Analysis of Factors Influencing Bicycling:
A Look at the 2009 NHTS and City-Level Characteristics

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Using 2009 National Household Travel Survey data, we examine the role of infrastructure on bicycling behavior in 30 large U.S. cities at an individual level. We find that demographic variables exhibit a stronger relationship to cycling behavior than the quantity of either dedicated lanes or shared-use paths. In fact, neither paths nor lanes are significantly and positively correlated to being either an occasional or frequent bicyclist. However, the density of facilities is positively correlated to both levels of bicycling. We interpret these results and place them within the context of existing literature to make recommendations for effective investment of resources for encouraging bicycling as a travel and recreation behavior.

Introduction:

Bicycling has grown steadily as a commute mode in the United States in the last two decades, with commute share almost doubling between 2000 and 2010 in the 70 largest U.S. cities (Pucher et al 1999, Census 2009). Fueled by support from federal funding programs like Transportation Enhancements and Recreational Trails, municipalities of all sizes have increased the size of their bike infrastructure networks in hopes of encouraging more residents to bicycle (rather than drive alone). The effectiveness of improved infrastructure in increasing bicycling, however, is not clear. Aggregate-levels studies comparing bicycling rates in cities with different levels of infrastructure are forced to accept the limitations of very broad generalizations and must make tenuous assumptions to reach any conclusions. Individual-level studies on the other hand frequently ignore infrastructure or have too little variation in it to say much that is useful. Combining state- and city-level with a large survey with excellent individual-level characteristics, this study provides new and better estimates of the impact of infrastructure on bicycling. This information is critical for understanding what investments will best encourage bicycling, so that cities interested in boosting their rates of bicycling can do so efficiently and effectively. Cities may do so to curb local or global emissions, reduce congestion, improve public health/quality of life, or boost economic growth[1].

Because of the interest in taking advantage of the aforementioned benefits, and realizing the success that competing cities have had in encouraging bicycling, there has been a consistent flow of research done on the role of various factors in influencing bicycling. The structure of this research has varied greatly, though most have in common an underlying understanding of travel behavior as a form of utility maximization, where individuals (consciously or subconsciously) weigh various costs, benefits, and conditions, the result of which is a preference for one particular mode (Krizek et al 2009). This approach to transportation decisions actively shapes the methods used for data collection

[1] A large supply of literature quantifies these benefits (Cavill et al 2008, Wakefield 2004, Unwin 1995, Pucher and Dijkstra 2003, Finkelstein et al 2010, de Hartog et al 2010).

(and analysis, as I'll discuss in a moment), but it is broadly accepted regardless of the specifics of research methodology.

One of the challenges in the field has been finding a source of data on travel behavior that includes relevant information on local environments, which may play a part in affecting mode decisions. This research examines whether, given one of the largest travel behavior data sets in the United States and appropriately paired city-level policy and infrastructure characteristics, there exists any relationship between state and local funding, demographic variables, or city-level infrastructure measurements, and the propensity of individuals to travel by bicycle. While some research has been done on the role of city-level variables on city-level dependents (particularly mode share), the inclusion of city-level variables into such a large individual-level survey provides an excellent opportunity to answer those research questions.

State of the Literature:

The presence of bicycle-specific infrastructure (such as on-street bike lanes or separated facilities like multi-use or bike-specific paths) has a significant positive correlation to bicycling in several studies (Akar and Clifton 2009, Buehler and Pucher 2012, Dill and Voros 2007, Dill 2009, Dill and Carr 2003, Garrard et al 2008, Krizek et al 2009, Nelson and Allen 1997, Pinjari et al 2011, Pucher and Handy 2010, Titze et al 2008, Winters et al 2011). Bicycle infrastructure appears particularly strongly associated with bicycling for men (Stronegger et al 2010) and those who already cycle to work (Tin et al 2010, Akar and Clifton 2009). A few studies, however, have found little or no association (Moudon et al 2005, Parkin et al 2008, Wardman et al 2007), and concluded that adding bicycling facilities would only produce modest increases in bicycle commute mode share.

