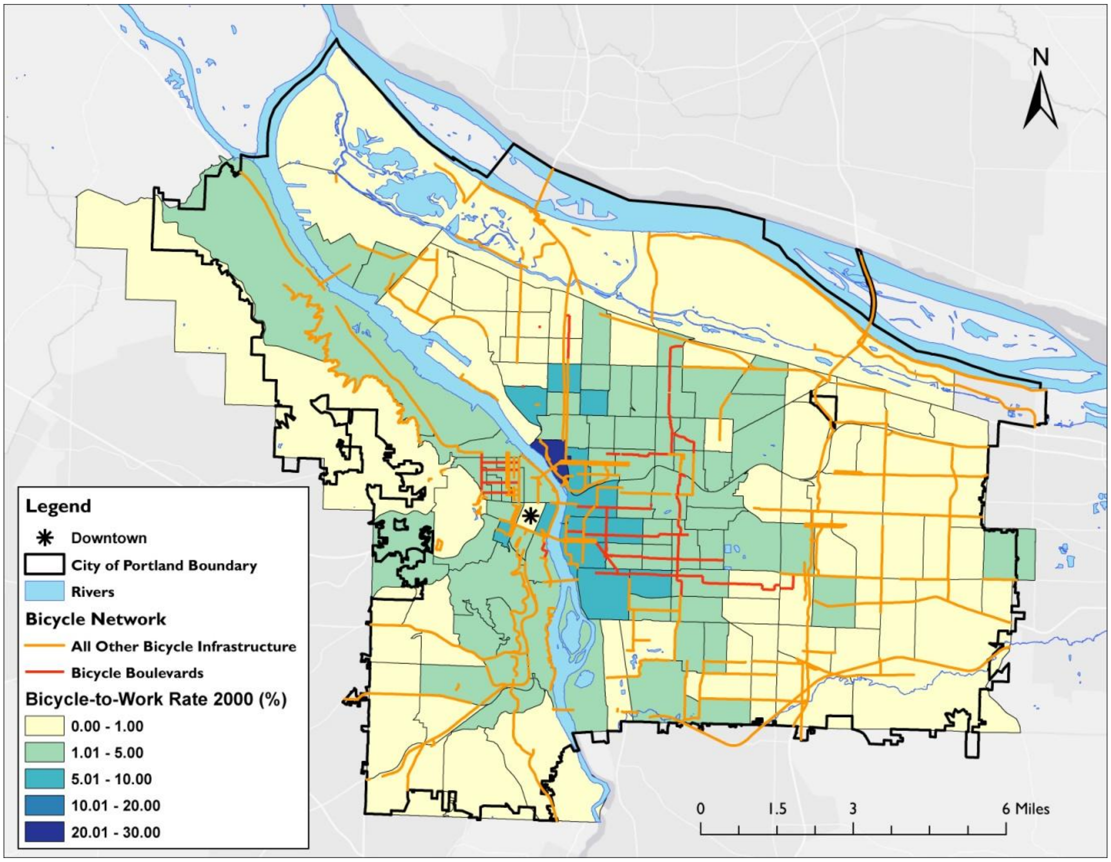
By 2000, the bicycle network throughout Portland is expanded drastically as both the bicycle boulevard and bicycle lane network is expanded. Both bicycle lanes and bicycle boulevards were added to fill gaps within the network and provide a robust network of infrastructure throughout Portland. This ultimately led to census tracts closest to the central business district seeing increased rates of bicycle-to-work commuting. At the same time, even with additions of bicycle lanes in the eastern portions of Portland, bicycle commute rates stayed relatively low and did not change (see Map 3).

