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Do Bicycling Experiences and Exposure Influence Bicycling Skills and Attitudes? Evidence from a bicycle-friendly university

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Abstract
Life changes are often associated with changes in travel behavior, due to a break in habitual travel cues and the introduction of a novel travel context. Universities provide a particularly appropriate setting to examine how these life changes can bring about changes in travel attitudes, norms, and skills – which together form a psychological construct called "motility" that describes the capability for travel. In this study, I pool data from seven years of the University of California, Davis' annual campus travel survey to create a longitudinal panel, and use a retrospective survey to collect the bicycling behaviors, attitudes, and skills of undergraduates every year since they graduated from high school. I find that, on average, UCD undergraduates' pro-bicycling attitudes decrease slightly over time while bicycling skills increase substantially throughout college. I then use the retrospective panel data to estimate a statistical model to analyze the influence of bicycling exposure and experiences on skills and attitudes. I find that riding a bicycle at any point during college increases both pro-bicycling attitudes and bicycling skills, while exposure to high levels of bicycling appears not to influence attitudes or skills. This study provides confirmatory evidence for the motility approach and suggests possible policy avenues, such as incentivizing short-term bicycle use in order to shift perceptions and attitudes about bicycling, with the intent of fostering a positive feedback cycle between greater bicycling attitudes and skills and increased bicycle use.

1 Introduction

How do life changes affect individuals' travel behavior? The literature of the mobility biographies approach has addressed this question by investigating how key life events, such as a new job, marriage, or childbirth, can result in travel behavior change (Müggenburg et al., 2015). The mobility biographies approach rests on two major theoretical assumptions: that life events are likely to bring about important changes in relevant travel characteristics and that these events also introduce a discontinuity in habitual travel behavior. The mobility biographies approach argues that these two elements combine to create a "window of opportunity" in which individuals re-evaluate their travel decisions and potentially choose a new mode of travel.

But in addition to changed habit, does anything more fundamental change in the individual? Can a new environment, and new experiences, result in more durable changes to travel attitudes, norms, and skills that will persist through future life events? These questions have not been well-explored by mobility biographies researchers, nor those in the rest of the field of travel behavior research. For individuals unfamiliar with a travel mode, the changed environment of a key life event may enable or prompt them to try new modes. Consequently, these experiences may help build or strengthen the aforementioned psychological elements – attitudes, norms, and skills – which together comprise the concept of "motility", the capability for travel (Flamm and Kaufmann, 2006). A better understanding of the interplay between attitudes, norms, skills, and behavior can help inform policy efforts, such as whether to prioritize marketing campaigns to influence attitudes (and therefore behavior) or to promote more direct interventions that encourage or challenge individuals to try alternative modes of travel.

Universities provide an excellent natural experiment to examine the impacts of travel experiences and exposure to unfamiliar modes of travel on students' motility. Incoming undergraduate students may be exposed to or adopt modes of travel with which they have had little recent experience as a child (McDonald et al., 2011), such as bicycling or taking public transit. These affordable, convenient travel modes are popular among college students, in a setting where single-occupant car use is often discouraged (Toor and Havlick, 2004). The University of California, Davis (UCD) is a particularly apt case study in this regard, as the town's bicycling infrastructure is well-connected and extensive (Buehler and Handy, 2008). At least partly due to the comprehensive bicycling infrastructure, roughly half of undergraduate students bicycle to campus (Thigpen, 2015).

In this study, I seek to answer two research questions: *(a) How does UCD undergraduate students' bicycling motility change over the course of their time in college?* and *(b) To what extent is any change influenced by attending UCD and consequently being exposed to high levels of bicycling, and to what extent are changes influenced by personal bicycling experiences?* In line with modern findings and interpretations of the theory of cognitive dissonance (Stone and Cooper, 2001) and theories of skill development (Newell and Rosenbloom, 1980; Zeuwts et al., 2016), I hypothesize that personal bicycle use will increase both bicycling attitudes and skills, while exposure to high levels of bicycling will improve bicycling attitudes but will have no effect on bicycling skills.

To address these research questions and hypotheses, I examine changes in college students' bicycling attitudes and skills through a longitudinal panel data set and examine the influence of bicycling exposure (living within a community where bicycling is commonplace) and experiences (from a student's own bicycling) through an analysis of panel survey participants. To operationalize these two explanatory factors, I take advantage of the unique setting of UCD, where a high proportion of undergraduate students gain personal bicycling experiences during college and where all students are exposed to the popularity of bicycling at UCD. Furthermore, I use the natural experiment provided by transfer students' time at community or junior colleges prior to arriving at UCD to introduce a control group by which to test the treatment of bicycling exposure while at UCD. I examine data pooled from seven years of the UCD annual campus travel survey and from a special retrospective section of the 2016-17 survey to answer these questions, using descriptive statistics and estimating a panel statistical model.

2 Literature Review

2.1 Attitude-Behavior Theories

In this study, I rely on the theoretical framework of "motility" to provide a conceptual structure for the relationship of travel behavior with skills and attitudes (see (Flamm and Kaufmann, 2006) for an accessible, thorough introduction to motility and its connections to social integration and mobility justice). This theory hails from the field of urban sociology, but has striking similarity to the Theory of Planned Behavior (TPB) (Ajzen, 1991), which travel behavior researchers are likely to be more familiar with, given its wide use in the field (Bamberg et al., 2003; De Bruijn et al., 2005; Dill et al., 2014). Briefly, the TPB conceives of behavior as stemming from intentions, which in turn arise from three characteristics: attitudes, subjective norms, and perceived behavioral control.

Given the clarity of the TPB conceptual model, I use its constructs to operationalize the dimensions of motility. The term "motility" was coined by Vincent Kaufmann and inspired by the phrase's use in biology and medicine to describe the capacity for movement (Flamm and Kaufmann, 2006). Kaufmann's travel motility has a similar meaning to the biology term, in that it takes both skill and knowledge to travel by any particular travel mode, as well as supportive attitudes and norms.

