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Factors associated with proportions and miles of bicycling for transportation and recreation in six small US cities

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ABSTRACT

The majority of bicycling in the US is for recreation rather than transportation purposes but few studies have examined the question of bicycling purpose. We use data from an online survey conducted in 2006 in six small cities in the western US to examine factors affecting bicycling for transportation compared to bicycling for recreation. The results indicate that individual, social-environment, and physical-environment factors have important influences on the balance between transportation and recreational bicycling and on miles of bicycling for each purpose. Bicycling comfort and an aversion to driving are associated with more transportation bicycling. A culture of utilitarian bicycling and short distances to destinations are also key factors for transportation bicycling. Bicycle infrastructure appears to play an indirect role through its effect on perceived bicycling safety and through the self-selection effect, by attracting bicycling-inclined people to bicycling-supportive communities.

1. Introduction

Facing volatile gas prices, potential mandates for greenhouse gas reductions, rising obesity levels, and strained capital budgets, communities throughout the US are giving increased priority to bicycling as a mode of transportation. For inspiration, they often look to other countries with similar economies, where bicycling is far more prevalent. The share of urban trips by bicycle in Canada, for example, is twice that of the US and the share in European countries is anywhere from four times (in the UK, France, Italy) to 28 times (in the Netherlands) higher than in the US (Pucher and Dijkstra, 2003). From one perspective, these numbers suggest significant potential for increasing bicycling in the US. On the other hand, they may reflect important differences between the US and these other countries that could limit the potential of bicycling in the US.

By nearly all measures, bicycling conditions are better in Europe than the US (Pucher and Buehler, 2008). European countries have more compact land-use patterns with higher average urban densities and consequently shorter average trip lengths than those of the US. Many cities in the US lack appropriate facilities for cycling compared with those in European countries. The extent of the car-dependent culture and lifestyle also make the US different from other countries. More pro-bicycling policies and programs as well as restrictions on driving in European countries have reinforced wider social support for bicycling. These factors help to explain much higher levels of bicycling for transportation in Europe than in the US. Most are not easily replicated in the US and only over considerable time.

In the short term, however, communities in the US might look more closely at the bicycling they currently have. There is a significant amount of bicycling in at least some parts of the US, but the vast majority of this bicycling is for recreation rather

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than transportation. Pucher and Dijkstra (2000) report that more than two-thirds of bike trips are for recreation in the US, and that the percentages of bicycling trips for work, school, and shopping in the Netherlands (60.0%) and in Germany (60.1%) are twice that in the US. Unfortunately, few studies have examined the question of bicycling purpose; existing research provides little evidence on factors that differentiate transportation bicyclists from recreation bicyclists and on differences in the factors that influence how much they bicycle for each purpose.

2. Some background

Our conceptual model borrows from the ecological models widely used in physical activity research within the field of public health (Sallis and Owen, 2002) and incorporates findings from previous studies. Ecological models focus on the links between people's environments and their behaviors and suggest that behaviors are affected by multiple levels of factors that begin at the level of the individual and expand outward to encompass the social and physical environments. Using this conceptual model, we hypothesize a multilevel array of factors that potentially influence bicycling purpose. At the first level are individual factors including socio-demographics, attitudes, preferences, and beliefs, as well as comfort with bicycling (related to a concept called "self-efficacy" in the field of public health). At the next level, physical-environment factors reflect land-use patterns, transportation infrastructure, and the natural environment. Finally, social-environment factors include the cultural norms of the community, as evidenced by the collective behaviors of its residents.