Map 2 – Portland bicycle network and commute-to-work rates in 1996



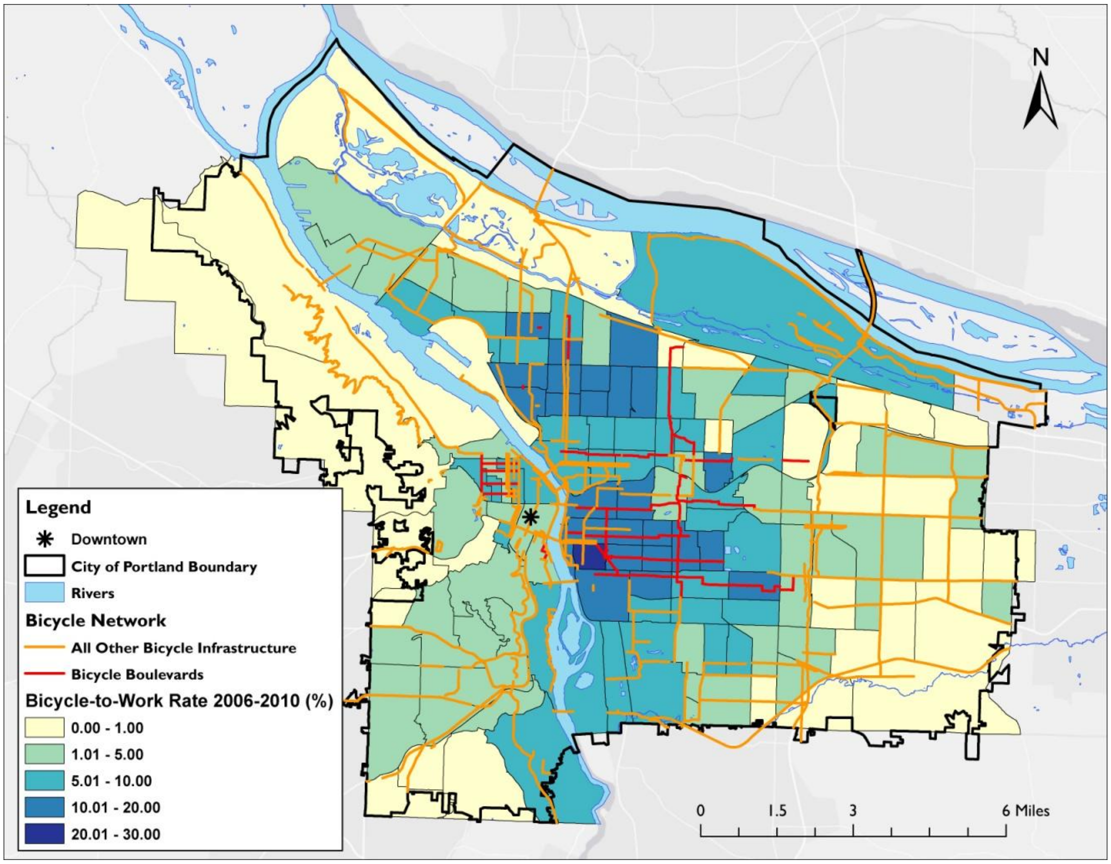
By 2010, most census tracts east of the river that are close to the central business district (CBD) have rates over 5% of commuters are bicycling to work. All of the census tracts that had bicycle boulevards built in 1990 have rates over 10%. At the same time, many census tracts in North Portland that do not have bicycle boulevards are seeing rates above 10%. With the additions of bicycle infrastructure in the form of bicycle lanes from 2000, similar gains are being made in the eastern portions of Portland as rates begin to climb above 1% (see Map 4).