In contrast to most applications of the TPB in travel behavior research, motility more explicitly acknowledges the *reciprocal* influence of behavior on attitudes, norms, knowledge, and skills and vice versa. This is likely an important line of inquiry, given the available evidence. Of the studies that have focused on the bi-directional relationship between attitudes and behavior, most have found reciprocal influences and several have found that the influence of behavior on attitudes was stronger than the influence of attitudes on behavior (Golob, 2001; Kroesen et al., 2017; Tardiff, 1977). This body of evidence is consistent with the theory of cognitive dissonance (Festinger and Carlsmith, 1959). Based on the available evidence that early travel experiences influence later travel behavior (Smart and Klein, 2017), the development of motility may provide a causal mechanism behind the observed association. For example, with respect to mode choice, individuals' early travel experiences can shape their motility, which in turn may influence the modes they later travel by or consider traveling by (i.e. their mode choice set).

2.2 Influence of Life Experiences

Broadly speaking, this study seeks to understand the influence of childhood and young adulthood experiences (personal bicycle use and exposure to high levels of bicycling) on bicycling motility. I use the term "exposure" to refer to the positive descriptive norms (i.e. the sense of normality provided by a majority of people adopting a behavior) embodied by a large proportion of the community using bikes, and explore how these descriptive norms might sway individuals' bicycling motility. This phenomenon is similar to what other scholars refer to as "social learning" or "socialization", which has been shown to influence travel behavior (Haustein et al., 2009).

One way to conceptualize previous personal bicycle use is as a habit - a routine, regular behavior that is strongly ingrained. Research into the role of habit in travel behavior suggests that previous behavior is a strong predictor of current behavior (Verplanken et al., 1994). But since these studies relate behavior to behavior, rather than behavior to attitudes and skills, their results do not directly translate to this study. Studies of habit also tend to focus on short time horizons and on adult travelers, as opposed to the longer durations across multiple years in childhood and young adulthood that are of interest in this study.

Along similar lines, some travel behavior researchers have undertaken studies of life experiences (or "key events") on travel behavior in what are commonly termed as "mobility biography" studies. The underlying assumption behind the mobility biographies approach, as it has typically been applied, is that these key events, including marriage, childbirth, and job changes, provide windows of opportunity to trigger a change in travel behavior (Müggenburg et al., 2015), and perhaps travel attitudes and preferences as well. Continuing with the aforementioned examples, research demonstrates that marriage may result in increased car ownership and use (Prillwitz, Jan, Harms, Sylvia, Lanzendorf, 2006; Scheiner and Holz-Rau, 2013); childbirth is associated with new activity patterns (Lanzendorf, 2010); and a new job may lead to changes in mode use (Oakil, A.M., D. Ettema, T. Arentze, 2011), particularly car use (de Haas et al., 2018). But in more general terms, the mobility biographies research agenda examines key events to determine *when* travel behavior is most likely to change, rather than *how* it occurs (i.e. via changes in motility as a causal mechanism), which is the focus of this study. Mobility biographies studies also use travel behavior as the dependent variable, while the present study employs behavior as an explanatory variable.

While the previously-mentioned research primarily relates to the attitude-behavior relationship, bicycling skill has also received attention from transportation scholars, especially those concerned with bicyclist safety. Human development scholars have linked skill acquisition to aging and maturation (Haywood and Getchell, 2009), as well as to practice, in what is termed the "power law rule" of practice (Newell and Rosenbloom, 1980). Bicycle safety scholars have replicated these findings in the realm of bicycling skill development (Ducheyne et al., 2013; Schepers, 2012; Zeuwts et al., 2016). Beyond the bicycle safety literature, travel behavior scholars have also attended to bicycling skill via the concept of perceived behavioral control (from the TPB) or the similar construct of self-efficacy (Bandura, 1982), which has been shown to be associated with greater bicycling frequency (De Geus et al., 2008). Though, again, it is worth noting that this line of research focuses on how self-efficacy influences behavior, while this study focuses on the reverse.

3 Methodology

3.1 Setting and Context

The city of Davis, home to about 66,000 people, has earned a reputation as a bicycling capital in the U.S., with a comprehensive network of on- and off-street bicycling facilities (Buehler and Handy, 2008) and a high bicycle mode share across all age groups (Fitch et al., 2016; Thigpen, 2015). Davis is home to UCD, attended by approximately 30,000 undergraduate and 7,000 graduate students. About 90% of freshmen live on campus, while roughly 70% of sophomores, juniors, seniors, master's students, and PhD students live off campus but within the city of Davis (Thigpen, 2015). Notably, most of the core campus area has restricted car and bus access, meaning that students use active modes of transportation while traveling between most campus destinations. Additionally, students living on-campus are ineligible for campus parking permits.

Roughly 65% of students admitted to UCD come from within California, and only about 2% of California children ride a bicycle to school (double the national average) (Safe Routes to School National Partnership, 2013). Therefore, it is likely that most freshmen arriving on the UCD campus for the first time have not recently bicycled on a regular basis. They are then exposed to the unusually high levels of bicycling prevalent in the city and on campus and have access to a uniquely extensive bicycle infrastructure network (for a US city and university campus). In addition, many freshmen take up bicycling to campus, with roughly 70% of freshmen riding their bicycle on an average weekday and continuing to do so in later years (~50% bicycle commute mode share by sophomores, juniors, and seniors) (Thigpen, 2015). Because of these characteristics, Davis is an advantageous setting to test the influence of immersion into a bicycling culture on bicycling attitudes and skills, in addition to understanding the influence of personal bicycling experiences.

3.2 Data Collection - the UCD Campus Travel Survey

The UCD Transportation and Parking Services department, in conjunction with the UCD Institute of Transportation Studies, has sponsored an annual campus travel survey (CTS) since 2006-07. Each fall, a graduate student administers the CTS to a stratified random sample of students, staff, and faculty. The survey typically achieves a response rate of 10 to 15 percent of the invited sample. The survey collects information on commute travel characteristics for long-range campus planning, program and policy evaluation, and greenhouse gas reporting. Many of the questions are asked in the same way each year, allowing for robust cross-year comparisons by planners and researchers.

