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The Reciprocal Relationship between Children and Young Adults' Travel Behavior and Their Travel Attitudes, Skills, and Norms

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The Reciprocal Relationship between Children and Young Adults' Travel Behavior and
Their Travel Attitudes, Skills, and Norms

By

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B.S. (University of California, Davis) 2011
M.S. (University of California, Davis) 2014

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

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2017

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ABSTRACT

At a fundamental level, individuals require specific competencies to travel. These include skills, knowledge, attitudes, and norms, which together form the construct of travel “motility.” Though the effects of possessing these basic travel competencies on travel behavior have been studied to varying degrees in isolation, motility has not been well studied as a cohesive unit nor as an outcome of interest. In this dissertation, I seek to understand how individuals’ travel experiences build their motility. I examine two longitudinal panels, with schoolchildren in Davis, CA and with undergraduate students attending the University of California, Davis, both focusing on *bicycling* motility. I find that early bicycling behavior is associated with increased probability of possessing positive bicycling attitudes, a high level of bicycling skill, and perceptions of bicycling as a normal, acceptable mode of travel.

In my third dissertation study, I investigate *driving* motility through a study of driver’s licensing delay. Licensure relates to motility directly and indirectly: getting a driver’s license directly increases motility, while not getting a driver’s license may indirectly lead to increases in motility for non-driving modes, since teenagers without driver’s licenses are likely to gain experiences bicycling, walking, or taking public transit. In recent decades, increasing numbers of American teenagers have chosen to delay or forego licensure; I study the factors that influence the decision to delay through a retrospective survey of students, staff, and faculty at the University of California, Davis. I find that graduated driver’s licensing laws, walkable residential locations, and driver’s licensing attitudes (which vary by generation) are associated with the timing of driver’s licensing. Combined with the results of my other two studies, this suggests that the teenagers who choose to delay driver’s licensing may gain valuable, motility-building experiences with sustainable alternative modes of travel.

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campus travel survey. Finally, thank you to the generous funding of the UD Davis Institute of Transportation Studies' Travel Award for funding my travel to multiple academic conferences, which allowed me to share my research and build a strong network of fellow travel behavior scholars.

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of a travel behavior graduate student researcher was the one for you. You have been a great friend and an excellent colleague, and I will miss our regular discussions of travel behavior, advanced statistical modeling topics, and R programming, in addition to time spent with your lovely family. We will just have to continue our discussions remotely, I suppose...

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Dad, thank you for your thoughtfulness and your natural curiosity. This dissertation demonstrates that what you do at a young age matters, and I can't help but think that the mathematical puzzles you introduced me to as a young boy, as well as the discussions we have had about human behavior and psychology, played a role in my current interests and career.

Mom, thank you for your love and unshakeable faith in me. You make holding many diverse talents at once – writing, art, language – seem both natural and important, and I appreciate you instilling a value for these aspects of life in me. Thank you, too, for your support of Abbey and me during your many weekly visits to Davis to spend time with Koen.

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Abbey, your love, encouragement, and willingness to go on academic adventures with me, even while pregnant and later with a toddler in tow, have blown me away. I would probably be finishing this a couple years from now without your talent and affinity for planning and without your steadfast support. And thank you for keeping things light with your goofy sense of humor – I love you. And lastly, thank you, Koen, for bringing such joy to my life. Thank you for dragging me off my computer and “out of my head” to focus on the good things in life as you explore and learn about the world around you. I love you.

TABLE OF CONTENTS

Abstract.....	ii
Acknowledgements	iii
1 Introduction.....	1
1.1 Outline	4
2 Literature Review	5
2.1 Motility and the Theory of Planned Behavior	5
2.1.1 <i>Travel Behavior Research Using Motility and the Theory of Planned Behavior</i>	<i>9</i>
2.2 Mobility Biographies.....	14
2.2.1 <i>Travel Behavior Research using Mobility Biographies.....</i>	<i>16</i>
2.3 Ecological Model.....	17
2.3.1 <i>Travel Behavior Research using the Ecological Model</i>	<i>20</i>
3 The Importance of Building a Stock of Bicycling Experience in Youth: Evidence from a Bicycle-Friendly City	22
3.1 Abstract.....	22
3.2 Introduction.....	23
3.3 Literature Review and Conceptual Model.....	24
3.3.1 <i>Motility.....</i>	<i>24</i>
3.3.2 <i>Influence of Personal Characteristics</i>	<i>29</i>
3.3.3 <i>Social Influences</i>	<i>30</i>
3.3.4 <i>Conceptual Model.....</i>	<i>32</i>

3.4	<i>Methodology</i>	34
3.4.1	<i>Setting</i>	34
3.4.2	<i>Sampling, Interviews, and Analysis</i>	35
3.4.3	<i>Limitations</i>	39
3.5	<i>Results</i>	41
3.5.1	<i>Descriptive Analysis</i>	41
3.5.2	<i>Exploratory Analysis</i>	66
3.6	<i>Discussion</i>	76
3.6.1	<i>Theoretical Contributions</i>	76
3.6.2	<i>Implications for Practice and Policy</i>	78
3.6.3	<i>Methodological Contributions</i>	80
3.7	<i>Conclusion</i>	80
3.8	<i>Acknowledgements</i>	81
4	The Influence of Bicycling Experiences and Exposure on Skills and Attitudes: Evidence from a Bicycle-Friendly University	82
4.1	<i>Abstract</i>	82
4.2	<i>Introduction</i>	83
4.3	<i>Literature Review</i>	85
4.3.1	<i>Attitude-Behavior Theories</i>	85
4.3.2	<i>Influence of Life Experiences</i>	87
4.4	<i>Methodology</i>	91
4.4.1	<i>Setting and Context</i>	91
4.4.2	<i>Data Collection - the UCD Campus Travel Survey</i>	92

4.4.3	<i>Data Cleaning and Matching</i>	95
4.4.4	<i>Descriptive Analyses of Attitude and Skill Change</i>	95
4.4.5	<i>Statistical Analyses of Causes of Attitude and Skill Change</i>	98
4.4.6	<i>Limitations</i>	105
4.5	<i>Results</i>	108
4.5.1	<i>Sample Characteristics</i>	108
4.5.2	<i>Descriptive Analysis</i>	108
4.5.3	<i>Statistical Analysis</i>	113
4.6	<i>Discussion</i>	124
4.6.1	<i>Interpretation and Theoretical Implications</i>	124
4.6.2	<i>Policy Implications</i>	127
4.6.3	<i>Methodological Implications</i>	130
4.7	<i>Conclusion</i>	132
4.8	<i>Acknowledgements</i>	132
5	Driver’s Licensing Delay: The Impact of Attitudes, Social Influences, and Intergenerational Differences among Residents of Davis, CA	134
5.1	<i>Abstract</i>	134
5.2	<i>Introduction</i>	135
5.3	<i>Literature Review</i>	137
5.3.1	<i>Findings</i>	137
5.3.2	<i>Statistical Approaches</i>	142
5.3.3	<i>Summary</i>	146
5.4	<i>Methodology</i>	147

5.4.1	<i>Data Collection</i>	147
5.4.2	<i>Statistical Analysis</i>	148
5.4.3	<i>Limitations</i>	155
5.5	<i>Results</i>	159
5.5.1	<i>Bivariate Analyses</i>	159
5.5.2	<i>Statistical Models of Driver’s Licensing</i>	160
5.6	<i>Discussion</i>	171
5.7	<i>Conclusion</i>	176
5.8	<i>Acknowledgements</i>	177
6	<i>Conclusion</i>	178
6.1	<i>Theoretical Contributions</i>	178
6.2	<i>Policy Implications</i>	180
6.2.1	<i>Motivation</i>	180
6.2.2	<i>Traditional Policy</i>	181
6.2.3	<i>New Policy Avenues</i>	184
6.3	<i>Further Research</i>	186
	References	188
	Appendix A – Interview Protocol Used in Longitudinal Panel of Davis Children and Parents	199
	Appendix B – Interview Survey Used in Longitudinal Panel of Davis Children and Parents	204