Map 3 – Portland bicycle network and commute-to-work rates in 2000



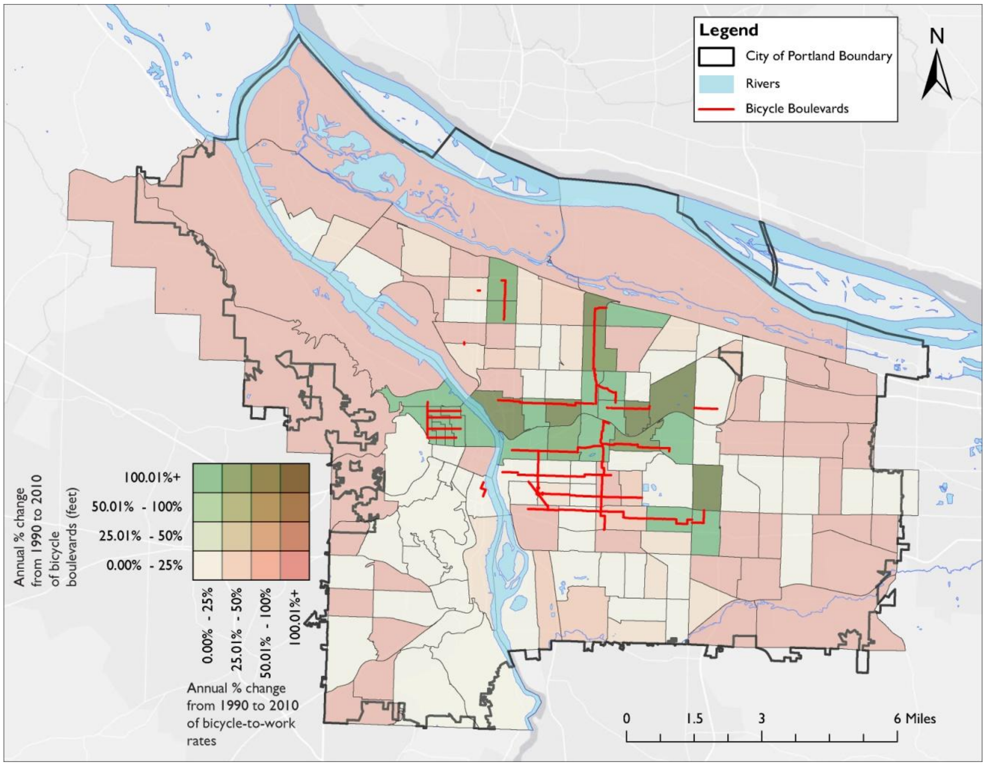
The bivariate map is more complicated to interpret. The original bicycle boulevards in 1990, show very small increases in the annual percent change of bicycle commute rates from 1990 to 2010. The census tracts that added bicycle boulevards from 1990 to 2000 also saw increases, but none of at a rate higher than a 50% increase. At the same time, it can be seen that throughout the city, many census tracts without bicycle boulevards saw doubling of their bicycle-to-work rates (see Map 5).

Map 4 – Portland bicycle network and commute-to-work rates in 2010

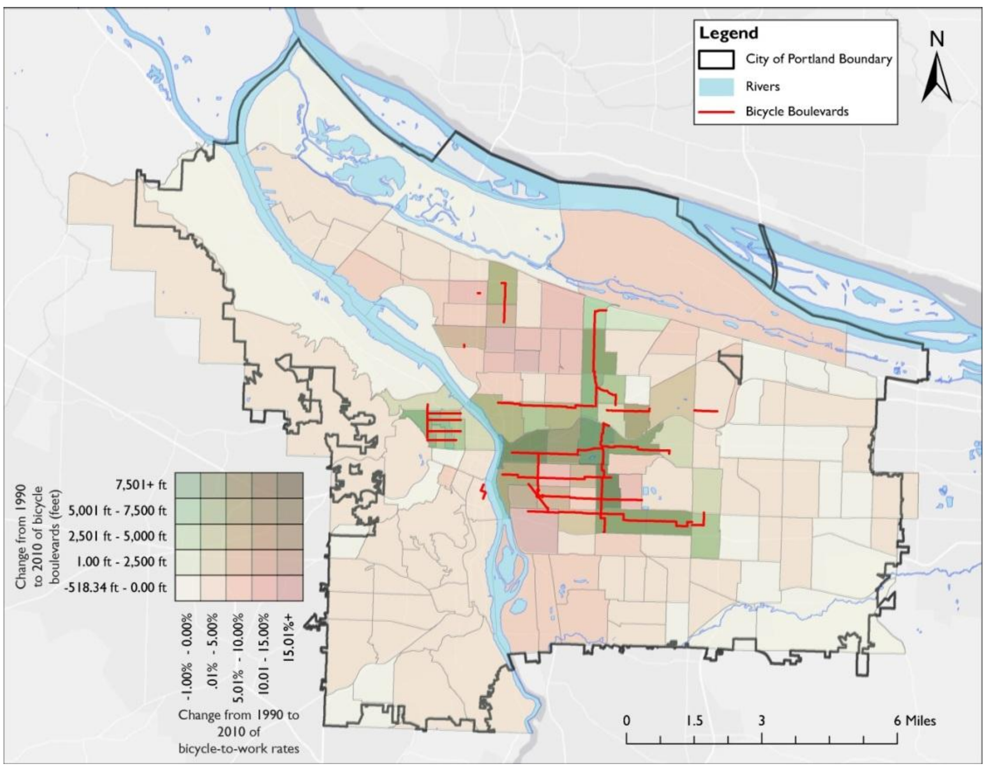


The second bivariate map shows the actual change between 1990 and 2010. By showing the actual change, one is able to see that the doubling of bicycle-to-work rates in the eastern portions of Portland are not actually very large. In many cases, there was only a change of a few percentage points. Conversely, the census tracts that are closest to downtown grew at a much larger rate. Many of the census tracts grew by over 10% from their levels in 1990. The census tracts directly east of downtown with bicycle boulevards show increases, while at the same time the census tracts that are northeast of downtown without bicycle boulevards also show similar increases from 1990 (see Map 6).