I use the seven most recent CTSs because, beginning with the 2010-11 edition of the CTS, each survey has asked for respondents' email addresses. I used this unique identifier to link individuals' responses across multiple years to form a longitudinal panel data set. I can therefore more readily make causal claims, since I can assess whether the presence of an explanatory variable (i.e. bicycling use) precedes change in the dependent variable (i.e. bicycling motility), which is not possible using cross-sectional data.

In this study, I measure bicycling motility via two of its underlying dimensions: attitudes and skills. While bicycling knowledge (e.g. knowledge of how to navigate a city by bicycle) and social norms are also important elements of motility, questions regarding these constructs were not asked in previous years of the survey and are consequently not assessed. All seven years of surveys asked about the dependent variables: bicycling skill (on a 4-point scale) and bicycling attitude (on a 5-point Likert-type scale). Importantly for the statistical analyses of the influence of bicycling exposure, the surveys also asked about transfer status: whether a student had attended UCD as a "four-year" student or had transferred from another college, typically a community or junior college. Other relevant questions on covariates such as gender were also asked in each year (Table 1).

In the 2016-17 CTS, I added a series of retrospective questions for undergraduate juniors and seniors, asking about their bicycling attitudes, skills, and behavior during the first two or three years of their college experience (Table 1). Since undergraduates are very likely to have incomplete responses across their undergraduate careers, due to chance (by randomly not being invited) or choice (by choosing not to participate), I used this section to obtain a more complete panel of undergraduate student responses regarding their bicycling skills, attitudes, and behavior over three or more years. Through these retrospective questions, I also captured the bicycling behavior and motility of transfer students, who, by their very nature, could not have taken the CTS while at their previous university and therefore could not have prospectively provided their freshman and sophomore year bicycling behavior and motility (Table 2). Lastly, I also asked about dimensions of bicycling skills and attitudes beyond the two primary attitude and skill questions that had been asked in previous editions of the CTS. For this purpose, I used survey questions developed by Kroesen and his collaborators for their study of mobility patterns among the Dutch (Kroesen et al., 2017) and designed additional questions of my own, all of which were subjected to rigorous pre-testing.

The panel data gathered in this retrospective section is used in the statistical analysis, but not in the descriptive analysis. Through this manuscript, I call this panel data the "*retrospective panel*" to distinguish it from the other panel data I describe earlier, which I term the "*prospective panel*", since the respondents' survey answers refer to their contemporaneous characteristics, behavior, and motility.

3.3 Descriptive Analyses of Attitude and Skill Change

I anticipate that both bicycling attitudes and skills will increase for an average UCD undergraduate over their time at UCD. To test this hypothesis, I analyze the overall trend of bicycle attitude and skill change among a prospective panel of undergraduates over time. The panel consists of 1,648 members, screened to exclude transfer students, as they enter the dataset after freshman year and therefore distort the trends in differences and changes.

The prospective panel features missing data, though, as many individuals only provided two or three years of responses with uniquely identifying information. I therefore ultimately have 3,498 observations (given multiple responses per panel member), whereas if all prospective panel members had answered in all of their possible years, the sample size would have been closer to 6,038. The presence of missing data made the task of tracking change on an annual basis more challenging. I therefore simplified the descriptive analyses by looking at individuals' first and last responses as their official "beginning" and "end" points, an effective means of answering the question about how individuals' bicycling motility change over time. In other words, some students may have 2, 3, 4, or even 5 year spans between their first response and their last recorded response. Note that this simplification (only using the first and last responses) was used only in the descriptive analysis, not for later statistical analyses.

3.4 Statistical Analyses of Causes of Attitude and Skill Change

Moving beyond descriptions of change over time in bicycling motility (skills and attitudes), I more directly assess the independent influence of the explanatory variables of interest: (a) *exposure to high levels of bicycling* (as a consequence of attending UCD) and (b) *riding a bicycle* (either at UCD or at a transfer student's first college). For this statistical analysis, I use the retrospective panel dataset, which is comprised of 1,097 undergraduates and a total of 3,950 time points (the number of observations for those 1,097 undergraduates). I estimate a latent Markov (LM) model (also called a latent transition model or hidden Markov model) to examine the influence of these variables over time. LM models are dynamic, including an individual's previous motility class (as well as other exogenous variables) in the model for the current motility class. In the LM model, I test the hypothesis that bicycling experiences will improve bicycling attitudes and skills, while exposure will improve bicycling attitudes but not bicycling skills.

The LM model analyzes skills and attitudes together as a joint measure of motility, using the full set of bicycling attitude and skill survey statements. The LM model treats the survey items regarding bicycling skills and attitudes as imperfect measures of an underlying, unobserved (or "latent") construct: *bicycling motility* (for further information on LM models, see Collins and Lanza (Collins and Lanza, 2010)). I estimated the latent Markov models using Latent Gold software (Vermunt and Magidson, 2005), beginning by estimating a 1-class nominal model and working upward. I stopped after the 3-class nominal model, as the LM models with 4 or more classes did not converge to a consistent global maximum. I selected the 3-class model due to its superior AIC and BIC and given the classes' ease of interpretation (Collins and Lanza, 2010). The indicators for the latent classes of motility included the nine questions related to bicycling attitudes and skills asked in the retrospective survey, each included as an ordinal indicator (see Figure 1 for the model form).

In the model of initial class membership, I included variables related to childhood characteristics: the number of years an individual regularly biked during elementary school (as a numeric predictor), regular biking during junior high and high school (numeric), and the individual's gender (nominal). I used gender (nominal), undergraduate class (nominal), bicycle use (nominal), and transfer status (nominal) to predict transition probabilities between latent classes, with the parameters conditional on latent class membership in the previous wave. I restricted the parameters on the LM model to ensure measurement invariance across time periods (i.e. across an individual's time at UCD, from freshman to senior year, or their last observation).

Evidence in favor of the bicycle experience hypothesis would come from positive coefficients for this variable in the model of transition probabilities from low-motility to high-motility classes (or negative coefficients in the reverse direction). Corroborating evidence for the bicycle use hypothesis could also be found in the model of initial states, if individuals with more years of regular bicycling in their youth are more likely to belong to high-motility latent classes. Similarly, I would expect transfer status to have a negative coefficient in the model of transition probabilities from low-motility to high-motility classes.