Appendix C – 2016-17 UC Davis Campus Travel Survey Questions Used in Undergraduate Longitudinal Panel Analysis	210
Appendix D – 2014-15 UC Davis Campus Travel Survey Questions Used in Driver’s Licensing Study	215
Appendix E – Analysis of Recall Accuracy among Undergraduate Students at the University of California, Davis	221
<i>Abstract.....</i>	<i>221</i>
<i>Introduction.....</i>	<i>222</i>
<i>Literature Review</i>	<i>224</i>
<i>Methods</i>	<i>225</i>
<i>Results.....</i>	<i>227</i>
<i>Usual Bicycling Use to Campus</i>	<i>228</i>
<i>Bicycling Liking</i>	<i>228</i>
<i>Bicycling Skill</i>	<i>229</i>
<i>Discussion.....</i>	<i>230</i>
<i>Difference between Different Types of Questions.....</i>	<i>230</i>
<i>Influence of Elapsed Time.....</i>	<i>231</i>
<i>Influence of Current Characteristics</i>	<i>231</i>
<i>Assessment of Dissertation Studies’ Reliability.....</i>	<i>232</i>
<i>Implications for Past and Future Research</i>	<i>232</i>
<i>Conclusion.....</i>	<i>233</i>
Appendix F – Key Terms	234

Table of Figures

Figure 2.1. The Theory of Reasoned Action (A) and Theory of Planned Behavior (B)	8
Figure 2.2. Ecological Model of Four Domains of Active Living (Sallis et al., 2006)	18
Figure 2.3. Bronfenbrenner's Ecological Systems Theory (Berger, 2011)	19
Figure 3.1. The Elements of the Theory of Planned Behavior (Ajzen and Fishbein, 1980).....	25
Figure 3.2. Conceptual Model of the Influence of Bicycling Behavior on Bicycling Motility, while Accounting for Additional Independent Variables (Parent Influences, Environmental Characteristics, Personal Characteristics, and Friend Influences).	33
Figure 4.1. Path Diagram of the Latent Markov Model Structure	107
Figure 4.2. Changes in Bicycling Skill Across the Four Undergraduate Classes, by Repeat Cross- Section (All Seven Study Years), Cohort (the Four Complete Cohorts), and Panel	111
Figure 4.3. Changes in Attitudes Toward Bicycling Across the Four Undergraduate Classes, by Repeat Cross-Section (All Seven Study Years), Cohort (the Three Complete Cohorts), and Panel.....	112
Figure 4.4. Posterior Probability Plot of Pro-Bicycle Attitudes by Year (Freshman vs Sophomore), Bicycle Use (“Experience”), and Transfer Status (“Exposure”).....	119
Figure 4.5. Posterior Probability Plot of Bicycle Skill by Year (Freshman vs Sophomore), Bicycle Use (“Experience”), and Transfer Status (“Exposure”)	120
Figure 5.1. Generational Differences in Travel Attitudes and Norms during High School (N = 1,586)	162
Figure 5.2. Varying Effects by Cohort for the Survival Analysis and Censored Regression Models, With and Without Personal Attitudes	174

Table of Tables

Table 2.1. The Correspondence of Skill, Knowledge, Attitudes, and Norms to Dimensions of Motility, Elements of the Theory of Planned Behavior, and the Dissertation Studies	9
Table 3.1. Characteristics of Panel Households.....	38
Table 3.2. Sociodemographic Characteristics of the Sample and the Davis Population	38
Table 3.3. Structural Coding Categories.....	39
Table 3.4. Children’s Bicycling Behavior over Time.....	45
Table 3.5. Children’s Bicycling Attitudes over Time.....	53
Table 3.6. Children’s Bicycling Norms over Time.....	64
Table 4.1. Campus Travel Survey Questions Asked All 7 Years	97
Table 4.2. Additional Questions Included in the Retrospective Survey in 2016-17.....	98
Table 4.3. Quasi-Experimental Research Design and Corresponding Statistical Analyses	102
Table 4.4. Sample Characteristics of the Three Study Datasets	110
Table 4.5. Percent Change in Bicycling Skill and Attitudes between Individuals’ First and Last Observations in Longitudinal Panel (n = 1,648).....	113
Table 4.6. Difference-in-Differences Model Parameter Estimates (log-cumulative-odds scale, n = 1,033)	118
Table 4.7. Latent Class Profile of the Three-Class Solution (N = 1,097).....	123
Table 4.8. Initial Latent Class Membership Parameter Estimates	123
Table 4.9. Transition Parameter Estimates of Time (x + 1) Latent Class Membership	124
Table 5.1. Characteristics of Previous Driver’s Licensing Studies	143
Table 5.2. Description of Variables in the Model (N = 1,586).....	150

Table 5.3. Sociodemographic Characteristics of the Sample Compared to the Population of
California (N = 1,586)..... 157

Table 5.4. Coefficient Estimates for Driver’s Licensing Possession and Timing (N = 1,586) .. 167

1 INTRODUCTION

Stop a bicyclist on the street and ask her why she bicycles. She will probably mention how bicycling allows her to get some exercise in her busy schedule, or how it is an affordable way to get around, or even that it might be the fastest way to work for her. But press her further, and ask about why she even considered bicycling at all, and she may instead cite the importance of skills, knowledge, attitudes, and norms she acquired at an earlier stage in her mobility biography, perhaps in her youth or young adulthood. Travel geographers and sociologists have posited that these psychological constructs, which together are called “motility”, are a critical determinant of actual travel behavior (Kaufmann, 2002). For that reason, understanding the how people develop motility is important; one important possible factor is the role of previous travel experiences. In this dissertation, I delve deeply into the concept of motility and its formation, seeking to answer the question:

How do individuals’ travel experiences influence their motility?

To answer this question, I use the constructs of the theory of planned behavior to measure motility, examine the effects of travel experiences on motility within the mobility biography framework, and use the ecological model to frame my work. I employ mixed methods across three studies that focus on the importance of two distinct periods within individuals’ lifespans: their high school and college years. My studies also center on two types of motility: *bicycling motility* and *driving motility* (as related to the acquisition of a driver’s license).

Two of my studies directly address the main research question of how previous travel experiences shape individuals’ travel motility. The first consists of a panel of interviews with

parents and their children in Davis, CA, conducted when the children were 9, 12, and 15-years-old. In these semi-structured interviews, I explore how bicycling experiences shape the respondents' bicycling attitudes and norms through qualitative coding techniques and content analysis. The second study utilizes a panel data set of UC Davis undergraduates' bicycling behavior, attitudes, and skills, gathered through the annual UC Davis campus travel survey. I use difference-in-differences and latent Markov models to investigate the role of bicycling behavior on subsequent bicycling attitudes and skills.

My third study investigates delay in driver's licensing. Licensure relates to motility directly, in that the process of getting a driver's license increases driving knowledge and skills, and indirectly, since teenagers without driver's licenses are likely to instead gain experiences bicycling, walking, or taking public transit, which may consequently build travel motility for those alternative modes. I therefore investigate the causes of driver's licensing delay using data from a set of retrospective questions in the 2014-15 UC Davis Campus Travel Survey. I asked respondents about their acquisition of a driver's license and their attributes when they were in high school, with questions cutting across all layers of the ecological model. I examine factors associated with delay in driver's license acquisition through a series of statistical models – a binomial logistic model, survival analysis, and censored regression.