Map 5 – Bivariate comparison of the annual rate of change from 1990 to 2010 of bicycle-to-work rates and bicycle boulevards



Map 6 – Bivariate comparison of the change from 1990 to 2010 of bicycle-to-work rates and bicycle boulevards



Descriptive Statistics

An initial analysis of the bicycle boulevard data shows there has been a large increase between 1990 and 2010. The data shows that between 1990 and 1996, the average amount of bicycle boulevards feet/sq. mi. barely changed while the average bicycle lane feet/sq mi. substantially. At the same time however, the average rate of bicycle commuters in 135 census tracts grew from 1.12% to 2.09%.

By 2000, as the census tracts grew to 144, the rate only grew to 2.13% although the average feet of bicycle boulevards per square mile rose from 797.72 ft./sq. mi. to 2,306.36 ft./sq. mi. At the same time, the average amount of bike lanes grew from 2,078 ft./sq. mi. to 6,983 ft./sq. mi. In 2010, the average rate of bicycle commuting rose to 5.33% as the average bicycle boulevard rose to 2,632.94 feet/sq. mi. and the average bicycle lane rose to 8,096.47 ft/sq. mi., both of which were increases from 2000 (see Table 5).

The increases in bicycle-to-work rates from 1990 to 2010 would seem to show that there were other factors are playing a role. As bicycle boulevard infrastructure is installed, there is a lag in the adoption rate of individuals choosing to bicycle commute. This can be seen when looking at 1990 and 1996 where bicycle boulevard infrastructure was not added and there was only a very small increase in bicycle commuting. However, after the installation of infrastructure in 2000 there was an increase in bicycle commute rates. Then by 2010, there was a sharp increase in the rate of bicycle commuting, which could indicate a lag as riders adopt the infrastructure.

Table 5 – Descriptive statistics for the bicycle network in the City of Portland (1990-2010)

	1990				***1996***			***2000***				***2010***			
	Obs.	Mean	Median	STDV	Mean	Median	STDV	Obs.	Mean	Median	STDV	Obs.	Mean	Median	STDV
Bicycle Boulevard (feet)	135	357.91	0	1,137.60	338.01	0	1,119.93	144	1058.12	0	2329.61	142	1,095.07	0	2,194.84
Bike Lane (feet)	135	9.28	0	22.52	1,994.65	0	5,009.31	144	4,679.69	3,500.47	5,609.47	142	5,818.81	4,410.58	7,556.12
Census Tract Area (Sq. Mile)	135	1.05	.55	2.07	1.04	.55	2.07	144	1.06	.59	2.02	142	1.08	.62	2.04
Bicycle Boulevard (feet) per Square Mile	135	821.50	0	2,771.40	797.72	0	2,759.45	144	2,306.36	0	5,338.99	142	2,632.94	0	5,460.25
Bike Lane (feet) per Square Mile	135	10.81	0	25.25	2,078.42	0	3,431	144	6,983.01	5524.94	7,668.69	142	8,096.47	6665.84	8,309.32
Distance to CBD (miles)	135	3.85	3.68	1.96	3.85	3.68	1.96	144	4.13	3.78	2.18	142	4.21	3.88	2.15
% of Bicycle Commuters	135	1.12%	0.72%	1.25%	2.09%	1.32%	2.84%	144	2.13%	1.10%	3.10%	142	5.33%	3.93%	5.22%

CHAPTER IV

STATISTICAL ANALYSIS

Once the data was prepared, an analysis of the relationships between census tracts occurred. The hypothesis is there is a correlation between the presence of a bicycle boulevard and the bicycle-to-work commute rate. Therefore, it can be assumed that the null hypothesis states that there is no difference between bicycle-to-work commute rates in census tracts in 1990 without a bicycle boulevard and census tracts that have bicycle boulevard installed. This same null hypothesis can be assumed for 1996, 2000 and 2010.