A good deal of research exists on preferences for particular types of infrastructure. Some studies found that bike lanes increased cycling more than paths for experienced cyclists (Pucher et al 2010), but paths increased cycling more for non-cyclists (Akar and Clifton 2009). Garrard and colleagues (2008) found that female cyclists preferred off-road paths over bike lanes or roads without facilities. In contrast, Dill and Carr (2003), who included types of facilities as unique variables in their model, found that on-street bike lanes were more strongly associated with bicycle mode share than separated bike paths were. This was supported by the stated preference work of Tilahun and colleagues (2007), which revealed that respondents were willing to trade 16 minutes of increased travel time for bike lane improvements, compared to only 5 minutes for off-road facilities.

In addition to the strong quantitative evidence, there is a compelling qualitative narrative to be considered. Bicycling, like driving or riding transit, is an experience reliant heavily upon the environment it occurs in. A gravel road is not an incentive to driving; neither is an over-crowded rail car. In the same vein, bicycling can be heavily discouraged by the presence of unsafe or unpleasant conditions, and heavily encouraged by a comfortable and expedient infrastructure. As such, we would expect (and have seen in much of the research) that the quantity and quality of bicycle-specific infrastructure are critical variables at work in individual decisions to ride or not ride.

Reviewing the existing evidence, my hypothesis is built upon the observation that bicycling is related to the quality or quantity of infrastructure present, and that all infrastructure is not equal in the eyes of individuals. As such, I hypothesize that bicycling

will be more common in cities with more infrastructure. I also expect that likelihood of bicycling is higher for males, students, and among those who own fewer automobiles. No hypothesis regarding income and likelihood of bicycling can be made on the basis of the existing literature alone, though it may be expected to at least have an indirect effect through automobile ownership. Trip distance is hypothesized to be negatively correlated to likelihood of bicycling, as is travel time.

As state and city-level funding have not been evaluated for correlation with bicycling on this level before, there is no evidence to support a particular hypothesis. However, given the evidence supporting the role of infrastructure in encouraging bicycling, I expect to see that cities with higher levels of support (in terms of both infrastructure and funding) will experience higher levels of usage, represented as increases in the likelihood of respondents being a bicyclist, and potentially more trips taken by bicycle. In sum, our focal hypothesis is that increases in funding (particularly at the city level) and infrastructure will increase the likelihood of a resident of that location being a cyclist, and make them also more likely to be a frequent cyclist.

Findings on demographic patterns are less mixed/conflicted. Men and students are more likely than women and non-students to bicycle individual bicycling is higher if they are male (Akar and Clifton 2009, Cervero and Duncan 2003, Moudon et al 2005, Parkin et al 2008, Plaut 2005), or a student (Akar and Clifton 2009, Buehler and Pucher 2012, Nelson and Allen 1997). Car owners are much less likely to bike than non-owners (Buehler and Pucher 2012, Cervero and Duncan 2003, Heinen et al 2011, Plaut 2005, Dill and Voros 2007).The findings on income are mixed . Trip distance was almost uniformly negatively correlated to likelihood of bicycling in those disaggregate models that included it. The longer the trip, the less likely people are to bicycle.

Data and Methods:

The 2009 National Household Travel Survey (NHTS), administered by the Federal Highway Administration, contains responses from over 300,000 individuals, making it one of the largest such surveys in the United States, and features demographic questions including age, race, gender, occupation, vehicle ownership, and transportation mode questions such as times traveled by particular modes and most common mode employed within the last week. Finally, it includes information about the respondent's location of residence including whether it is urban or rural, their particular region, state, and metropolitan area, and densities of population, employment, and housing within their census tract and block.