With this dissertation, I am one of the first to answer the call from motility researchers to quantitatively examine the consequences of travel experiences on motility in youth (Flamm and Kaufmann, 2006). My studies also address the appeals of several recent literature reviews of travel behavior to measure and consider all the layers of the ecological model simultaneously (Handy et al., 2014; Heinen et al., 2010; Panter and Jones, 2010; Pucher et al., 2010; Saelens et al., 2003; Sallis et al., 2008).

In the study of Davis children's bicycling behavior, attitudes, and norms, I find that bicycling frequency among Davis children stays relatively consistent within their individual lives. Differences in bicycling frequency are associated with the strength and types of bicycling attitudes held by the panel participants, as well as with the bicycling norms the children perceive. At age 15, frequent and daily bicyclists are the most likely to value the independence and convenience of bicycling and cite these as reasons why they like to bicycle. Daily bicyclists unanimously felt that anyone could be a bicyclist, while infrequent and frequent bicyclists were more likely to describe a typical bicyclist as someone with particular trip purposes (e.g. recreational bicyclists) or lifestyle orientation (e.g. environmentalists).

The study of bicycling behavior, attitudes, and skills among UC Davis students demonstrates that personal bicycling experiences both as a child (before coming to UCD) and while at UCD were associated with improved bicycling attitudes and skills in subsequent years. In contrast, the mere exposure to high levels of bicycling at UCD did not appear to play an important role in building bicycling attitudes or skills.

In my study of driver's licensing acquisition and timing, I found that car access, graduated driver's licensing (GDL) laws, travel attributes, and travel attitudes are associated with driver's license delay. Furthermore, I found that personal attitudes toward driver's licensing vary by generation, with millennials less likely to hold strongly positive attitudes toward driver's licensing than members of previous generations, which supports the hypothesis that cultural changes in travel attitudes are behind some of the shift in driver's licensing rates.

Across the three studies, I find that previous experiences riding a bike are associated with later attitudes, skills, and norms. This supports my hypothesis that acquiring "stocks of experience" helps to build travel motility. Furthermore, children growing up in walkable settings,

without primary car access in high school, and under the legal restrictions of GDLs are more likely to delay getting a driver's license. The results of my studies of motility suggest that if delay leads teenagers to make greater use of alternative modes of transportation to meet their mobility needs, these teenagers will likely gain valuable travel motility for public transit, bicycling, or walking.

In addition to their theoretical contributions, my examinations of motility are relevant to transportation planning and policy. My studies provide a better understanding of how individuals' experiences shape their motility, knowledge that planners and policymakers can use to help craft programs and policies to enhance young people's sustainable motility. Based on my dissertation results, such programs might include augmented graduated driver's licensing policies, mandatory bicycle and pedestrian education in elementary schools, and enhanced university programs to promote alternative transportation use.

1.1 OUTLINE

This dissertation is organized around the chapters for each of the three studies (Chapters 3, 4, and 5). Each of these chapters is self-contained, with sub-sections tailored to the particular topic and setting at hand, allowing an interested reader to skip ahead to any particular study of interest. But to set the scene, I have provided a list of key terms used in the studies in Appendix F. And since all three studies use many of the same theories and frameworks of travel behavior and psychology, I delve into these theories in greater depth and breadth in the Literature Review (Chapter 2). Additionally, I provide an overall conclusion (Chapter 6) to the dissertation that weaves the results and implications of the three studies into a cohesive whole. And for the intrepid reader, I have also included appendices for those interested in the survey and interview instruments used to collect the data for these studies.

2 LITERATURE REVIEW

In this review of the literature, I focus on the development, findings, and status of the core concepts, theories, and frameworks of my dissertation: motility and the theory of planned behavior, mobility biographies, and the ecological model.

2.1 MOTILITY AND THE THEORY OF PLANNED BEHAVIOR

The core of my dissertation focuses on how individuals' previous travel experiences influence their motility. The concept of motility was posited in the early 2000s by Vincent Kaufmann (Kaufmann, 2002) and is derived from its use in biology and medicine to describe the capacity for movement of an animal or an organ, as in the motility of an eye (Flamm and Kaufmann, 2006). Travel motility has a similar meaning. Kaufmann's original definition of motility includes three elements: *access* – “the range of possible mobilities according to place, time, and other contextual constraints”; *competence* – the physical ability, acquired skills, and organizational wherewithal to travel; and *appropriation* – how individuals “consider, deem appropriate, and select specific options” (Kaufmann et al., 2004). But I argue that an individuals' travel motility could be approximated more straightforwardly by their answers to three questions about a particular mode of travel: “Are you able to do it?”; “Do you want to do it?”; and “Do you feel you should do it?”. The first question acknowledges the *skill* and *knowledge* necessary to travel by any particular travel mode, and relates to the original dimension of competence. The second and third questions relate to the psychological “representations” or appropriations (i.e. *attitudes* and *norms*, respectively) an individual has of particular modes or ways of travelling. An individual builds their motility over the course of their lifetime, as their experiences sculpt their skills, enhance their knowledge, and mold their attitudes and norms. In my dissertation, I use the

following definition of *motility*, which I feel stays true to Kaufmann and his colleagues' original meaning:

transportation-related *skills, knowledge, attitudes, and norms*

My definition of motility omits the access element, which I instead account for in the physical environment layer of my ecological model framework. I also focus on the motility for a specific mode of travel, such as bicycling motility, though the concept of motility has also been applied more broadly across modes, to travel of any type.

My definition of the dimensions of motility closely aligns with the independent variables of the Theory of Planned Behavior (TPB), a social psychological theory. The TPB is widely used and cited in the travel behavior literature, but it has also been applied to fields as far-flung as e-commerce adoption (Pavlou and Fygenon, 2006) and condom use (Albarracín et al., 2001). Despite the similarity of motility to the independent variables in the TPB, it appears that Kaufmann and his colleagues developed the concept of motility without reference to the TPB.

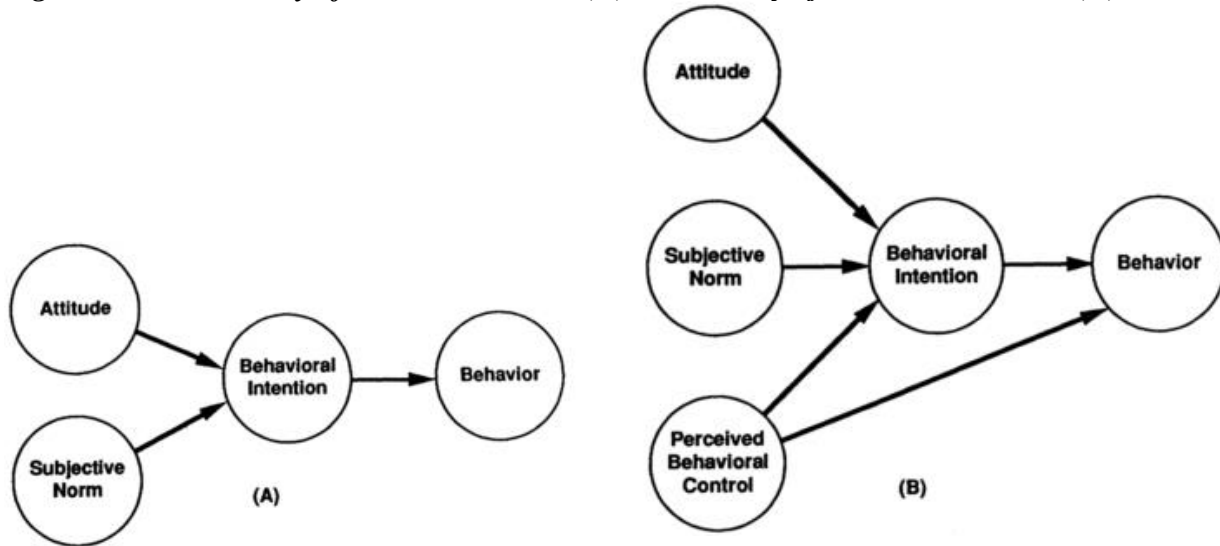
Building off of previous works by social psychologists in the 1960s and 70s, the TPB (Ajzen, 1991) seeks to understand the link between cognitions and behavior. The core elements of the TPB are: *attitudes* – favorable or unfavorable evaluative reactions to a behavior; *subjective norms* - perceptions of whether people important to an individual think they should or should not perform a behavior and whether that behavior is typically enacted among their friends and family and in their community; and *perceived behavioral control* – the extent to which people believe they have the skills and ability to enact the behavior (Dill et al., 2014). In early work concerning the link between attitudes and behaviors, only weak associations were found