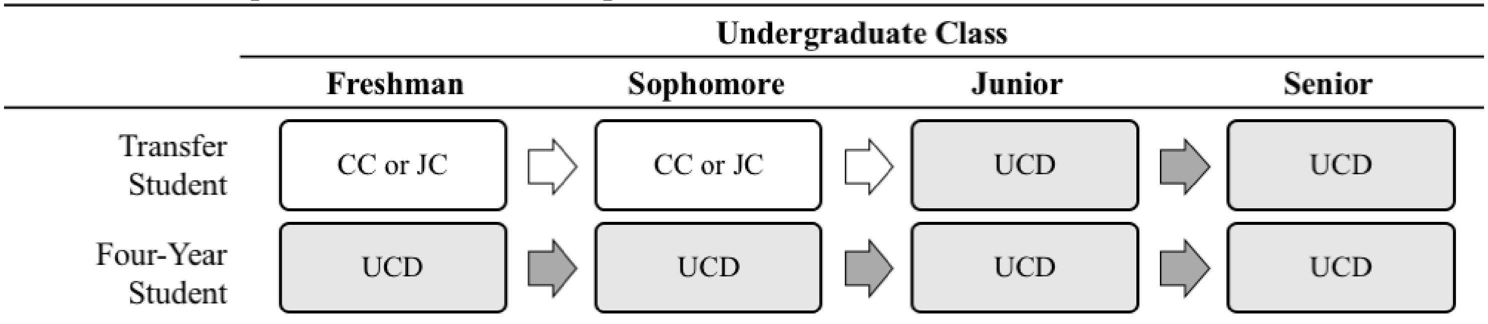
Table 1. Campus Travel Survey Questions

Questions		Answer Options
Dependent Variables	How would you rate your ability to ride a bike?	○ I cannot ride a bike at all because I do not know how ○ I can ride a bike, but I am not very confident doing so ○ I am somewhat confident riding a bike ○ I am very confident riding a bike
	To what extent do you agree or disagree with the following statement: “I like riding a bike.”?	○ Strongly disagree ○ Disagree ○ Neutral or don’t know ○ Agree ○ Strongly agree
	In general, how comfortable would you be riding a bicycle on a four-lane street (two lanes in either direction) without a bicycle lane, in daylight and good weather?	○ Uncomfortable and I wouldn't ride on it ○ Uncomfortable but I would ride on it ○ Comfortable
	How strongly would you have agreed or disagreed *[with the following statements]*?[1] • "I know how to fix a flat bicycle tire." • "I am comfortable biking alongside another bicyclist." • "I can confidently ride a bicycle without my hands on the handlebars." • "Bicycling is fun." • "Bicycling is convenient." • "Bicycling is safe."	○ Strongly disagreed ○ Somewhat disagreed ○ Neutral ○ Somewhat agreed ○ Strongly agreed
Independent Variables	What means of transportation do you usually use to travel to campus for school or work? *[respondent could only choose one]*	○ Walk ○ Skate or skateboard ○ Bike or electric bike ○ Motorcycle or scooter ○ Drive alone in a car (or other vehicle) ○ Carpool or vanpool with others also going to campus ○ Get a ride ○ Bus ○ Train or light rail ○ Other
	What year are you?	○ Freshman ○ Fifth-year senior

	○ Sophomore ○ Junior ○ Senior	○ Post-baccalaureate ○ Visiting / exchange student
Did you transfer to UCD from a college, university, or community college?[2]	○ Yes	○ No
What is your gender?	○ Male ○ Female	○ Other ○ No answer
Of the years you were in elementary school, how many years did you regularly ride a bike (once a month or more) for any purpose (e.g. mountain biking, to school, around the neighborhood)?[1]	○ 0 ○ 1 ○ 2 ○ 3 ○ 4	○ 5 ○ 6 ○ 7 ○ 8
Of the years you were in junior high and high school, how many years did you regularly ride a bike (once a month or more) for any purpose (e.g. mountain biking, to school, around the neighborhood)?[1]	○ 0 ○ 1 ○ 2 ○ 3 ○ 4	○ 5 ○ 6 ○ 7 ○ 8

[1] Asked only in the retrospective section of the 2016-17 survey
[2] Transfer status was not asked in the 2010-11 survey

Table 2. Quasi-Experimental Research Design



Note: "CC or JC" stands for Community College or Junior College. "UCD" stands for the University of California, Davis. With respect to bicycling exposure, the white arrows represent the control effect and the grey arrows refer to the treatment effect. The diagram depicts four years of data (a senior survey participant), though respondents may have had one year more or one year less if they were a fifth-year senior or a junior.