Since each respondent could be identified by state and city of residence, I could then add to the NHTS dataset variables for state-level bicycle and pedestrian funding, as well as per capita state funding, plus city-level funding and per-capita city funding. Total city spending was included as proxy for level of city support for bicycling, though total state funding was not, based on the logic that it would be a stretch to associate statewide investment with any meaningful impact to a given individual. While per-capita city spending controls for city size, the total amount of spending represents a more abstract and potentially significant ideological commitment on the part of a city to supporting bicycling. In this way, total city spending may be a way to quantify a city's overall interest

in being a bike-friendly city in a way that per capita spending does not entirely capture[2]. This data, as well as data on the density of bicycle infrastructure (expressed in miles of bike facility (lanes and paths both) per square mile), the total mileage of bike lanes within the city, and the total mileage of shared-use pathways in the city, was sourced from the 2012 Benchmarking Report produced by the Alliance for Biking and Walking (Alliance 2012). Data was only available for 33 of the cities that appeared in the NHTS, though this was sufficient to produce a sample of 292,627 whose data included at least state-level funding values, 117,461 of whom also included city-level funding and facility values (smaller samples in computations are the result of missing values). Total lane and path mileage represent the total size of the bicycle infrastructure network within a city; while density of facilities may better capture their prevalence for a given size of city, it does not necessarily capture the spread of that network or its ability to connect destinations. Total mileage shows the size of that network, and may better capture the quality of the network in cities, for example, where bicycle infrastructure is installed along prominent corridors rather than throughout a neighborhood or urban core.

Given the large sample and the individual-level analysis, I employ two separate sets of models with different dummy dependent variables to represent bicycling. The first dummy dependent variable represented all those respondents who had ridden a bicycle in the last week (this dummy represents at least occasional cyclists). To capture whether any of the independent variables had a smaller or larger effect on more active bicyclists, a second dummy represents all respondents who had ridden a bicycle five or more times within the last week (five was selected based on the logic that it would capture those who had ridden to or from work for at least half of a common work week).

Underlying the decision to employ both dependent variables is a curiosity regarding whether there is a difference between those factors which contribute to frequent cyclists' behaviors and those which produce at least occasional cyclists; the application of the both dependent variables will provide a more complete understanding of the causal factors at work in the decision to bicycle or not. Logistic regression was used to identify the impact of the independent variables on whether respondents rode a bicycle during the past week and whether they had ridden more than 5 times during the past week[3].

Since data was not available on all the cities represented in the NHTS dataset, the first models in Table 1 contain only individual-level variables and state per capita funding (complete data for which was available). Then the dataset was pared down to only those respondents who live within cities for which funding and infrastructure data was available, and the city-level variables were introduced into the models in Table 2. Since the city-level variables are not completely independent, the standard errors for those models that include city-level variables were clustered by city to produce robust standard errors.

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[2] City bike-related spending as a percentage of total budgets might be a better variable, but the prevalence of so-called "complete streets" projects and other investments make it difficult to identify where a budget dollar is specifically for bicycling.

[3] My application of logistic regression to mode share data follows a common precedent within the field (Buehler and Pucher 2012, Cervero 1996, Cervero and Duncan 2003, Garrard et al 2008, Heinen et al 2011, Noland and Kunreuther 1995, Parkin et al 2008, Plaut 2005, and Wardman et al 2007).

Findings:

A glance at the data shows that 10% of the respondents were at least occasional cyclists; of those, 3% rode once, and 2.6% rode at least 5 times in the course of the week. Given the large size of the NHTS dataset, these percentages provide more than sufficient occurrences of the two dependent variables. Only .35% of respondents rode 10 or more

Table 1. Full Sample (Individual Characteristics)

	(1) Occasional	(1) Prchange	(2) Avid	(2) Prchange
White	0.095**	.58	0.319**	.15
	(2.96)		(3.18)	
Age	-0.020**	-8.7	-0.025**	-.93
	(21.86)		(9.39)	
Male	0.728**	4.6	1.230**	.67
	(29.27)		(14.77)	
Education	0.221**	5.3	0.174**	.35
	(18.69)		(4.92)	
Income	0.017**	1.7	-0.013	-.12
	(5.62)		(1.52)	
# of Cars	-0.089**	-7.5	-0.415**	-1.5
	(7.97)		(10.27)	
State spend Per capita	0.035** (3.91)	2.6	0.052* (2.02)	.34
Distance to Work	-0.003** (4.43)	-6.7	-0.026** (7.07)	-.74
Constant	-2.866** (39.98)		-4.009** (19.62)	
Observations	105575		105575	