until Martin Fishbein demonstrated that this disparity was due to social psychologists measuring attitudes toward objects, rather than attitudes toward behaviors with respect to objects (e.g. attitude toward an illness vs. attitudes toward different treatments for that illness) (Montaño and Kasprzyk, 2008). Fishbein and Icek Ajzen’s collaboration gave rise to one of the most prominent attitude-behavior models in the early 1980s, the Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1980). This theory articulated a path model, leading from attitudes and subjective norms about the behavior in question, to the behavioral intention, and finally to the behavior itself (see Figure 2.1). The TPB modifies the TRA by adding an additional element to the model: the actor’s perceived behavioral control (PBC) (see Figure 2.1). This element represents the actor’s perception of available resources and opportunities as well as their perceived ability to perform the behavior. Unlike attitudes and subjective norms, PBC affects behavior directly as well as indirectly through behavioral intentions. This subtlety acknowledges that PBC plays a role in motivation as well as a direct role as a barrier/opportunity for behavior.

Other scholars have suggested refinements of the TPB, incorporating new elements or merging the TPB with other theoretical models. One of the direct descendants of the theory, the Integrated Behavior Model, incorporates knowledge, salience, environmental constraints, and habit as important determinants of behavior. This represents a departure from Ajzen and Fishbein’s model, particularly with the inclusion of habit, which Ajzen argued repeatedly and forcefully against as an important determinant of behavior (Ajzen, 2011, 2002; Bamberg et al., 2003). Additionally, Sebastian Bamberg, a social scientist who has often used the TPB to study travel behavior, has recently proposed a “stage model of behavior change” (Bamberg, 2013), using concepts from the TPB to categorize individuals’ behavior change along a time-ordered sequence of stages. Although there are other adaptations of the TPB, for brevity I will stop here –

the sheer volume of scholarly work that has applied and supported the TPB confirms it is a useful theoretical model, even if modifications may slightly improve its predictive power.

Figure 2.1. The Theory of Reasoned Action (A) and Theory of Planned Behavior (B)



As previously mentioned, the dimensions of motility, as I define it, map nicely to the independent variables of the TPB (Table 2.1). Since motility scholars have used unconventional terms to describe the construct of motility, I instead opt to use more orthodox labels to characterize individuals' motility at a particular moment in time: *skills* and *knowledge* (which together roughly correspond to “perceived behavioral control”) as well as *attitudes* and *norms*. In addition to borrowing and modifying the elements of the TPB's to provide a measure of individuals' motility, in this dissertation I also *reverse* the TPB's causal framework to examine whether individuals' motility can be predicted by their previous travel behavior.

Table 2.1. The Correspondence of Skill, Knowledge, Attitudes, and Norms to Dimensions of Motility, Elements of the Theory of Planned Behavior, and the Dissertation Studies

		Skill	Knowledge	Attitude	Norms
Motility	Access				
	Competence	X	X		
	Appropriation			X	X
Theory of Planned Behavior	Attitude			X	
	Subjective Norm				X
	Perceived Behavioral Control	X	X		
Dissertation Studies	Davis Children' Bicycling Motility			X	X
	UCD Undergraduates' Bicycling Motility	X		X	
	Driver's Licensing	X	X		

2.1.1 Travel Behavior Research Using Motility and the Theory of Planned Behavior

This dissertation reverses the TPB's causal structure to look at how previous behavior and experiences shape skills, knowledge, attitudes, and norms. Nonetheless, assessing the associations found in traditional application of the TPB could provide hints at whether the reverse specification holds any promise. A growing number of studies have applied the TPB to understand travel behavior, and several recent review papers have summarized the state of knowledge. Gardner and Abraham (2008) reviewed 23 studies explaining car use with the TPB and found that all three elements (attitudes, PBC, and subjective norms) were all typically significant in predicting car use. This suggests that the reverse causal relationship could also exist.

With respect to active travel, Dill et al. (2014) used the TPB to show that attitudes and PBC were both strong predictors of walking and bicycling while subjective norms were not. Their findings mirrored the pattern of results from their literature review of 15 other studies of active travel, which also had strong evidence for the role of attitudes and PBC but less consistent confirmation of the importance of subjective norms. Dill and her colleagues also noted that much

of the literature using the TPB to explain travel behavior omits the role of the built environment; in contrast, they account for respondents' physical environments in applying the TPB.

Research using other theories and frameworks further corroborates the importance of the TPB's three core elements to travel behavior, which I briefly outline in the sections below.

2.1.1.1 Attitudes

I rely on the definition of attitudes provided by Icek Ajzen, as "the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question" (Ajzen, 1991).

Attitudes relate to the fundamental motility question of "Do you want to do it?". In this dissertation, I assess individuals' answers to that question through survey and interview items related to mode liking (i.e. whether someone likes to bike) and the different reasons that they like or dislike the mode.

Relative to the other constructs of motility, the travel behavior literature has provided a relatively strong evidence base behind the association between travel attitudes and behavior. Heinen et al. (2010) reviewed the literature on commute bicycling and found that attitudes were consistently powerful in explaining bicycle mode choice, as "every one of the few studies that considered multiple factors identified attitude as being very influential." They therefore urged future researchers to take a comprehensive approach to studying the determinants of bicycling by including attitudes and accounting for social influence.

But this dissertation examines the opposite: the influence of behavior on attitudes. The theory of cognitive dissonance is particularly relevant to this framing of the behavior-attitude relationship. In the late 1950s, Leon Festinger posited that individuals are likely to work to re-align dissonant or conflicting attitudes and behaviors, with attitudes more likely to change to be consonant with behaviors than the reverse (Festinger and Carlsmith, 1959). In the limited travel

behavior literature that has investigated the reciprocal relationship between travel behavior and attitudes, the evidence generally points to attitude-to-behavior as the stronger relationship (Golob, 2001; Kroesen et al., 2017; Tardiff, 1977).

2.1.1.2 Subjective Norms

Norms can be considered as unwritten rules of proper behavior, and scholars have demonstrated that norms have a strong relationship with behavior. They are related to the fundamental motility question I introduced previously: “Do you feel you should do it?”. Norms come in multiple flavors; psychologists often distinguish between different types of norms, such as personal, descriptive, and injunctive. Personal norms are self-imposed rules about one’s own behavior and are therefore strongly tied to self-concept; violating personal norms tends to result in guilt while complying yields feelings of pride (Onwezen et al., 2013; Schwartz, 1973). “Social norms” include descriptive norms (what is perceived as typical behavior) and injunctive norms (what behaviors are considered acceptable) (Cialdini et al., 1991) – in both cases, an individual’s *perception* is the most important element, rather than “objective” reality. Though motility scholars do not mention norms explicitly in their definition of motility, they describe the importance of “appropriations” and “project[ions]”, which refer to a bundle of psychological elements, including perceptions and personal meanings of different travel patterns (Kaufmann et al., 2010).