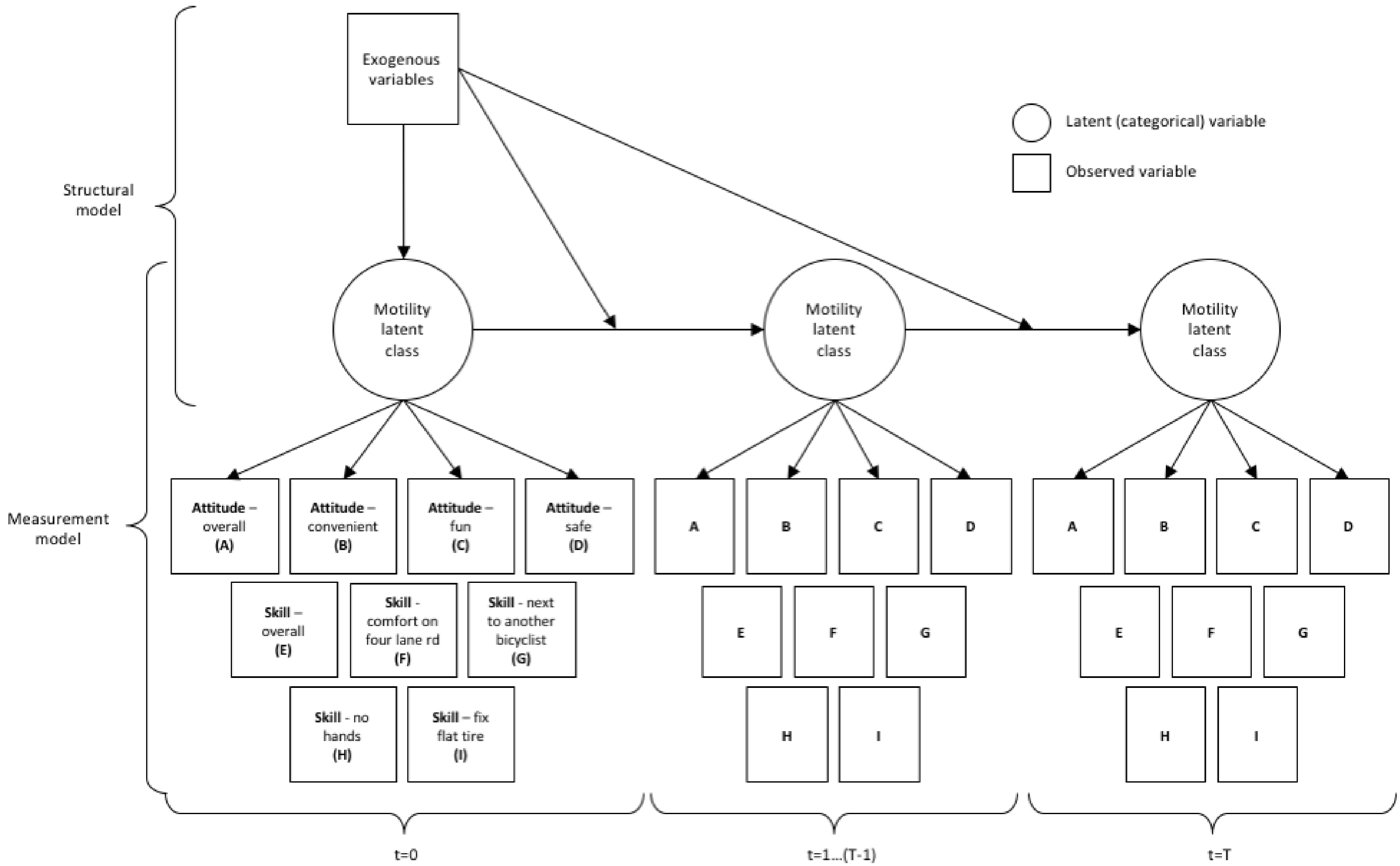


Figure 1. Path diagram of the latent Markov model structure.

3.5 Limitations

As mentioned previously, the relationship between travel behaviors and attitudes are likely to interact reciprocally, while the analysis only analyzes the influence of behaviors and experiences on attitudes and skill. Further analysis could be done, by estimating models of behavior and perhaps structural equation models of behavior, attitudes, and skill's reciprocal influence (Kroesen et al., 2017), to compare the relative strength of the relationships.

I sought to maximize the construct validity of the questions, while balancing the potential for survey burden in a survey used by both campus planners and researchers. Though the measures "How would you rate your ability to ride a bike?" and "I like riding a bike" may not achieve full content validity for the multifaceted constructs of bicycling skill and attitudes, they pass the face validity test. I also addressed this deficiency by asking the additional questions about dimensions of bicycling attitudes and skills in the retrospective survey. And though it might seem that bicycling skill can only increase over time, an individual's perception of their skill can decrease, especially after a period of bicycling disuse.

Though answers to retrospective survey questions are often prone recall bias, this does not appear to be of overwhelming concern in this case. I tested the respondents' reliability by comparing their recalled answers to those given contemporaneously in previous years and obtained Cramer's V values of 0.64, 0.39, and 0.71 for bicycling skills, attitude, and behavior, respectively (Thigpen, 2017), which indicate relatively high levels of reliability (Cohen, 1988).

The stratified random sampling plan leads to good sample generalizability. But if UCD undergraduate students are not representative of other college students or if they chose to attend UCD for its bicycle-friendly characteristics, the descriptive results are unlikely to generalize across populations to other universities or cities. In order to address this concern, in the 2015-16 CTS I asked undergraduates why they chose UC Davis over other universities they could have attended. Of the seven options provided, bicycling was the least selected, while academics and affordability were the two most frequently selected (Gudz et al., 2016). I further accounted for the possibility of selection bias in this study by asking about the respondents' bicycling history before they attended UCD, and I have included their responses in the LM model. Furthermore, though the descriptive results are unlikely to generalize to other populations, the relationships I identify in the statistical models could generalize to other settings. And despite UCD's bicycling reputation, a substantial proportion of the sample reports not liking to bicycle and does not ride to campus, providing valuable variation for the statistical models.

4 Results

4.1 Sample Characteristics

I summarize the characteristics of the samples for the two datasets used in this study in Table 3. Female respondents make up over two-thirds of the respondents, while they comprised only 57 percent of the campus population (as of the 2014-15 CTS) (Thigpen, 2015). Transfer students comprised only a third of the prospective panel dataset and two-fifths of the retrospective panel data set.

For both data sets, a majority of respondents states that they usually ride a bicycle to campus. Similarly, most respondents report a positive attitude toward bicycling and have confidence in their bicycling skill. However, the retrospective panel members have slightly less positive bicycling attitudes and are slightly less skilled than their counterparts in the prospective panel (Table 3).

Table 3. Sample Characteristics of the Study Datasets

Variables	**Prospective panel**		**Retrospective panel**	
	%	**N**	**%**	**N**
Gender				
Male	33%	905	31%	1,221
Female	67%	1,825	69%	2,729
Undergraduate class				
Freshman	32%	884	28%	1,097
Sophomore	32%	886	28%	1,097
Junior	22%	588	28%	1,097
Senior	11%	295	14%	548
Fifth-year senior	3%	77	3%	111
Transfer status				
Four-year student	50%	1,353	61%	2,406
Transfer	50%	1,377	39%	1,544
Usual mode to campus				
Bicycle	64%	1,736	59%	2,047
Other mode	36%	994	41%	1,395
Pro-bicycle attitude (“I like riding a bike”)				
Strongly disagree	9%	258	9%	310
Somewhat disagree	11%	310	11%	387
Neutral	23%	620	21%	733
Somewhat agree	32%	870	32%	1,114
Strongly agree	25%	672	26%	892
Bicycle skill (“How would you rate your ability to ride a bike?”)				
Cannot ride	5%	129	4%	151
Not very confident	17%	467	16%	526
Somewhat confident	26%	706	25%	852
Very confident	52%	1,428	55%	1,843

Note: “Prospective panel” refers to the data collected and pooled across all the campus travel surveys since the 2010-11 school year, which includes all participants who provided at least two years of answers (n = 1,648). The “Retrospective panel” only includes respondents who completed the retrospective section of the 2016-17 campus travel survey (n = 1,097, t = 3,950).