Characteristics of the physical environment are of particular interest, given the influence that planners and engineers have over these characteristics. Studies show that various characteristics of the physical environment influence transportation bicycling, though neither the characteristics examined nor the results are entirely consistent across studies. Bicycle infrastructure, including the number of separated bicycle paths and on-street bike lanes per mile, and the proportion of off-road routes seem to have a significant effect on bicycling (Parkin et al., 2008), though one study did not find any association (Geus et al., 2007). Facilities such as bike racks or lockers have also been found to influence transportation bicycling (Stinson and Bhat, 2004). Dangerous traffic conditions or larger traffic volumes were found to be determinants of not bicycling for transportation (Parkin et al., 2008), though Geus et al. failed to find this association. Land-use patterns, such as population density and accessibility to the workplace or transit, were associated with bicycling to work Stinson and Bhat (2004), but the relationship was unclear in Geus et al. (2007). Parkin et al. (2008) found a significant effect of natural environment factors such as hilliness and weather.

Many of the factors that affect recreational bicycling appear to also affect transportation bicycling. For example, physical environment characteristics significantly correlated with recreational bicycling in a study in Melbourne included design, safety, prevalence of destinations, and aesthetic features (Kamphuis et al., 2008). However, few studies look directly at the differences between transportation and recreation bicycling, and these point to some differences in the factors affecting the two types of bicycling. Perceived accessibility to bike lanes, for example, was associated with engagement in any transportation-oriented bicycling vs. non-transportation bicycling in Hoehner et al. (2005), while Troped et al. (2003) concluded that streetlights, enjoyable scenery, sidewalks, and distance to a community rail–trail significantly affect weekly minutes for transportation-motivated physical activities (including walking and bicycling) but have no impact on weekly minutes for recreational activities. Similarly, studies on walking show that physical-environment factors are more important in explaining walking for transportation than for recreation (Saelens and Handy, 2008), a pattern that might hold for bicycling as well.

Thus, empirical knowledge about factors related to the balance between transportation and recreational bicycling for individuals is still limited. It is not clear whether bicycle infrastructure and land-use patterns correlate with both transportation and recreational bicycling, nor what characteristics of the physical environment are most important. Additionally, studies have not addressed why some bicyclists are more transportation-oriented and some are more recreation-oriented than others. We identified only one study that examined the effect of attitudinal factors. Further, the impact on bicycling purpose of the social environment, such as cultural norms toward different types of bicycling, has not been evaluated in previous studies, to our knowledge. Finally, previous studies have not explored the influence on bicycling purpose of "self-selection", the possibility that an individual's preference for bicycling leads him to choose to live in a community with an environment supportive of bicycling of one type or the other (Handy et al., 2006). Our analysis thus aims to assess the relative effects of a more comprehensive set of variables drawn from each level of the conceptual model.

3. Methodology

The study employs a cross-sectional research design to determine the relative influence of individual factors, physical-environment factors, and social-environment factors on bicycling purpose. The unit of analysis for the study is the individual, and the sample is drawn from six small cities in the western US that differ with respect to physical and social environments. This approach enables an assessment of the relationships between variables representing both environments and bicycling purpose, though it is important to note that it does not establish the direction of causality between the factors and bicycling purpose, nor does it address the potential interaction between factors.

3.1. Sampling and administration

Six communities were selected for the study based on several factors. Davis, California with a high bicycling level (Buehler and Handy, 2008) with selected as a starting point. We then looked for comparison cities that were similar with respect to size, weather, topography, and presence of a community college or university but differed with respect to bicycle infrastructure and culture. Chosen as comparison cities were Woodland, Chico, and Turlock, all in the Central Valley of California, and Eugene, Oregon and Boulder, Colorado.

For each of the communities, we purchased a random sample of 1500 residential addresses from Martin Worldwide, a commercial provider; for Davis, we ordered an additional sample of addresses for 1000 residents who had moved in the previous year. Participants were recruited for the online survey by mail and hard copies of the survey were offered on request in June 2006, with two reminder postcards mailed in July and August. As an enticement for participation, respondents could choose to be entered into a drawing for one of three $100 prizes. The overall response rate for the survey was 12.6%, for a sample of 965. This analysis is based on the subsample of 581 respondents who bicycled within the last year, labeled bicyclists.