The alternative hypothesis states that there is a difference between bicycle-to-work commute rates in census tracts in 1990 with and without a bicycle boulevard installed. It can also be expected that there is a positive association with bicycle-to-work commute rates and amount of bicycle boulevards installed in the census tract. This alternative hypothesis can also be assumed in 1996, 2000 and 2010.

Using regression analysis will show if there is a relationship between the dependent (bicycle-to-work commute rates) and independent (bicycle boulevard per square mile) variables. A perfect relationship of the independent and dependent variables would result in a correlation coefficient of one. Additionally, a model will be created to control for other factors that might have an influence on bicycle-to-work commute rates. The mathematical equation would be:

$$y = \alpha + b_1x_1 + b_2x_2 + b_nx_n + \varepsilon$$

Where: α is the constant, y is the dependent variable (bicycle-to-work commute rates), x_1 to x_n are the independent variables (i.e. bicycle boulevard per square mile, bicycle lane per square mile, distance to central business district), b_1 to b_n are parameters of the independent variables, and ε is the error term.

The second analysis used a fixed effects regression to look at possible differences before and after bicycle boulevards were installed in an individual census tract. With the simple regression, the analysis does not differentiate between different census tracts and only looks at the variation from one census tract to another within one period. By using a FE regression, the analysis would instead look at the variation within one census tract over time. This analysis would provide a better understanding if bicycle boulevards within a census tract drive a change in bicycle-to-work rates within that census tract. A FE regression utilizes a different type of mathematical equation to incorporate the changes over time:

$$y_{it} = \mu_t + \beta x_{it} + \gamma z_{it} + \alpha_i + \varepsilon_{it}$$

Where: y_{it} is the dependent variable (bicycle-to-work commute rates), x_{it} are the independent variables (i.e. bicycle boulevard per square mile), z_{it} are the variables that do not change over time (distance to central business district), $\mu_t$is the intercept for each period and β and γ are the coefficient vectors. The ε_{it} and α_i are both error terms that are either unobserved or purely random variation over time.

In using this equation with the addition of dummy variables, the census tracts will each have one variable for each period. Then the change of that variable within those census tracts can be used to look at the differences and be used to calculate and provide the coefficients estimates.

Regression Results

The analysis shows that there is a statistically significant relationship in 1990, 1996, 2000 and 2010 between the amount of bicycle boulevards feet per square mile and the rate of commuter's bicycling-to-work. However, in 1996 and 2000, the analysis showed that the variable is only significant at the 95% confidence level whereas 1990 and 2010, the bicycle boulevard variable is significant at the 99% confidence level (see Table 6).

Table 6 – Correlation between bicycle boulevards and bicycle-to-work rates 1990-2010

	1990	***1996***	***2000***	***2010***
1,000 ft. of Bicycle Boulevard per Sq. Mi.	0.16115 (3.00)**	0.14649 (2.37)*	0.20578 (2.33)*	0.39334 (3.95)**
R-squared	.13	.02	.15	.17
N	135	135	144	142

Value of t statistics in parentheses
* significant at 5%, ** significant at 1%

The data for 1990 shows that bicycle boulevards have an impact on bicycle-to-work rates. The estimates indicate that for every 1,000 feet of bicycle boulevards/sq. mi. there is an increase of bicycle-to-work commuters by .161%. Similarly, the data for 1996 shows an increase of bicycle-to-work commuters by .146%. In 2000, there is an increase of .206% and in 2010, the largest increase at .393%. However, in each of the years, the analysis also show only a weak relationship as the R-squared values are below .20, which means that the data can only explain less than 20% of the variation within the data.

As can be seen during 1996 and 2000, the data showed that the strength of the relationship is weak. In 1996, this could partly be due to the small amount of bicycle boulevards added while at the same time the bicycle-to-work rate increased throughout the city. As for 2000, a larger amount of bicycle boulevards was installed by that time. Therefore, the reason for its small coefficient could be a result of the lag caused by the lack of newly installed infrastructure in 1996.

When the regression was conducted again using the added variables of 1,000 ft. of bicycle lanes per sq. mi. and distance of centroid from the central business district, the data shows that both in 1996 and 2000, the variable of 1,000 ft. of bicycle boulevard/sq. mi. is no longer statistically significant (see Table 7).