In their recent review of bicycling research, Handy et al. (2014) called for further research on the effects of norms and social influence on bicycling behavior, both at the community and interpersonal levels. A small but growing confluence of evidence supports the TPB’s assertion of normative influences on behavior, including research into bicycling (De

Bruijn et al., 2005), public transit use (Bamberg et al., 2007), and general pro-environmental behavior (Bamberg and Möser, 2007).

Other related research also suggests that norms and social influences play a role in travel behavior. For example, Klinger et al. (2013) suggest “mobility culture” as an organizing concept for the study of the determinants of travel behavior. Their model of a city’s mobility culture integrates variables from several thematic areas: urban form, socio-economics, transportation infrastructure, travel behavior, travel attitudes, mobility symbols/discourses, and transportation. After performing a cluster analysis on these variables, the authors identified mobility culture clusters such as *cycling cities*, *transit metropolises*, and *auto-oriented cities*. Notably, some of the clusters were identifiable more by their policies and social norms than their infrastructure, suggesting that social norms may have a particularly strong influence on how those cities’ residents travel.

Social norms are also part of the ascendant social networks approach. Social network research focuses specifically on the structure and strength, both spatially and interpersonally, of the network of social ties (Carrasco and Miller, 2006; Pike, 2014). Despite evidence for the explanatory power of the intricate details of social ties collected by social networks researchers, for simplicity’s sake my operationalization of social norms focuses on general patterns of influence from close relations and the community.

Evidence for the role of socialization also comes from studies of children’s travel attitudes and aspirations. Baslington (2008) proposes a theory of travel socialization based on several of her studies on childhood travel attitudes, finding that their perspectives on travel are shaped by their parents, peers, and the media. Further support for this concept of socialization comes from studies of immigrant travel behavior. Tal and Handy (2010) found that recent

immigrants to the U.S. have different patterns of travel than individuals born in the U.S. or immigrants who had lived in the U.S. for a longer period.

2.1.1.3 Perceived Behavioral Control

The fundamental elements of real and perceived behavior control can be assessed in response to the fundamental motility question of “Are you able to do it?”. In the field of travel behavior, perceived behavioral control is comprised of the skills and knowledge needed to use a mode of transportation. This dimension of motility has not received as much attention from travel behavior scholars as it has from bicycle safety scholars, despite its vital role as a potential barrier in selecting and using a mode of transportation, especially active modes. In a very general sense, humans develop motor skills as part of a continuous, hierarchical process of growth that is strongly related to their age, with most of the maturation process occurring, unsurprisingly, in youth (Haywood and Getchell, 2009).

Scholars have confirmed that this overall trend in motor skill development is borne out in the realm of bicycling, as several studies have demonstrated that young children (7 to 8 years old) lack the skills of their older peers (9 and older) (Ducheyne et al., 2013; Zeuwts et al., 2016). But as might be intuited based on the power law rule of practice (Newell and Rosenbloom, 1980), children with more experience riding a bicycle are also likely to have superior bicycling skills (Zeuwts et al., 2016), improved hazard detection (Zeuwts et al., 2016), and reduced likelihood of getting into a bicycle crash (Schepers, 2012).

In addition to the work of bicycle safety researchers, travel behavior scholars have also examined the influence of bicycling skill through other, related constructs: perceived behavioral control, “self-efficacy” (Bandura, 1982), and the concept of “comfort” (which may be a product of both an individual’s skill as well as the built environment they would ride a bicycle in). These

constructs have been demonstrated to be associated with greater bicycling frequency (De Geus et al., 2008; Dill et al., 2014) or likelihood of bicycling (Winters et al., 2011).

The knowledge needed to traverse a city has also been relatively neglected by transportation scholars. Though I also do not focus on knowledge as part of motility in this dissertation, the role of knowledge is an important one for all modes. And the development of knowledge for how to use a certain mode of travel may not transfer well to other modes, as different types of knowledge are required or emphasized for each mode of transport. For example, bus passengers need to be able to read time tables, transit route maps, etc. (Guo, 2011).

Though I have thus far focused my discussion on skills and knowledge as the two main elements of perceived behavioral control, the entire concept itself has been featured in a number of travel behavior studies, as, for instance, an important predictor of adult bicycling (Dill et al., 2014; Handy et al., 2010). However, other factors also influence perceived behavioral control. Decision-making autonomy can also play an important role, as described extensively in the literature on children's school travel (Mitra, 2012), which notes how children's decision-making autonomy increases as they age, particularly when they go to college.

2.2 MOBILITY BIOGRAPHIES

In this dissertation, I examine individuals' motilities within the context of their "mobility biographies," a concept that travel behavior researchers derived from the life course approach. The sociologists W.I. Thomas and Florian Znaniecki pioneered the life course approach in a 1920 study of Polish peasants, focusing on how the Polish peasants represented themselves over time, as they aged and experienced broad social changes. Though it would be several decades before the approach became widely used, it has since become the "pre-eminent theoretical

orientation in the study of lives” (Elder Jr. et al., 2003). Some travel behavior researchers have adopted this approach and given it the moniker of “mobility biographies.”

In transportation research, the life course approach has great potential to contribute to a better understanding of the motivations and influences underlying individuals’ travel patterns. The mobility biography approach has most commonly been used, in quantitative studies, to determine the “key events” in life when travel behavior, and perhaps travel attitudes and preferences as well, are most amenable to change (Müggenburg et al., 2015). Key events, such as marriage, childbirth, residential relocation, and job changes, are seen to be triggers of travel behavior change. This perspective essentially uses mobility biography – “travel behavior stability and change over time” – and key events to determine *when* travel behavior is most likely to change, but not *how* it occurs.

Thus, though the mobility biography approach can help identify important windows of opportunity for nudging individuals toward sustainable travel behavior, most applications of the approach have lacked the finer contextual, experiential richness of the motility perspective in explaining why those particular key events prove to be associated with travel behavior change. It is in this motility context that I focus my application of the mobility biography approach: my dissertation examines how travel experiences at early points in life may influence later travel motility. An individual’s *travel experiences* could include their own behavior as well as witnessing or being exposed to other ways of traveling. This dissertation relies on a definition of *mobility biography* that refers to:

an individual’s transportation-related experiences across their lifespan.

2.2.1 Travel Behavior Research using Mobility Biographies

Despite its promise as a research approach, the life course approach has only recently been utilized by transportation scholars. Though evidence for the explanatory value of the traditional application of mobility biographies (key events leading to travel behavior change) is mounting (Müggenburg et al., 2015), little to no quantitative evidence exists for the long-term influence of early travel experiences on later travel motility (Flamm and Kaufmann, 2006).

Few quantitative studies investigate the influence of previous travel behavior on later skills, knowledge, attitudes, or norms. Haustein et al. (2009) show that socialization in youth plays an important role in the car use of young adults, and Smart and Klein (2017) demonstrate that public transit exposure in youth is associated with an increased likelihood of transit use later in life. Further, a small amount of qualitative evidence for the influence of previous travel experiences on later motility has recently accrued. Using interviews with 54 adults, Underwood et al. (2014) illustrated how attitudes and subjective norms toward bicycling shifted across the respondents' childhoods. The authors further connect the respondents' childhood bicycle use and attitudes to their adult bicycling, in some cases in the face of negative subjective norms in childhood. Though these studies primarily investigate travel behavior as the dependent variable of interest, it seems feasible that the development of motility provides a likely causal mechanism behind this observed association between early and later travel behavior.