Given the response rate, non-response bias is a reasonable concern. The survey results show that 32.3% of Davis respondents usually commute to work by bike, in comparison to 14.4% in the 2000 census; the survey share was higher than the census share for all cities except Turlock. To evaluate the non-response bias further, a short phone survey was conducted in May 2008 in Davis. Random-digit dialing was used to achieve a representative sample of 400 residents. The results show slightly lower bicycling levels (measured by share of bike ownership, share of biking in last 7 days, share of biking within last year, and share of biking to work), but not significantly different at the 5% level from the online survey according to chi-squared tests, implying that the non-response bias of the data from the online survey is not as serious as Table 1 suggests. Further, because our focus is on explaining bicycle behavior as a function of other variables rather than on describing the simple univariate distribution of bicycling per se, these differences are not expected to materially affect the results (Babbie, 1998).

3.2. Variables

To explore factors associated with the tradeoff between bicycling for transportation and recreation, the dependent variable is derived from a survey question that asked the respondents who bicycled at least once within the last year about their portion of bicycling for transportation and recreation purposes, in this way: "What portion of your bike rides are for transportation (commuting, shopping, visiting people) and what portion are for recreation (exercise, pleasure rides, adventure)? By 'bike ride' we mean a time you ride a bicycle for five minutes or more." Five choices were offered: (1) All bike rides for transportation. (2) Most bike rides for transportation. (3) About 50% for each. (4) Most bike rides are for recreation. (5) All bike rides for recreation. The distribution by category is shown in Table 2. In this sample, more people bicycle completely or mostly for recreation (48.7%) than do people for transportation (34.4%), consistent with the finding of Pucher and Dijkstra (2000) that recreational bicycling is more popular than transportation cycling in the US.

Using the responses to the survey question on portions of bicycling for transportation and recreation purposes, we generated new variables representing the proportions of bicycling for each purpose (Table 2). The proportion of transportation bicycling – "Imputed Transportation Proportion" – was created as follows: "All bike rides for transportation" was recoded as 100%, "Most bike rides for transportation" was recoded as 75%, "About half and half for each" was recoded as 50%, "Most bike rides for recreation" was recoded as 25%, and "All bike rides for recreation" was recoded as 0%. The share of recreational bicycling – "Imputed Recreation Proportion" – was created using the same approach.

To examine factors influencing miles of bicycle rides for transportation and recreation, two other dependent variables, Weekly Miles of Transportation Bicycling and Weekly Miles of Recreation Bicycling, were derived from two survey questions. We calculated the product of the Imputed Transportation Proportion and the reported miles of bicycling in an average week to estimate approximate weekly miles of bicycling for transportation. Similarly, the Imputed Recreation Proportion and the

Table 1
Bicycling levels: census (2000) vs. online survey (2006).

	Davis	Chico	Woodland	Turlock	Eugene	Boulder
Census						
Share usually biking to work	14.4%	5.2%	2.0%	1.1%	5.5%	6.9%
Survey						
Share usually biking to work	32.3%	13.7%	7.2%	0.0%	17.8%	22.7%
Share bicycle ownership	78.0%	67.4%	55.3%	60.9%	72.3%	80.5%
Share biking in last 7 days	53.0%	37.3%	20.2%	12.0%	37.7%	50.0%
Share frequent bicyclist in last 7 days	20.9%	11.2%	4.8%	1.1%	14.6%	14.3%
Share transportation-purpose bicyclist within last year	49.6%	20.0%	14.6%	9.5%	32.9%	28.9%
Number of respondents	354	135	125	92	130	129
Response rate	18.8%	11.7%	10.2%	7.2%	12.1%	12.2%

Table 2
Distribution of respondents by portion of bicycling purpose.