Table 7 – Correlation between dependent variables and bicycle-to-work rates 1990-2010

	1990	***1996***	***2000***	***2010***
Constant	2.15894 (7.53)**	4.75375 (5.47)**	3.63023 (3.75)**	10.2877 (7.91)**
1,000 ft. of Bicycle Boulevard per Sq. Mi.	0.11529 (2.30)*	0.03667 (0.57)	0.12155 (1.36)	0.21260 (2.10)*
1,000 ft. of Bicycle Lane per Sq. Mi.	0.58196 (0.22)	0.06151 (0.28)	.050120 (1.22)	-0.08325 (-1.81)
Distance from Downtown (miles)	-0.29499 (-5.24)**	-0.73377 (-4.26)**	-0.52472 (-4.02)**	-1.15107 (-6.17)**
R-squared	.33	.27	.30	.35
N	135	135	144	142
Value of t statistics in parentheses * significant at 5%, ** significant at 1%				

The variable distance from downtown (miles) is significant for all years whereas the variable 1,000 ft. of bicycle lane/sq. mi, was also not significant for any of the years and actually had a negative coefficient in 2010. Additionally the R-squared value increases from between .02 and .17 in the previous regression to between .33 and .35 for the statistically significant years and 2.7 and .30 for years that are not statistically significant.

Table 8 shows the same variables without census tract normalization. The removal of the census tract normalization looks at the possible effects that larger census tracts, which are furthest from the central business district, have on the smaller census tracts closest to downtown. When looking at the distribution, the larger census tracts have the ability to skew the distribution closer to zero (see Table 8).

Table 8 – Correlation between dependent variables and bicycle-to-work rates 1990-2010 without census tract size normalization

	1990	***1996***	***2000***	***2010***
Constant	2.18709 (7.69)**	4.85994 (5.54)**	3.76031 (4.60)**	9.07589 (8.26)**
1,000 ft. of Bicycle Boulevard	0.22574 (1.79)	0.10430 (0.67)	.413946 (1.63)	.722509 (3.21)**
1,000 ft. of Bicycle Lane	-2.37890 (-1.18)	0.09251 (1.68)	0.04834 (1.09)	-0.05321 (-1.12)
Distance from Downtown (miles)	-0.29119 (-5.12)**	-0.77477 (-4.44)**	-0.55548 (-4.93)**	-1.00461 (-6.03)**
R-squared	.31	.29	.33	.37
N	135	135	144	142
Value of t statistics in parentheses * significant at 5%, ** significant at 1%				

The regression analysis shows that the bicycle boulevard coefficient for 1990 is no longer significant. The bicycle lane coefficient is still not statistically significant while the distance to downtown coefficient shows little change.

Table 9 shows that the FE regression, which looks at the variation within each census tract to look for possible relationships. By using a FE regression, the model can look at the effects of variables as they change over time by holding constant the average of each variable within each census tract (see Table 9).

Table 9 – Fixed effects regression (with and without census tract normalization)

	Fixed Effects		***Fixed Effects***
Constant	0.75026 (3.65)**	Constant	0.82233 (3.98)**
1,000 ft. of Bicycle Boulevard	0.56176 (2.01)*	1,000 ft. of Bicycle Boulevard per Sq. Mi.	0.14626 (1.29)
1,000 ft. of Bicycle Lane	-0.04074 (-1.05)	1,000 ft. of Bicycle Lane per Sq. Mi.	-0.02427 (-0.67)
1996	1.06184 (4.49)**	1996	1.02251 (4.14)**
2000	1.00567 (2.85)**	2000	1.13106 (3.15)**
2010	4.50231 (8.26)**	2010	4.63365 (8.48)**
R-squared	.39	R-squared	.37
N	556	N	556

Value of t statistics in parentheses
* significant at 5%, ** significant at 1%

The FE regression shows, when controlling for possible differences between census tracts, the normalization of bicycle boulevards by census tract size can change whether the variable of bicycle boulevards is statistically significant. When there is no census tract size normalization, there is a statistically significant relationship where there is an increase of 0.56% for every 1,000 ft of bicycle boulevards. However, that relationship decreases to a .15% increase for every 1,000 ft of bicycle boulevard/sq. mi. and is no longer significant when you normalize for census tract size. The variable of bicycle lanes is not significant with or without normalization and have coefficients that are negative in both FE regressions. The R-squared can explain between .37 and .39 for variation within each census tract.

Limitations

The use of statistical analysis in this study does have to be placed within context of its ability to be more generalized. Since the data is specific to Portland and the statistical model leaves out many factors, the results can only provide findings specific to Portland. Additionally there are many areas within this study that limitations have been identified and if improved upon would be able to increase accuracy and decrease the specificity to Portland.