4.2 Descriptive Analysis

I examine differences and changes in bicycling skills and attitudes over time to answer the question: *How do bicycling skills and attitudes differ across undergraduate classes or change over time?* (see Figure 2). Most respondents began and ended with the same bicycling attitude (58%) and skill (78%). However, of the panel respondents who changed their skill, twice as many reported increasing their bicycling skill (13%) than reported decreasing (6%). The biggest change in bicycling skill appears between freshman to sophomore years, with smaller gains in subsequent years.

The reverse pattern was true for bicycling attitudes; 23% of prospective panel respondents exited the panel with more negative attitudes than they began while 16% exited with more positive bicycling attitudes. And rather than exhibiting sudden shifts, the share of individuals holding negative attitudes steadily, though moderately, increased over time. Despite this decline in the global average bicycling attitude, most individuals hold pro-bicycling attitudes (either "Strongly Agree" or "Agree" they liked riding a bike) in all four undergraduate years.

4.3 Statistical Analysis

As mentioned in the methodology section, I selected the 3-class LM model as optimal. Table 4 presents the mode response for the survey question (rows) for the relevant latent class (columns). I have assigned the latent classes evocative names based on their pattern of responses to the bicycle attitude questions and skill questions. I have arranged the table to present the latent classes in approximate order from most negative attitude and least skill to most positive attitude and most skilled.

The lowest motility class, "Novice Bike-Phobes," had high probabilities of professing discomfort and low confidence in their bicycling skill as well as a strong aversion to bicycling overall. They comprised about twenty percent of the sample. The second class, "Skilled Enthusiast", represented just over a majority of the sample. Despite generally lacking the ability to fix a flat tire and expressing discomfort over bicycling on a four-lane road, Skilled Enthusiasts tended to have confidence in their skill at bicycle handling and hold mildly positive attitudes toward bicycling. Finally, "Expert Aficionados" were supremely confident in their bicycling skill and held enthusiastic attitudes toward bicycling. These individuals comprised about a quarter of the sample.

The coefficients in the model of initial class membership confirm my hypothesis: I find that elementary school bicycling is associated with decreased probability of an individual being in the lowest motility class, Novice Bike-Phobes (Table 4). The number of years an individual regularly rode their bicycle in junior high and high school bicycling is also strongly, negatively associated with being a Novice Bike-Phobe and positively associated with membership in the Expert Aficionado class. I further find that young women are less likely to be in the higher-motility classes as they enter UCD as a freshman.

In the transition model, I predict class membership in a given time period based on characteristics and class membership in the previous time period (Table 5). The intercept terms for the transition model are all negative, indicating that individuals are more likely to stay in their current motility class than they are to transition either to a higher or lower class, *ceteris parabus*.