Biking purpose	Imputed transportation proportion (%)	Imputed recreation proportion (%)	Number	Share (%)
1: All bike rides for recreation	0	100	156	26.8
2: Most bike rides for recreation	25	75	127	21.9
3: About half and half for each	50	50	98	16.9
4: Most bike rides for transportation	75	25	142	24.4
5: All bike rides for transportation	100	0	58	10.0
Total			581	100.0

reported weekly miles were combined to estimate weekly miles of bicycling for recreation. Although some respondents who had ridden a bicycle within the last year reported their portions of bicycling by purpose, their reported weekly miles are zero, presumably because their bicycling is irregular.

Explanatory variables fall into four categories: individual factors including socio-demographics and attitude factors, physical-environment factors, social-environment factors, and city specific dummy variables. All agree-disagree questions used a 5-point scale from strongly disagree (1) to strongly agree (5). For several variables, such as "Bike Infrastructure" and "Biking is Normal", indexes were created from a set of survey questions, either through factor analysis or simple mathematical computation (for example, taking a count or averaging); alternative indexes were tested for significance in the model and tested for internal consistency using Cronbach's alpha. The city dummy variables could pick up city-specific characteristics associated with bicycling that are unmeasured in our survey; Turlock, with the lowest level of bicycling, is designated as the reference group, based on the suggestion of Hardy (1993).

3.3. Model choice and procedure

Three approaches were considered for modeling choices of bicycling purposes. Because the raw data is ordinal (from "1: All bike rides for recreation" and none for transportation to "5: All bike rides for transportation" and none for recreation), an ordinal logistic regression, which translates the observed ordinal categories ($Y = 1, 2, \ldots, 5$) to intervals on the underlying latent scale (relative demand for transportation bicycling vs. recreational bicycling) whose endpoints are not known, is one logical choice for modeling. Another implicitly possible approach is the binary logit proportions model assigning the responses of "1, 2, ..., 5" to correspond to "0% for transportation vs. 100% for recreation, 25% for transportation vs. 75% for recreation, ..., 100% for transportation vs. 0% for recreation", respectively. Because in fact the actual proportion could be anywhere in a wide interval, e.g. a response of "2: Most bike rides for recreation" could in principle correspond to proportions ranging from 1% to 49% for transportation vs. 99% down to 51% for recreational bicycling, in that respect the binary logit model is conceptually inferior to ordinal logistic regression. However, the scale of interest (the "portion of bike rides" for two bicycle purposes) is bounded from 0 to 1, whereas the latent variable in an ordinal response model is not bounded. So from that standpoint, binary logit is more appropriate. The third approach is multinomial logit regression (MLR), which is more flexible because it assumes that all categories are nominal, but which disregards the ordinal or proportional nature of the categories and hence their possible inter-relationship, compared with the other two approaches.

All approaches were tried and the binary logit model was chosen as representing the best balance among the considerations of theoretical appropriateness, empirical parsimony, statistical goodness of fit, and conceptual interpretability. Instead of values of zero and one, the imputed proportions of bicycle rides for transportation and recreation were employed as the dependent variable in the binary logit model. This approach is more realistic and informative than drawing an artificial and reductionist distinction between transportation bicyclists and recreation bicyclists using simple binary (0, 1) variables. The binary logit model with proportions of bicycling for transportation vs. that for recreation as the dependent variable can be used to identify factors distinguishing people for whom most of their cycling is transportation-oriented from those for whom most is recreational, or people for whom all of their cycling is transportation-oriented from those for whom most but not all is transportation-oriented.