Absolute value of z statistics in parentheses
* significant at 5%; ** significant at 1%
Note: Prchange represents percentage point change

times, the number of bike trips most logically connected with consistent bike commuters. 59% of cyclists in the sample were male, and 85% of them were white; the median income for cyclists was $75,000 - $79,999, compared to $55,000 - $59,999 for the sample as a whole. There were no regional differences. Only 71% of cyclists lived in an urban area. The average age within the sample was 49.4, and the average level of education was some amount of college.

With no controls for bike infrastructure, Table 1 shows that sex, race/ethnicity, age, education, number of cars in the household, state spending per capita, and distance to work all affect whether one bikes occasionally or frequently. Discussing them in order of their appearance in Table 1, income is significant for biking occasionally, but not for being an avid cyclist. Holding the other variables at their means, whites are .58 percentage points more likely than non-whites to be occasional cyclists and .15 percentage points more likely to be frequent cyclists. The odds of a white individual being a frequent bicyclist are 1.37 times those of a non-white person. Age was also significant to both, with each year of age corresponding to a .02 decrease in log-odds of being either an occasional or avid bicyclist. The probability of being an occasional cyclist rises 4.6 percentage points by virtue of being a male, and the odds of a male being an avid bicyclist are 3.4 times the odds of a female

being an avid cyclist. Unlike age, which corresponds to a drop in the likelihood of being a cyclist, education actually increases the odds of both occasional and frequent cycling.

Income was significantly associated only with being an occasional bicyclist, where an increase of $5000 in income corresponded to a .017 increase in the log-odds of being a cyclist. Despite more income being associated with higher likelihood of being a cyclist, owning more vehicles was associated with .089 lower log-odds of being a cyclist, and the probability of being a frequent cyclist drops by 1.5 percentage points between owning no cars owning and the maximum size in the sample; this is the second largest impact of any independent variable on being a frequent cyclist. In this case, it may also be the case that being a frequent cyclist reduces the need for owning as many cars; the direction of causality is not as clear. As might be expected, the distance from home to work in miles was negatively associated with the log-odds of being both an occasional and frequent bicyclist, though the effect was fairly small (though a bit larger for frequent cyclists).

Since data for all individuals' cities of resident was not available, we conducted the same regressions as we did for the full sample, but this time excluding those individuals for whom city-level data was not available (the full sample data in Table 1 was included to demonstrate that the city sample used below is representative of the general population, and to show relationships for the full NHTS sample where possible). Table 2 shows that being white was significantly correlated to both dependents for bicycling behavior. Age, income, and number of household vehicles all had more or less the same impact (in size, direction, and significance) as in the full sample, with the exception that income is no longer significantly negatively associated with being a frequent bicyclist. Gender had a more pronounced impact on being an occasional bicyclist in the city-limited sample (the odds of a male being a bicyclist were 2.2 times the odds for females), though roughly the same impact on the log-odds and probability of being a frequent bicyclist as in the full sample (3.2 times higher odds for males).

Distance to work continues to be associated with a decrease in log-odds of being a bicyclist, reducing the log-odds of being a frequent bicyclist by .026 with each mile of commute distance. We can see that for our sample of cities, gender, education, and ethnicity were more prevalent in influencing cycling behavior, while age, income, distance to work, and vehicle ownership are all less prevalent than the full sample.