In a review of the research needs and challenges for better understanding bicycling use and behavior, Handy et al. (2014) singled out experiences and learning processes, such as how to ride and navigate a bike, as one of the more promising future research directions on bicycling use. The authors further identified the need to account for bidirectional effects, such as between bicycling habit and bicycle use. Longitudinal data collection, as part of the mobility biography

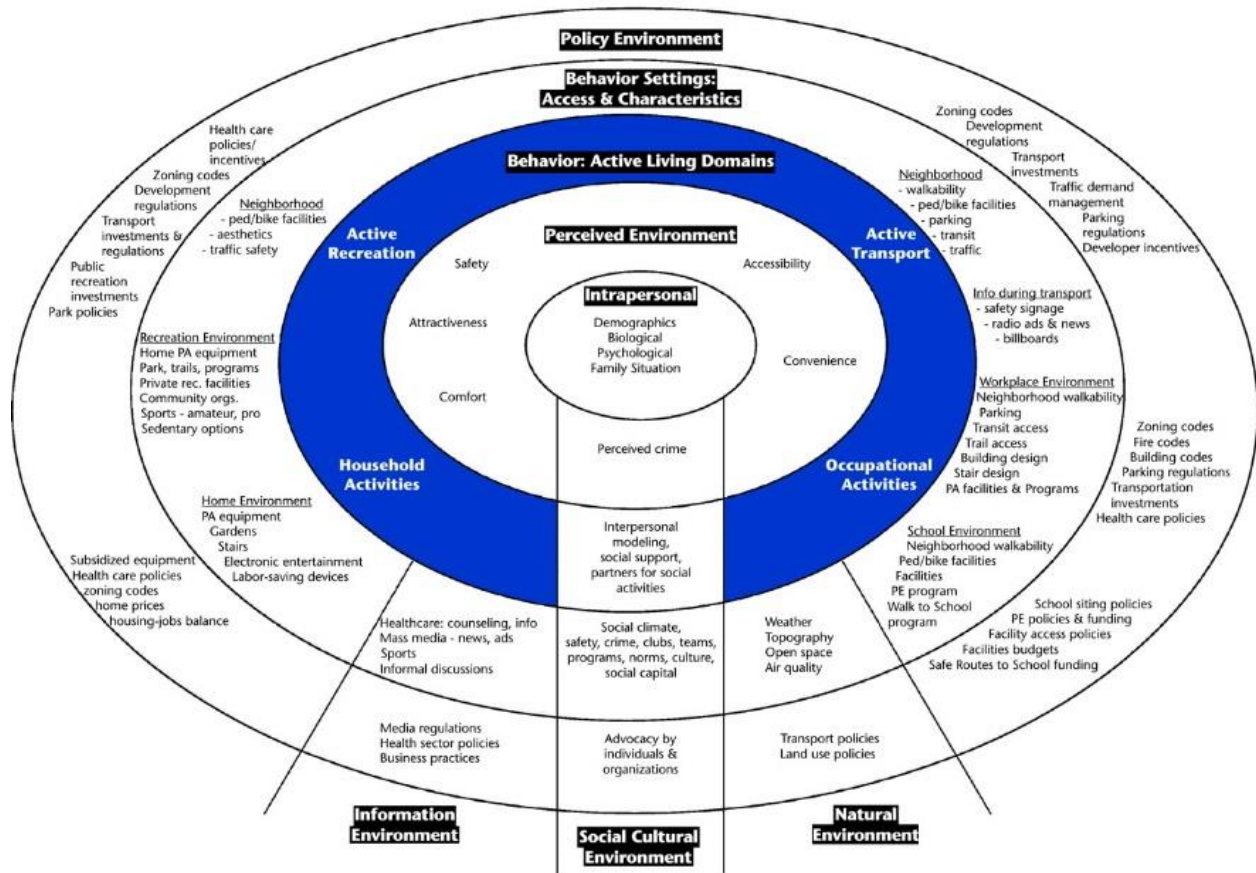
approach, can help tease out such bidirectional relationships in ways that cross-sectional designs can not; several literature reviews call for the collection of longitudinal data in the study of active travel (Heinen et al., 2010; Panter and Jones, 2010).

2.3 ECOLOGICAL MODEL

Ecological models have a long history as a framework for understanding the many levels of influences on behavior. The ecological model accommodates and categorizes these dimensions into several layers of behavioral influences. The layers can be imagined as concentric rings of influence, stretching from the individual layer in the center through the interpersonal layer, socio-cultural environment, physical environment, and policy environment layers, in the particular version of the ecological model used in this dissertation. In the field of travel behavior research, the use of ecological models can be viewed as a remedy to over-reliance on studies focusing only on one level, when human behavior is known to be multi-faceted (Sallis et al., 2008). For example, travel behavior researchers have been prone to over-emphasize the environmental layer (Oosterhuis, 2014) while physical activity researchers historically have focused on individual interventions (Sallis et al., 2006).

As early as the 1950s, simple precursors of the ecological model were proposed by Lewin and by Skinner (Sallis et al., 2008). Since then, many other scholars have posited modifications and refinements to the ecological model. Sallis and colleagues put forth what has become one of the more well-known versions of the ecological model in the fields of public health and urban planning. Their ecological model of active living features four levels, stretching from the innermost intrapersonal level through perceived and objective environments to the outermost policy environment (see Figure 2.2) (Sallis et al., 2006).

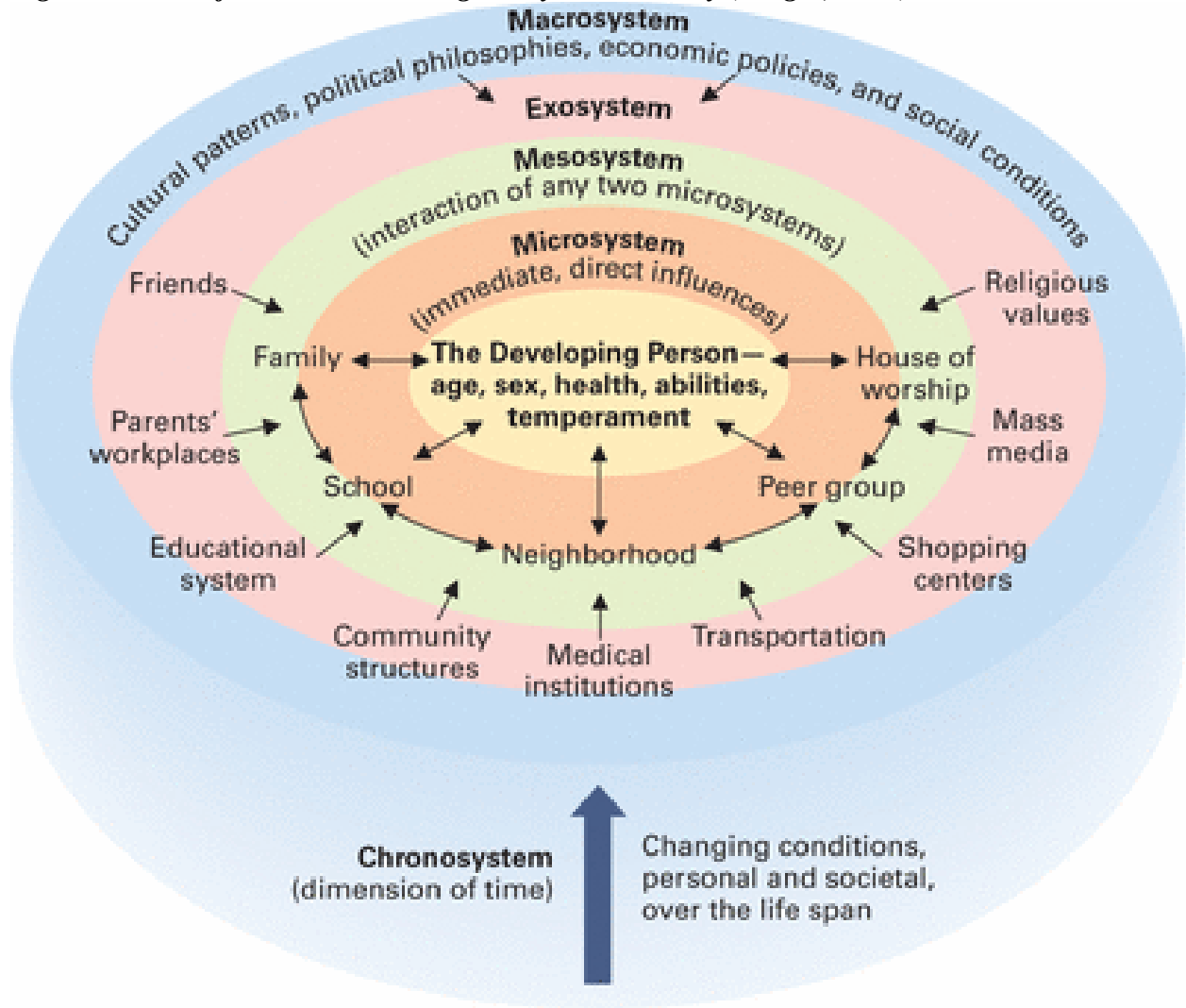
Figure 2.2. Ecological Model of Four Domains of Active Living (Sallis et al., 2006)
Ecological Model of Four Domains of Active Living