Two other models are estimated, for transportation miles and recreation miles, using multiple linear regressions. To meet the assumption of normality of residuals, we took the natural log of the values of weekly miles of bicycling for each purpose. To all zero scores (for bicyclists who reported their weekly bicycling miles are 0) we added a very small constant of 0.001 mile before the logarithmic transformation to avoid taking the log of zero, which is negative infinity.[1]

Because entering the explanatory variables into the models all at once would result in a significantly reduced sample size owing to missing data for many variables, the explanatory variables were entered into the model in steps, as sets defined according to the conceptual model. At each step, only the statistically significant variables were retained and insignificant variables were dropped using a backward process (Xing et al., 2008). The order in which sets of variables were entered into the model was consistent with the progression of the ecological model from individual factors at the core to external

[1] We tested for multicollinearity among the explanatory variables that entered the binary logit model by employing a heuristic approach, treating the dependent variable as continuous in a linear regression and looking at Variance Inflation Factors (VIFs) for the estimated coefficients. All models were found to meet the accepted standard that the VIFs are less than 2.5 (Allison, 1999).

environmental factors that affect the entire community. We entered socio-demographic variables first, as control variables. Individual attitudes were the second set of variables. We then entered physical-environment variables to test their significance after controlling for the individual level factors. We next entered social-environment factors to test whether they explain additional variation once individual and physical-environment factors have been accounted for. City specific dummy variables were entered as the last set into the model to check for city-specific effects not accounted for by other variables.

4. Results

4.1. Binary logit proportions model for bicycling purpose

The summary of the proportions model estimation is shown in Table 3. The McFadden ρ^2 (Ben-Akiva and Lerman, 1985) measures based on the equally-likely model, containing no explanatory variables, and the market share model, containing constant terms only, are 0.341 and 0.334. Analogous to the adjusted R-squares of linear regression models, the adjusted ρ^2 ($\bar{\rho}^2$) corrects for the number of estimated parameters. In the case of proportions data based on a single measurement per person (as opposed to explicitly measuring multiple choice occasions and the variables pertaining to each), the upper bound for ρ^2 (equally-likely base) is not unity for the perfect model (Hauser, 1978). Accordingly, we follow the method employed by Mokhtarian and Bagley (2000) and find the theoretical maximum log-likelihood to be -183.290.[2] By this method, about 34.4% of the information represented by the sample data has been explained by this binary logit proportion model with respect to the equally-likely model; this is considered good for disaggregate models. A positive sign for a coefficient indicates that an increase in the corresponding explanatory variable yields an increase in the proportion of transportation bicycling, given that the other variables are held constant; a negative sign means a lower proportion of transportation bicycling (and a higher proportion of recreational bicycling) produced by an increase in the corresponding explanatory variable.

4.1.1. Individual factors

According to the model, respondents with higher education levels are more likely to make a higher proportion of bike rides for transportation than recreation. Higher annual household income decreases the proportion of bicycling for transportation, which may reflect a higher value of time.

After controlling for socio-demographics, attitude factors significantly affect the portion of bicycling by purpose. The level of bicycling comfort[3] is positively associated with the proportion of bicycling for transportation. The insignificance of the attitude of liking biking (agreement that "I like riding a bike") suggests that the preference for bicycling could encourage bicycling for both purposes (and therefore that it cannot help distinguish between preferences for doing it more for one purpose than for another). The attitude of liking driving (agreement that "I like driving") has a negative influence on the portion of bicycling for transportation, reflecting the potential substitutability between modes. Predictably, the attitude of limiting driving (agreement that "I try to limit driving as much as possible") positively correlates with the proportion of bicycling for transportation.

The significance of the variable "Bike Community Preference" [4] demonstrates a self-selection effect on bicycling for transportation purposes; that is, people who chose their residential location in part because of the supportive bicycling environment do a greater share of their bicycling for transportation. This may be tied to the importance of the physical environment in supporting transportation bicycling: those who want to bicycle as a mode of transportation consciously seek a community where that is possible. It is possible that bicycling for transportation is more dependent on the configuration of the residential neighborhood (where destinations/activities are close enough to bicycle to) or a limited set of physical conditions (e.g. good bicycle infrastructure or flat typography), whereas recreational bicycling could take place in low-density residential-only neighborhoods, or even out of the neighborhood altogether (e.g. mountain biking in regional parks or cycling on rural byways), so that residential location choice is influenced more in the former case than the latter. In addition, recreational bicyclists may be more experienced and well-equipped on average than transportation bicyclists; if so, recreational bicyclists may be less sensitive to the physical environment than transportation bicyclists.