Having captured the effect of the individual-level characteristics, and comfortable in the similarity of the city-limited sample to the full sample, we can introduce our block of city-level characteristics to both models. Doing so does not change the direction or significance of any of the individual-level variables in either model, though of course the size of the effects changed (being white has a larger impact on both dependent variables in the second models, while the effect of state spending per capita shrank from model 1 to 2). Most of the city-level variables had no significant impact on bicycling, leading me to fail to reject the null hypothesis of no interaction, and thus reject our research hypotheses that state spending per capita, city spending per capita, or total city spending increase the likelihood of individuals being either occasional or frequent bicyclists. Employment density within the census tract was positively associated (with a coefficient of close to zero).

Table 2. Impacts of Individual and City-Level Independent Variables on bicycling

Variable	(1) Occasional Cyclist	(2) Occasional Cyclist	(2) Probability Change	(3) Frequent Cyclist	(4) Frequent Cyclist	(4) Probability Change
White	0.152*	0.205**	1.4	0.454**	0.577**	.28
	(2.46)	(2.86)		(3.33)	(4.86)	
Age	-0.019**	-0.019**	-9.3	-0.025**	-0.024**	-.9
	(13.46)	(14.49)		(6.20)	(5.92)	
Male	0.797**	0.803**	5.7	1.21**	1.179**	.67
	(19.71)	(20.87)		(10.69)	(10.31)	
Education	0.207**	0.198**	5.3	0.224**	0.200**	.41
	(8.89)	(8.61)		(3.82)	(3.44)	
Income	0.013**	0.014**	1.6	-0.031**	-0.032**	-.35
	(3.26)	(4.18)		(2.97)	(3.68)	
# of cars	-0.047*	-0.048**	-3.9	-0.332**	-0.241**	-.95
	(2.08)	(3.10)		(3.15)	(2.77)	
State spend	0.125	0.110	5.1	0.093	0.116	.43
Per capita	(1.59)	(1.27)		(0.68)	(0.89)	
Distance	-0.005**	-0.004*	-7.8	-0.026**	-0.020*	.47
to work	(3.07)	(2.51)		(2.94)	(2.02)	
Density		0.048	1.9		0.141**	-.73
of facilities		(1.28)			(3.14)	
City spend		-0.012	-3.1		-0.060	.61
per capita		(0.67)			(1.17)	
Lane mileage		0.001	2.9		0.001	.36
		(1.72)			(1.61)	
Path mileage		-0.002*	-5.4		-0.003*	-.51
		(2.34)			(2.04)	
Pop. Density		-0.000	-1.3		0.000	.08
		(1.46)			(0.86)	
Emp. Density		0.000**	2.2		0.000**	.59
		(4.26)			(4.93)	
Constant	-3.044**	-3.107**		-4.212**	-5.013**	
	(14.05)	(10.68)		(11.50)	(10.45)	
Observations	42974	42104		42974	42104	

Robust z statistics in parentheses

* significant at 5%; ** significant at 1%

Interestingly, increases in the total mileage of shared-use paths within a city were correlated with a (very small) decrease in the log-odds of being either an occasional or frequent cyclist. Since it is common for long stretches of shared-use pathways to be built that have a limited accessibility on their own (and since many of these are primarily recreational), it may be the case that they increase bicycling for those close to the pathway, but divert funds away from other projects that might encourage bicycling elsewhere. They might also be efforts to quell complaints about the under-provision of bicycle facilities, which make it less likely for other facilities to be bike-friendly. Either way, it appears that simply constructing more miles of pathway is actually vaguely counter-productive as a whole, and that adding lane mileage has no appreciable effect. At the same time, the density of bicycle facilities was positively correlated with increasing log-odds of being a frequent cyclist (each additional mile of facility per square mile increased the log-odds by .141).