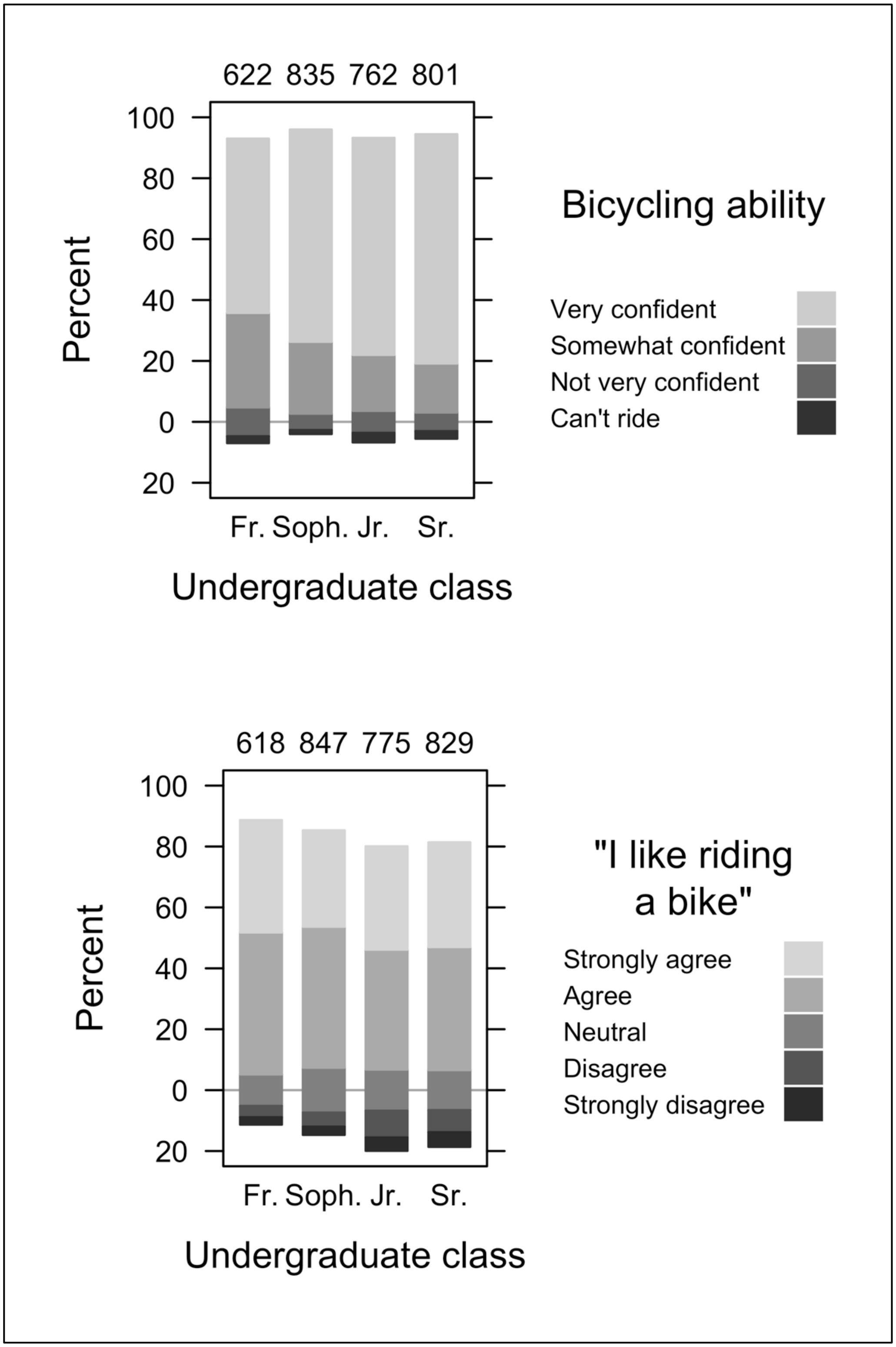


Figure 2. Changes in self-rated bicycling skill and bicycle attitude across the four undergraduate classes within the prospective panel (n = 1,648). "Fr." stands for "Freshman", "Soph." for "Sophomore", "Jr." for "Junior", and "Sr." for "Senior".

Table 4. Latent class profile and initial latent class membership parameter estimates for the three-class solution (n = 1,097)

		Novice Bike-Phobe		Skilled Enthusiast		Expert Aficionado	
	Size (%)	21.5		51.3		27.3	
	Indicators[1]						
Skill	Overall	Not very confident		Very confident		Very confident	
Skill	Comfort on 4-lane road	Uncomfortable and would not ride		Uncomfortable but would ride		Comfortable	
Skill	Next to another bicyclist	Strongly disagree		Somewhat agree		Strongly agree	
Skill	No hands	Strongly disagree		Somewhat agree		Strongly agree	
Skill	Fix a flat tire	Strongly disagree		Strongly disagree		Strongly agree	
Attitude	Overall	Strongly disagree		Somewhat agree		Strongly agree	
Attitude	Convenient	Somewhat agree		Somewhat agree		Strongly agree	
Attitude	Fun	Neutral		Somewhat agree		Strongly agree	
Attitude	Safe	Somewhat disagree		Neutral		Somewhat agree	
	Parameters[2]	Estimate	SE	Estimate	SE	Estimate	SE
	Intercept	**-0.5**	**0.2**	-	-	**-0.6**	**0.2**
	Female	**0.7**	**0.2**	-	-	**-0.4**	**0.2**
	Elementary School Bicycling	**-0.3**	**0.0**	-	-	0.0	0.0
	Junior/High School Bicycling	**-0.3**	**0.1**	-	-	**0.1**	**0.0**

[1] The responses listed in the table indicate the mode response for the relevant latent class.
[2] "SE" refers to the standard error. Parameters that exceed the 95% confidence level are highlighted in bold.

Table 5. Transition parameter estimates of time (x + 1) latent class membership

Time (x)	Transition parameters	Time (x + 1) Latent Class Membership: Novice Bike-Phobe Estimate	Novice Bike-Phobe SE	Skilled Enthusiast Estimate	Skilled Enthusiast SE	Expert Aficionado Estimate	Expert Aficionado SE
Novice Bike-Phobe	Intercept	0	0	**-2.5**	**0.6**	**-4.4**	**1.4**
	Female	0	0	-0.1	0.6	**-3.4**	**0.9**
	Transfer	0	0	-0.4	0.4	-0.4	0.9
	Bicycle Use	0	0	**3.5**	**0.5**	**6.4**	**1.6**
	Junior	0	0	**-1**	**0.5**	-0.6	0.9
	Senior	0	0	-2.3	1.4	-4.4	5.8
	Fifth-year Senior	0	0	-0.1	1.1	-4.2	7.3
Skilled Enthusiast	Intercept	**-5**	**1.1**	0	0	**-4.2**	**0.6**
	Female	1.3	1.1	0	0	-0.2	0.3
	Transfer	0.1	0.6	0	0	0.7	0.4
	Bicycle Use	-5.7	5.2	0	0	**3.4**	**0.5**
	Junior	0.7	0.8	0	0	**-0.8**	**0.4**
	Senior	0.9	0.9	0	0	**-2.1**	**0.9**
	Fifth-year Senior	1.5	1	0	0	-4.9	7
Expert Aficionado	Intercept	-6.4	4.3	**-3.7**	**0.6**	0	0
	Female	3.8	4.3	**1.3**	**0.4**	0	0
	Transfer	-3.8	4.3	0.3	0.3	0	0
	Bicycle Use	-1.4	1.2	**-1.8**	**0.5**	0	0
	Junior	-4.7	5.8	**2**	**0.6**	0	0
	Senior	-3.9	5.8	1.3	0.7	0	0
	Fifth-year Senior	-3.2	7.1	1.6	0.9	0	0

Note: "SE" refers to the standard error. Parameters that exceed the 95% confidence level are highlighted in bold.

In several instances, there is strong evidence that riding a bicycle in the previous time period makes an individual more likely to transition to a higher motility class (or less likely to transition to a lower motility class), in support of my bicycle use hypothesis. Novice Bike-Phobes who ride a bicycle are very likely to transition into either the Skilled Enthusiast or Expert Aficionado classes. Likewise, using a bicycle regularly to get to campus is strongly associated with moving from the Skilled Enthusiast to the Expert Aficionado class, and makes an individual less likely to move from Expert Aficionado to Skilled Enthusiast.

In contrast, the bicycle exposure hypothesis saw little support: in no instance did the transfer term have a significant, negative coefficient estimate of moving from a lower-motility class to a higher motility class (nor a positive coefficient for the reverse direction).
Though not true for every class-combination, in some instances gender was found to significantly predict the likelihood of an individual transitioning from one class to another. In

both cases, female undergraduates were more likely to be in lower-motility classes: undergraduate women are less likely to move from being a Novice Bike-Phobe to an Expert Aficionado and more likely to move from being an Expert Aficionado to a Skilled Enthusiast.