Another widely-cited ecological model is Bronfenbrenner’s ecological systems theory, which describes five levels of environmental influences: the microsystem, mesosystem, exosystem, macrosystem, and chronosystem (see Figure 2.3) (Bronfenbrenner, 1994). Face-to-face interactions characterize the microsystem, such as with family and peers and at school and the workplace. Relationships between an individual’s microsystems, such as between family and school, constitutes the mesosystem. The exosystem is similar to the mesosystem except that the settings in the exosystem do not contain the individual but indirectly affect the individual’s development, such as the link between a parent’s workplace and a child’s home. The macrosystem encompasses the pattern of relationships between the three lower systems that are characteristic of a society or culture. In addition to these four levels, Bronfenbrenner also asserts

the importance of time, not only in an individual’s development but also in the historical context within which they live. He terms this dimension the “chronosystem”.

Figure 2.3. Bronfenbrenner's Ecological Systems Theory (Berger, 2011)



Though his theory applies generally to human behavior, Urie Bronfenbrenner acknowledged the relevance of ecological model theory to urban planning:

“In the planning and designing of new communities, housing projects, and urban renewal, the planners both public and private, need to give explicit consideration

to the kind of world that is being created for the children who will be growing up in these settings. Particular attention should be given to the opportunities which the environment presents or precludes for involvement of children with persons both older and younger than themselves” (Bronfenbrenner, 1972).

Ecological model theorists advocate for the creation of behavior-specific ecological models rather than the reliance on an overgeneralized model (Sallis et al., 2008). In the three studies of this dissertation, I take elements from both the Sallis et al. ecological model and Bronfenbrenner’s ecological systems theory to create more customized conceptual models with layers including: individual characteristics, interpersonal environment, socio-cultural environment, physical environment, and policy environment. My conceptual models adapt Bronfenbrenner’s model by accentuating layers that have been shown to be particularly relevant to travel behavior, like the physical environment, that are not explicitly included in his model. They modify Sallis et al.’s model by collapsing their two environment layers and introducing an inter-personal and socio-cultural layer.

Though ecological models are laudably flexible and holistic, they are not without weakness. Their lack of specificity makes it difficult to test concrete hypotheses across fields of study (Sallis et al., 2008). Instead, it is up to the researcher to create hypotheses for the critical factors in their particular study, as I do in my dissertation studies.

2.3.1 Travel Behavior Research using the Ecological Model

Reviews of bicycling behavior call for the use of an ecological perspective, accounting for multiple layers of influence. Handy et al. (2014) identified the importance of investigating higher-level effects on individual behavior, such as the effect of a community’s bicycle use on individual bicycle use. Similarly, they note the potential, under-explored role of community and

interpersonal social influences on bicycling behavior. Another review of bicycle interventions found that simultaneous support from multiple levels and sources was the best predictor of increased bicycle use (Pucher et al., 2010), further supporting the need for research that takes an ecological approach.

Just as travel behavior research using the TPB has typically ignored the role of the built environment, many of the early studies investigating the influence of the built environment on physical activity failed to also account for personal and social influences (Sallis et al., 2008), though this may be changing in recent years. This assertion is supported by a similar review of 43 studies of adult's active travel, which found that only 14 examined psychological correlates and only 7 considered both environmental and psychological correlates (Panter and Jones, 2010). Heinen et al. (2010) similarly lament the lack of research on bicycling commuting that accounts for many sources of influence.

Those studies that simultaneously investigated all three levels of influence have “found that built environment variables, such as the presence of sidewalks and nearby destinations, accounted for the least variance” (Sallis et al., 2008). However, the role of the built environment on travel behavior is well-documented and should hardly be excluded from an ecological analysis (Handy et al., 2002).

3 THE IMPORTANCE OF BUILDING A STOCK OF BICYCLING EXPERIENCE IN YOUTH: EVIDENCE FROM A BICYCLE-FRIENDLY CITY

3.1 ABSTRACT

As children grow toward adulthood, they improve their travel “motility” – the supportive attitudes, norms, skills, and knowledge needed for independent travel. In this study, I seek to identify the factors that influence the development of bicycling motility through the analysis of a prospective panel of 19 children, interviewed at ages 9, 12, and 15. This study is set in Davis, CA, where bicycling infrastructure is comprehensive, which allows me to focus instead on the role of bicycle experiences in building children’s bicycling motility. I analyze the interviews using structural and longitudinal coding techniques and find that bicycling experiences are associated with the types of attitudes held by the participants, especially at age 15, when the children become increasingly likely to value the independence and convenience of bicycling as reasons for why they like to bicycle. In addition, parental behavior and rules proved to have important associations with the children’s bicycling behavior and motility, particularly at younger ages. Friends reinforced bicycling behavior directly, and motility indirectly, through the logistical challenges of traveling as a group at age 15. Though Davis generally has excellent bicycle infrastructure provision, variations in the quality and connectedness of bicycle infrastructure were also mildly associated with bicycling behavior. Finally, gender was not associated with differences in bicycling behavior or motility in the sample, contrary to most other American settings. This study provides confirmatory evidence for the importance of behavior in explaining motility, and future studies should examine the relevance of motility to other modes, ages, and settings.

3.2 INTRODUCTION

As children age toward adulthood, they acquire the knowledge and skills need to travel independently of their parents. Driver’s training, for example, is considered a rite of passage for most American teenagers. By completing on-line courses and in-vehicle training, they acquire the knowledge and skills needed to earn their driver’s license and become safe drivers. But, depending on where they live, they may also acquire skills and knowledge necessary to make use of other modes of transportation, such as riding a bicycle or taking the bus. The competence to make use of transportation modes is called “motility.” Kaufmann (2002) defines this competence as having several components: transportation access, skills and knowledge, and attitudes and norms.

But how do individuals develop their motility? Just as motility is necessary for travel, travel experiences are necessary to build motility, too. An adult who was never taught to bicycle as a child is unlikely to pick up the habit later in life, due to lack of bicycling skills and knowledge, and perhaps thanks to negative perceptions about bicycling, too. The process of motility development has not been well studied, though many studies of travel behavior have investigated the influence of attitudes, norms, and skills on behavior (rather than the reverse, as I do in this study) and a substantial proportion examine these characteristics at only one point in time (Handy et al., 2014).