Discussion & Conclusion:

While both the quantity and quality of bicycle mode-choice research has been increasing in the last two decades, the field has struggled to produce the data and methods required to extend findings of correlation to ones of causality. While independent variables such as climate and socioeconomics can be clearly identified as having a direct or indirect effect, the interrelation between rates of bicycling and infrastructure (did the infrastructure trigger a cyclist to ride, or did the rider trigger the city to build infrastructure?) has been very problematic in its limitation of any policy conclusions that might otherwise be reached on the basis of the findings of this or any other similar research. Complicating this difficulty is a lack of comprehensive data on funding and infrastructure provision; while the availability of such data is improving, the reliance upon city and state self-reporting introduces the possibility (though perhaps small) that methods of measurement may differ (center-line miles vs. curb miles, for example), or that data may be outdated or incomplete.

In addition, because I do not have detailed information on whether bike trips were for recreation or commute, it may be the case that the result of no observed correlation between distance to work and being an occasional cyclist is attributable to a sample with more recreational riders, rather than commuters (though as noted before, distance to work was correlated with being a frequent cyclist). It is hypothetically possible that some of the relationships identified in this study are predominantly influencing the likelihood of an individual being specifically a recreational cyclist, while others influence only commuting behavior; since it's very possible for either an occasional or frequent cyclist to be a commuter and/or recreational rider, this forces me to make some broad conclusions about cycling behavior. These conclusions are, simply, that for most of the United States, bicycling is still significantly more common among males, whites, and those with higher levels of education. Future efforts to employ propensity score matching or similar treatment-control methods may better identify whether significant differences exist in the impact of independent variables on bicycling behavior between certain subgroups.

There has been mixed evidence in other research on the impact of climate/weather on bicycling behavior (Gatersleben and Appleton 2007, Flynn et al 2012, Heinen et al 2011, Nankervis 1999, Noland and Kunreuther 1995). While the inclusion of weather data was considered, the extreme variability of weather for a given trip (what conditions were like

during that day or week, much less during the period of travel specifically) led me to opt not to include it; in the future, this a set of variables which I hope to find a way of incorporating. Similarly, variables representing measures of safety were not included, since previous research suggests that actual data on crash incidence is less relevant to travel behavior than perceptions of safety. While the NHTS includes a question on perception of safety, the very low response rate to this question forced me to exclude it. Hopefully future installments will include a higher response rate.

While I can interpret these results as evidence supporting correlation, I have been careful to avoid making claims of causation. While it's clear that bicycling does not have a causal impact on gender or ethnicity, and it's unlikely to have a causal impact on education, it becomes less clear when talking about income, distance to work, funding levels, or infrastructure quantities. For some people and places, bicycling behavior may in fact be acting as a causal factor itself, influencing the willingness of states and cities to invest in infrastructure, or influencing the decisions of particular individuals to live in certain places, take certain jobs, and so forth. Given these questions about the direct(s) of causality, it is important to be aware of the limitations of this analysis. That said, there are quite a few potential policy implications that could be drawn from the results.

All told, the most obvious policy implications to be drawn from the results are that the current preponderance of cyclists are young white, educated males, and that simply increasing funding or sheer mileage of infrastructure does not increase the likelihood of residents being either occasional or frequent cyclists. While building more miles of lanes and paths does not have an appreciable or even positive impact on bicycling, the density of such facilities does. Based on these results, I suggest that efforts to increase bicycling as an activity and particularly as a mode of transportation should focus on the factors that make may act as barriers to bicycling for women, minorities, and individuals with less education. Some research has been done to identify what those factors are, though again, more diverse evidence is needed. They should also invest in the intelligent planning of facilities (particularly more dense networks of facilities) rather than the construction of more total miles of facilities.

This research has only scratched at the surface of this dataset, and access to funding and infrastructure data for the full range of cities represented within the NHTS would provide an even more impressive sample. Despite these limitations, the pairing of state and city-level characteristics to a large disaggregate sample featuring such a diversity of cities is novel within the field, and has produced results worthy of discussion, many of which may warrant further analysis and application in the future. It is my hope that this research may trigger the development of a more comprehensive and accessible accessory to this and future NHTS datasets that allows more opportunity for analyzing the role of city and state-level variables (for example the presence of certain regulations or policies) on individual travel behavior, particularly bicycling.

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