One of the largest limitations of this analysis can be related to the data. As with using census data, there can be issues of how the data is asked and captured. The Census bureau asks individuals to list their most usual way of commuting during the week. This could cause individuals who use multiple modes of transportation to over report their most likely mode and underreport all other modes. Additionally, the time of year that the surveys are sent out, generally around April 1, could have an effect on the rate of bicycle commuting. These issues with the data could be a possible reason for the skewed distribution of the data. The data shows many census tracts have no bicycle boulevards or other bike facilities and a rate of zero bicycle commuters.

This phenomenon of no bicycle facilities and a rate of zero bicycle commuters can also be a symptom of spatial autocorrelation. Within geography, it is widely accepted that, "Everything is related to everything else, but near things are more related than distant things" (Bone 2012). This could mean that groups of census tracts that are closer to each other are more similar than census tracts that are further apart. In looking at the maps, it would seem that the census tracts that are closest to the central business district have similar bicycle commute rates. Additionally the tracts that have similar distances of bicycle boulevards also have similar rates of bicycle commuting.

If spatial autocorrelation is occurring, this could create another major issue with the analysis in regards to simultaneity. This issue arises when it is unknown if the dependent variable caused a change in the independent variable. This could be the case where planners saw that the rate of bicycle commuting was increasing in census tracts closes to downtown therefore city planners installed more infrastructure. In this case, the independent variable caused a change in the dependent variable.

CHAPTER V

DISCUSSION

The results of the regression while not exhaustive can be used as a starting point to begin a wider discussion of the use of bicycle boulevards, their impact on bicycling in Portland and possible wider implications nationally. As cities look at low cost solutions to add additional infrastructure to their bicycle network, bicycle boulevards are an attractive alternative. However, without understanding their effectiveness as a method of encouraging bicycling other options might provide higher returns on investment.

The implications of the data analysis and descriptive statistics show trends exist within Portland. It can be seen that as the bicycle boulevard network grew, bicycle-to-work rates grew. This trend can be seen in 1990, when there was approximately 8.64 miles of bicycle boulevards. By 2000, there was 25.42 miles. At the same time, the bicycle-to-work rate grew from 1.12% to 2.09%. An increase also occurred from 2000 to 2010 where the amount of bicycle boulevards increased from 25.42 miles to 29.85 miles, but Portland saw an increase of bicycle-to-work rates to 5.33%. Anecdotally, it would seem that, as the presence of bicycle boulevards increased there was also an increase in bicycle-to-work rates.

However, in looking at that same data, between 1996 and 2000 there was a large increase in the average of bicycle boulevards present yet there was only a small increase in the rate of bicycle commuting. One possible reason for this could partly be attributed to a delay between the installation of the bicycle boulevards and bicycle-to-work rates.

The bivariate maps of the change from 1990 to 2000 also show mixed findings. If bicycle boulevards were the only explanatory variable, then census tracts that did not add bicycle boulevards would not see increases in their commute rates. Generally, the census tracts that added or had bicycle boulevards installed in 1990 showed consistent increases from 1990 to 2000. At the same time, areas of North Portland also showed similar increases in bicycle-to-work rates without the addition of bicycle boulevards. Two possible reasons for this could be a result of the distance of those census tracts to the central business district or the amount of bicycle lanes added to those tracts.

Supporting the initial descriptive statistics trends, the initial OLS regression and FE regression both show that there is a possible link between the amount of bicycle boulevards and bicycle-to-work rates in Portland. The OLS regression showed that there is a relationship between bicycle-to-work rates and bicycle boulevards in 1990, 1996, 2000 and 2010. When controlling for the possible effect of bicycle lanes and distance to central business district has on bicycle-to-work rates, bicycle boulevards become only significant for 1990 and 2010. These findings are generally in line with the analysis by Jennifer Dill and Theresa Carr in their study looking more generally at all bicycle facilities in major cities (Dill and Carr 2003). However, the 1996 and 2000 data is not consistent since the data was not statistically significant.

Surprisingly, the variable of bicycle lanes was not statistically significant for any of the years in the OLS regressions. This could be partly caused by the location of most of the bicycle lanes in Portland. As seen in the maps, most of the bicycle lane network exists in the eastern portions of the City, which in many cases have the lowest bicycle-to-work rates.