4.1.2. Physical environmental factors

The model does not show an influence of perceived bicycle infrastructure on proportion of bicycling for transportation. However, the perception of safety of bicycling to selected utilitarian destinations (grocery, post office, school, etc.)[5] is positively related to proportion of transportation bicycling. This suggests the potential of an indirect role for bicycle infrastructure on transportation bicycle use through its impact on perceived safety. In addition, the average perceived distance to selected destinations has the largest negative effect of all variables on the proportion of bicycling for transportation. This finding implies an indirect influence of land use mix on bicycling for transportation. Short distances act as an encourager or a facilitator for trans-

[2] Calculated by using: theoretical $LL_{Max} = \sum_n \sum_i f_{in} \ln(f_{in})$, in which f_{in} is the observed proportion of choice for individual n of alternative i.

[3] Measured as average comfort biking on an off-street path or quiet street, two-lane local street with or without bike lane, four-lane street with or without bike lane, on a 3-point scale defined as uncomfortable and I wouldn't ride on it (1), uncomfortable but I'd ride on it (2), and comfortable (3).

[4] Measured as importance of "a good community for bicycling" when choosing the residential location, on a four-point scale from not at all important (1) to extremely important (4).

[5] Average perception of safety bicycling to usual grocery store, nearest post office, local school, restaurant, bike shop, on 3-point scale, defined as uncomfortable and I would not ride there (1), uncomfortable but I would ride there anyway (2), comfortable (3).

Table 3
Binary logit proportions model for bicycling purpose.

Variable	Transportation biking proportion vs. recreation biking proportion coefficient
Alternative-specific constant	−2.807**
Individual factors: socio-demographics	
Education level	0.213**
Income	−0.006**
Individual factors: attitudes	
Biking comfort	0.817**
Like driving	−0.258**
Limit driving	0.304***
Bike community preference	0.179**
Physical-environment factors	
Distances	−0.610**
Safe Destinations	0.400*
Social-environment factors	
Biking Is Normal	0.206*
Kids bike	−0.229**
Valid *N*	489
LL (0)	−338.949
LL (MS)	−333.849
LL ($\hat{\beta}$)	−285.428
ρ^2 equally-likely base = 1 − [LL ($\hat{\beta}$)/LL(0)]	0.341
ρ^2 market share base = 1 − [LL ($\hat{\beta}$)/LL(MS)]	0.334
$\bar{\rho}^2$ equally-likely base = 1 − [(LL ($\hat{\beta}$) − 11)/LL(0)]	0.158
$\bar{\rho}^2$ market share base = 1 − [(LL ($\hat{\beta}$) − 10)/LL(MS)]	0.145
Theoretical maximum log-likelihood	−183.290
Proportion of the distance between the equally-likely and theoretical maximum log-likelihoods explained by the model	0.344

* 10% Significance level.
** 5% Significance level.
*** 1% Significance level.

portation-oriented bicycling. For recreational bicycling, which does not necessarily have particular destinations as a goal, land-use patterns are much less important.

4.1.3. Social environmental factors

A perceived transportation-oriented cycling culture in a community increases the proportion of bicycling for transportation significantly, where perceived culture is reflected in the variable "Biking is Normal," measured as higher average agreement that "bicycling is a normal mode of transportation for adults in this community" and "it is (not) rare for people to shop for groceries on a bike." People who agree that "kids often ride their bikes around my neighborhood for fun," possibly implying a lack of nearby destinations where they might go, are less likely to bicycle for transportation relative to recreation.