5 Discussion

5.1 Interpretation and Theoretical Implications

The results suggest that regular bicycle use, both in childhood and during college, is associated with increased pro-bicycling attitudes and skills, while exposure to high levels of bicycling at a bicycle-friend university has little to no effect on skills or attitudes.

The association between bicycle use and skill is intuitive and supported by the literature. While casual bicycle use for commuting to campus or other purposes does not necessarily constitute the “deliberate practice” that contributes to expert skill attainment (Ericsson et al., 1993), the result fits in with the framework that increased time “practicing” an activity is likely to improve one’s abilities following the power law of practice (Newell and Rosenbloom, 1980).

The statistical models report a strong association between bicycle use and attitudes, both from childhood to freshman year and during college. Higher bicycling experience during elementary school years is associated with being a member of the two high-motility classes, suggesting that even a small amount of bicycling experience can have a lasting influence. But perhaps even more notably, bicycle use during junior high and high school further distinguishes between the three motility classes. In other words, bicycling in elementary school appears to make individuals proficient, enthusiastic bicyclists, but bicycling in junior high and high school is more likely to make individuals expert bicyclists. Why does the timing seem to matter? Evidence from related qualitative research suggests that children learn to appreciate bicycling for its convenience, flexibility, and independence during their teenage years rather than at younger ages (Thigpen and Handy, in press).

A similar relationship holds in college, where individuals who ride a bicycle are more likely to gain skills and more positive bicycling attitudes. I would expect that this association with improved bicycling attitudes is caused by a similar mechanism as for high school students, wherein college students come to enjoy bicycling as an efficient, convenient mode of transportation, given budgetary constraints at this age. This is consistent with the overall increase in independent mobility of young adults and with evidence from other research (Simons et al., 2013).

This attitude-behavior relationship is consistent with the theory of cognitive dissonance (Festinger and Carlsmith, 1959): undergraduates who ride a bicycle may report more positive attitude toward bicycling at least in part to maintain consistency. Alternatively, through the act of riding a bicycle for what may be the first time in many years or ever, undergraduates might simply be (re-)discovering the enjoyment of bicycling. Regardless of the causal mechanism, the question remains whether their attitude would persist in other settings, after the students graduate from college – this would be a fruitful extension of this work.

These statistical results contrast with the aggregate pattern of slightly decreasing attitudes across undergraduate classes (freshman to senior), though. But perhaps the most likely explanation is also the simplest. While on average, over half of all undergraduate students bicycle to campus on an average weekday, the rate of bicycling to campus declines from its freshman year peak (~70%) to a junior and senior year trough (~47%) (Thigpen, 2015). This decline in bicycling to campus, due to increased distance to campus after moving out of the freshman campus dorms or other factors, is the likely culprit behind the small, aggregate decline in pro-bicycling attitudes.

I also find that female undergraduates are less likely to like bicycling and are less likely to have confidence in their bicycling skill than their male counterparts. This is consistent with previous literature suggesting that, in childhood, girls are likely to have comparable bicycling attitudes to boys, while in early teen years young women are much more likely to hold negative attitudes toward bicycling than their male peers (Goddard and Dill, 2014; Underwood et al., 2014).

The latent classes identified in the latent Markov model were ordered along a continuum of increasing bicycling motility, even though I specified the classes according to a nominal/categorical model. I chose to do so to allow non-linear, discontinuous classes, such as, for example, two classes with similar attitudes but one with low skill and the other with high skill. These ordered motility classes therefore emerged naturally from the data. One possible interpretation of this emergent pattern is that skills, attitudes, and behavior develop in synchrony, which is consistent with the idea that these constructs have positive reciprocal relationships.

5.2 Policy Implications

The majority of research into the relationship between bicycling attitudes and behavior has focused on the influence of attitudes on behavior (Handy et al., 2014), generally finding evidence to support the association. Consequently, policy suggestions have tended to emphasize the possibilities of marketing campaigns and other techniques to change attitudes, with the intent to therefore change behavior. However, this research investigates the reverse behavior-attitude relationship, and in finding that bicycling behavior is associated with improved attitudes toward bicycling, perhaps lends to simpler, more straightforward policy interpretations. Rather than change people's attitudes about bicycling in order to get them on a bike, what if instead policymakers focused on getting people to ride bicycles, even for a short span of time, in order to change their perceptions and attitudes toward bicycle use? And given the reciprocal nature of the bicycling behavior-attitude relationship (Kroesen et al., 2017), could this tactic therefore result in greater long-term adoption of bicycling by the general public? As mentioned previously, this reciprocal relationship deserves further investigation, as does the relationship between earlier travel experiences (e.g. in college) on later residential location decisions and mode use choices.

Though this analysis focused on the consequences of immersion in a bicycle-oriented university, it is possible that its conclusions regarding travel behavior and psychology would extend to older ages, different modes, and other contexts. The findings of this study should ideally be replicated in other bicycle-friendly settings (especially those that are not university cities) as well as focus on other modes of travel beyond bicycling.

But even if these specific results ultimately are relevant only to the college setting, the trend of decreasing independent mobility among American children (McDonald et al., 2011) suggests that they may have lower motility overall, but especially bicycling, walking, and transit motility. So if incoming college freshmen arrive with fewer experiences with independent travel and with non-automobile modes of transportation, perhaps colleges may have an enhanced role in facilitating the development of young adults' attitudes, abilities, and habits toward sustainable transportation. The results suggest that campus transportation programs should experiment with programs and policies that encourage students to sample different modes of transportation. In the vein of free bus pass promotions, which have proven effective at inducing lasting behavior change among adults (Fujii and Kitamura, 2003), this encouragement could come in the form of education programs or perhaps promotions or challenges that persuade students to ride a bicycle, walk, or take transit to campus. Concrete examples include campus bikeshare systems that lower the barriers to bicycling as well as efforts like May is Bike Month and Bike to Work Day where organizations offer social encouragement and material rewards for bicycling. To further develop our understanding of motility, I would recommend that researchers rigorously evaluate such interventions with respect to bicycling behavior but also changes in attitudes, skills, and knowledge.

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