The FE regression results are also mixed in their results. The analysis without normalizing census tract size shows a statistically significant relationship, which supports the previous OLS regression. By holding constant the average of each census tract over time, the average of each variable within each census tract shows that for every 1,000 ft. of bicycle boulevards there is a .56% increase in bicycle-to-work rates. However, when conducting the same FE regression with a normalizing for the size of each census tract the bicycle boulevard variable is no longer statistically significant. The bicycle lane variable was not statistically significant which was consistent with previous OLS regression. In both FE regression with and without normalization of census tract size the analysis showed that bicycle lanes were not statistically significant.

This inconsistency between census tracts that are and are not normalized in size could possibly be explained by the effect of location and census tract size. In this case, larger census tracts are generally along the periphery of Portland and have little to no bicycle boulevards. This could result in these census tracts on the periphery lessening the importance of the smaller census tracts closer to the central business district.

The census tracts that are closest to the CBD are critically important as seen in the OLS regression. In general, the census tracts that are closest to the central business district are smaller and have a larger amount of the bicycle infrastructure. This resulted in a relationship where the distance to the CBD was statistically significant for all years and was negative. In looking at the maps, this relationship was supported visually as census tracts that were further from the central business district had lower rates of bicycle commuting.

The trends within the data and the regression analysis while they cannot be interpreted as a cause and effect relationships, are encouraging for Portland and their work developing their bicycle boulevard network. As can be seen with the census tracts closest to the central business district, bicycle boulevards have a positive relationship with bicycle-to-work rates. This relationship partly explains the effect that bicycle boulevards have in encouraging individuals to locate near these facilities. However, while directionality of this type of relationship cannot be fully determined it is encouraging for bicycle commute rates, especially if a similar relationship continues as Portland expands into the eastern census tracts.

Future Studies

The results from this study at this time can only be applied to Portland because of it specific characteristics. Additional research needs to be conducted to expand the applicability for these findings to be applied more broadly. To accomplish this, one possibility should increase the sample size to look at other cities that have established bicycle boulevard networks. Both Berkeley and Palo Alto are other cities that are used as models of successful bicycle boulevards. By conducting a similar regression analysis with a larger sample size of cities, the analysis can be applied more universally to the effect of bicycle boulevards on bicycle commute rates.

As Portland adds additional bicycle boulevards to its network, before and after studies could be conducted using actual counts. If the bicycle facilities nearest to the newly designated bicycle boulevards were also looked at through bicycle counts, the analysis could look to see if the bicycle boulevards were creating new riders or if bicyclists are just detouring their routes to use the calmer streets.

Additionally, in Portland, different types of bicycle facilities are identified within their GIS data. An analysis of each of the different type of infrastructure might prove beneficial to see whether bike lanes, buffer bike lanes or bicycle boulevards prove to be a more effective infrastructure treatment at encouraging bicycling.

Conclusion

The amounts of bicycle infrastructure throughout Portland and bicycle commute rates have continued to grow since 1990. While this paper finds that there is a statistically significant relationship between the amount of bicycle boulevards and bicycle-to-work rates, the ability to infer causality must be tempered. As can be seen from other studies, there is a correlation between the amount of total bicycle infrastructure, regardless of type, and bicycle rates. Therefore, the effect of bicycle boulevards alone has to be placed with the context of a wider network of bicycle infrastructure in Portland.

With their dedication to continue to build out a cohesive singular bicycle network through 2030, Portland is in a position to boost their bicycle rates even further. As the Portland implements their plan to encourage the “Interested but Concerned” bicyclists, this segment of the population will require streets that are more sheltered from fast moving traffic. A built out and expansive bicycle boulevard network will give this category of bicyclists an important segment of infrastructure. Coupled with this vision, this analysis showed that when comparing bicycle lanes and bicycle boulevards, boulevards have a much larger effect on bicycle-to-work rates.

This analysis supports Portland’s vision of expanding their bicycle boulevard network. With boulevards being statically significant, it gives Portland further evidence that they should continue to focus on bicycle boulevards as critical components within their bicycle network. Conversely, the addition of bicycle lanes needs further consideration since the data did not show a statistically significant relationship. The initial investment of bicycle boulevard infrastructure has created an environment where demand is inducing bicycle infrastructure and simultaneously bicycle infrastructure is inducing demand.

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