4.1.4. City-specific effects

A dummy variable for Davis showed a significant positive influence on bicycling for transportation, suggesting that some factors in Davis other than those measured in the survey are important. However, the variables "Bike Community Preference", "Safe Destinations", and "Biking Is Normal" became insignificant after entering the city dummies. This may be caused by the city effect: for example, some characteristics of the built environment associated with the balance of bicycling purpose in Davis may be captured by the measure of bicycling safety to selected destinations. In the interest of identifying specific factors associated with bicycling, the city dummy variable was not included in the final model.

4.2. Weekly miles of bicycling models

The model for weekly miles of transportation bicycling accounted for about 42% of variance in the dependent variable (Table 4), a level considered good for a disaggregate analysis. However, the lower *R*-square of 0.175 for weekly miles of recreational bicycling implies insufficient measurement of factors associated with miles of recreational bicycling in our survey. Given that the focus of the study was on transportation bicycling, this result is not surprising, and it is also consistent with findings for studies of walking, in which models of walking for transport usually have substantially higher *R*-square values than models of walking for recreation (Saelens and Handy, 2008).

Table 4
Factors associated with log-miles of recreational and transportation bicycling.

Variable	Weekly log-miles of transportation bicycling		Weekly log-miles of recreational bicycling	
	Coefficient	Standardized coefficient	Coefficient	Standardized coefficient
Constant	−19.945**		−16.039***	
Individual factors: socio-demographics				
Age	–	–	0.037***	0.131
Education level	0.274**	0.081	–	–
Individual factors: attitudes				
Biking comfort	2.290***	0.161	–	–
Good health	–	–	0.296*	0.071
Like biking	1.546***	0.244	1.672*	0.310
Like driving	−0.503**	−0.115	–	–
Limit driving	0.877***	0.199	–	–
Bike community preference	0.517***	0.121	–	–
Physical-environment factors				
Distances	−0.727**	−0.099	0.686**	0.110
Safe destinations	1.052**	0.135	0.895**	0.136
Social-environment factors				
Biking is normal	0.655**	0.145	–	–
Kids bike	−0.263*	−0.058	0.356**	0.092
Bikers not concerned with safety	0.284*	0.071	–	–
City dummy variables				
Boulder			1.089**	0.101
N	520		502	
Adjusted *R*-squared	0.403		0.164	

Notes: – indicates the variable was insignificant and then excluded from the model. Blank means the variable was excluded because it resulted in a model that was either empirically or conceptually inferior.
* 10% Significance level.
** 5% Significance level.
*** 1% Significance level.

4.2.1. Individual factors

Two socio-demographic characteristics have significant effects on miles of bicycling by purpose. Age is positively associated with weekly miles of recreational bicycling but not transportation bicycling. The effect on recreational bicycling may reflect more leisure time for recreational activities for older individuals, particularly those who are retired. In contrast, education level is positively associated with weekly miles of transportation bicycling but not for recreation. This result may be due to an association between education level and working or studying at the local college or university and thus within bicycling distance of home.

Attitudes are also correlates of both recreational and transportation bicycling. Agreement with the statement "I like riding a bike" positively correlates with miles of bicycling for both purposes; the significance of this variable for both is consistent with the insignificance of this variable in explaining the balance between the two purposes. Agreement that "I am in good health" is associated with more miles of recreational bicycling, which may reflect a reciprocal, reinforcing relationship: health enables bicycling for exercise, which in turn contributes to health. Greater biking comfort increases weekly miles of transportation bicycling, suggesting the importance of "self-efficacy" in explaining bicycling for transportation. The lack of significance of this variable for recreational bicycling is somewhat surprising and not readily explained. Attitudes toward driving also influence miles of transportation bicycling though not recreational bicycling. The attitude of liking driving decreases miles of transportation bicycling significantly, possibly caused by a substitutive relationship between driving and bicycling. Conversely, the attitude of limiting driving is positively associated with weekly miles of transportation bicycling. In addition to the important influence of self-selection on the proportion of transportation bicycling noted earlier, biking community preference is associated with more miles of bicycling for transportation.

4.2.2. Physical-environment factors

The perception of safety biking to destinations is positively associated with miles of both recreational and transportation bicycling, suggesting a key role for infrastructure that contributes to perceived safety. Average distance to destinations, which reflects the locations of different types of land uses (residential, commercial, institutional, recreational, etc.), is negatively associated with miles of transportation bicycling: greater distances mean fewer miles. This finding suggests that greater distances reduce the frequency of trips enough to yield fewer total miles of bicycling (frequency times average trip distance). In contrast, longer distances to potential destinations increase miles of recreational bicycling. Given that recreational bicycling does not generally involve a specific destination, this finding is hard to interpret, though it may indicate that our measure of distances to destinations serves as a proxy for characteristics of the community that are conducive to recreational bicycling.

4.2.3. Social-environment factors

Social-environment factors were also found to affect weekly miles of bicycling. A higher score on the variable "Biking Is Normal" is associated with more miles of bicycling for transportation. Higher agreement that "Most bicyclists appear to have little regard for their personal safety" is correlated with more miles of transportation bicycling. This variable may reflect a perception of generally safe bicycle conditions that give little reason for bicyclists to be concerned with safety rather than a perception that other bicyclists in the community are reckless. On the other hand, the perception that kids bike, which possibly reflects a culture of recreational bicycling but also may be caused by destinations unavailable nearby, is positively associated with miles of recreational bicycling but negatively associated with miles of transportation bicycling.

4.2.4. City effects

In the model for weekly miles of recreational bicycling, the significance of the dummy variable for Boulder implies that some unmeasured characteristics of Boulder are positively associated with weekly miles of recreational bicycling. This result may be consistent with Boulder's reputation as a home for outdoor- and exercise-enthusiasts. The insignificance of the other city dummies implies that the average impacts of unobserved variables are similar across these cities.

In an alternative model for weekly miles of transportation bicycling, all five city dummies were positively correlated with miles of transportation of bicycling, implying that some specific city characteristics in the five cities beyond the factors measured in the survey increase transportation bicycling as compared with Turlock. However, the variables "Education Level" and "Biking Is Normal" became insignificant after entering the city dummies. As with the prior binary logit model, the city dummy variables were therefore excluded in the final model because they resulted in a model that is conceptually inferior.

5. Conclusions

The results provide new insights into factors that US communities must consider if they want to build on current levels of recreational bicycling to increase transportation bicycling. Common to bicycling for both purposes are a general liking of bicycling, and perceptions of safe bicycling routes. Communities with these characteristics are likely to have higher levels of recreational bicycling and have the potential for higher levels of transportation bicycling. Higher levels of transportation bicycling are likely if the community also has residents with an aversion to driving and who have a high level of comfort with bicycling. Shorter distances to destinations will also encourage transportation bicycling, as will a social environment in which transportation bicycling is a part of the community culture. Though good bicycle infrastructure was not directly connected to bicycling for transportation, it appears to play two indirect roles: by contributing to perceptions of safe bicycling routes (which also increases recreational bicycling) and by attracting bicycling-oriented residents through the self-selection effect.

The results together suggest that to promote bicycling for transportation, whether as a strategy for achieving sustainable community goals or for other aims, policy-makers should recognize the influence of the physical environment as well as the social environment on bicycling purpose. To promote bicycling as an environmentally benign mode of transportation, mixed land-use patterns can help to ensure shorter distances. Bicycling for transportation as well as recreation purposes could be increased by expanding the bicycling network or otherwise improving bicycling infrastructure to increase bicycling safety. A social environment supportive of transportation bicycling can be encouraged through training for bicyclists, promotional events such as "bike to work day", publicizing of high-profile role models, or even financial incentives to encourage bicycling for transportation. Such programs can also improve individual attitudes toward bicycling, which have a significant effect on bicycling of both types. Comprehensive approaches that include improvements to the physical environment as well as programs to enhance the social environment are needed.

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