In this study, I focus on bicycling motility for two reasons: it provides insights into motility development more generally, and it is important in and of itself, given that many communities have the goal of increasing bicycling. And because secondary school is often a pivotal time of change in bicycling attitudes and norms (Underwood et al., 2014), I study bicycling motility development in childhood and young adulthood in Davis, CA. To understand

how children build motility, I examine a prospective panel of interviews with Davis parents and their children at ages 9, 12, and 15. Since Davis has an extensive network of bicycle infrastructure, these interviews offered an opportunity to analyze motility's psychological constructs and causal influences in a context where infrastructure is not a severe limiting factor, unlike most other American cities. I explore the questions: *How do bicycling behavior, attitudes, and norms change over time in childhood? What role do bicycling experiences play in developing bicycling attitudes and norms?* In addition to the behavior-motility relationship, I also adopt a socio-ecological approach to further understand the influence of the built environment, parents, peers and friends, and personal characteristics on behavior and motility. I find that bicycling motility is associated with bicycling behavior among the panel of children, which provides confirmatory evidence for the causal relationship from travel behavior to motility.

3.3 LITERATURE REVIEW AND CONCEPTUAL MODEL

In the following section, I provide an overview of the concept of travel motility, which I define as an individual's travel skills, knowledge, attitudes, and norms. I subsequently discuss and evaluate the factors that I hypothesize could influence the development of motility, which include travel experiences, personal characteristics, and social influences.

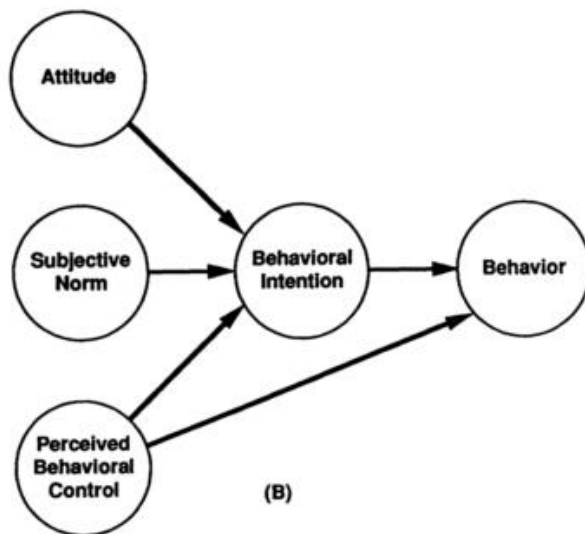
3.3.1 Motility

The term "motility" has a well-established meaning in the fields of biology and medicine, referring to the ability to move (Flamm and Kaufmann, 2006). But in the early 2000s, the sociologist Vincent Kaufmann co-opted the term, applying it more abstractly to the skill and knowledge to travel (Kaufmann, 2002), like understanding a timetable or bus route map. And

even beyond travel skills and knowledge, Kaufmann went further in postulating that motility also includes individual's "representations" of modes of travel, such as their attitudes or norms, as well as the constraints imposed by context, which could be physical or monetary barriers. Importantly for this study, individuals can increase their motility over time through their travel experiences.

To more clearly operationalize the concept of motility, which at times is hazily described in the primary literature, I borrow the elements of the Theory of Planned Behavior (TPB), a social psychological theory. The TPB is widely used and cited in the travel behavior literature, but it has also been applied to fields as far-flung as e-commerce adoption (Pavlou and Fygenon, 2006) and condom use (Albarracín et al., 2001). Despite the similarity of their theoretical constructs, it appears that Kaufmann and his colleagues developed the concept of motility without reference to the TPB.

Figure 3.1. The Elements of the Theory of Planned Behavior (Ajzen and Fishbein, 1980)



Building off of previous works by social psychologists in the 1960s and 70s, the TPB (Ajzen, 1991) seeks to explain the link between perceptions and behavior. The TPB is composed of three independent variables: (a) *attitudes* – how favorably a person views a behavior; (b) *subjective norms* – an individual’s perception of the collective attitude toward or approval of a behavior; and (c) *perceived behavioral control* – how much control a person believes they have in their relevant skills and abilities (Dill et al., 2014) (Figure 3.1). I borrow these three concepts (I refer to perceived behavioral control using the terms “skills” and “knowledge”) from the TPB to use as key dimensions of motility; they serve as the dependent variables in this study’s analysis, and I focus on their change and development over time, particularly as influenced by bicycling behavior and experience (see Figure 3.2).

Unlike most travel behavior studies, though, which use psychological constructs to explain or predict travel behavior, I focus on the process of motility development: how travel experiences, personal characteristics, social influences, and the built environment shape bicycling motility. I therefore place the TPB’s psychological constructs as the outcome variables of interest and behavior as a key determinant. As I discuss further in the “Attitude Change” section, this resembles the theory of cognitive dissonance, which posits that people work to align their behaviors with their attitudes (Festinger and Carlsmith, 1959), though motility expands the outcome to include skills and norms.

3.3.1.1 Attitude Change

The theory of cognitive dissonance is particularly relevant to the motility framework’s positioning of behavior as a determinant of attitude. Briefly, cognitive dissonance theory originally posited that individuals are likely to work to re-align dissonant or conflicting attitudes and behaviors, with attitudes more likely to change to be consonant with behaviors than the

reverse (Festinger and Carlsmith, 1959). One might expect, given the authority dynamic between children and their parents, that children who are encouraged, instructed, or otherwise told to bicycle may be likely to bring their bicycling attitudes in line with their behavior. But this tendency has also been shown to hold true among adults as well, as Kroesen et al. (2017) show that dissonant Dutch travelers in a panel survey were more likely to shift their attitudes to a consonant state than shift their behavior (Kroesen et al., 2017).

3.3.1.2 Norm Formation

Norms, unwritten rules of proper behavior, have also been demonstrated to have a strong relationship with behavior. Psychologists often distinguish between different types of norms, such as personal, descriptive, and injunctive. Personal norms are rules regarding one's own behavior and are strongly tied to self-concept: violating personal norms tends to result in guilt while complying yields feelings of pride (Onwezen et al., 2013; Schwartz, 1973). Descriptive norms relate to what is perceived as typical behavior, and injunctive norms describe what behaviors are considered acceptable (Cialdini et al., 1991). Though the motility approach does not mention norms explicitly, it describes the importance of "appropriations" and "project[ions]", which refer to a bundle of psychological elements, including perceptions and personal meanings of different travel patterns (Kaufmann et al., 2010). Research into bicycling (De Bruijn et al., 2005), public transit use (Bamberg et al., 2007), and general pro-environmental behavior (Bamberg and Möser, 2007) confirms that social norms (i.e. descriptive and injunctive norms) have strong influences on behavior.

Social norms are also related to the concept of lifestyles, which describe an individual's motivations and orientations (Van Acker et al., 2016). Research into lifestyles in the field of travel behavior has found it relevant to the understanding of travel behavior (Gatersleben and

Haddad, 2010; Kitamura et al., 1997; Van Acker et al., 2016) and to consumer behavior and the adoption of low-carbon transportation products and practices (Axsen and Kurani, 2012). Since travel decisions can be considered, at least in part, as an elaborate, outward expression of a lifestyle orientation, then understanding how people perceive bicycling – as a mode that anyone can use or as a lifestyle-particular mode – can help understand why they may or may not adopt it themselves, by comparing their perceptions with their actual behavior. For example, if someone perceives bicycling as primarily a mode for men going on recreational rides, and they are not a man and/or are not focused on exercise as part of their lifestyle, it would likely follow that they would be unlikely to ride a bicycle. In other words, their conceptualization of who bicycles could be considered as an injunctive norm, or whether they think bicycling is viewed as acceptable. Though it is possible that teenagers’ personal lifestyle orientations may be poorly-defined at this point in their life, Baslington’s findings and review of the literature suggest that children and young adults are very attentive and receptive to social perceptions of different modes of travel (Baslington, 2008).

3.3.1.3 Skill Development

One of the major components of motility – the skills and knowledge needed to use a mode of transportation – has not received as much attention from travel behavior scholars as it has from bicycle safety scholars, despite its vital role as a potential barrier in selecting and using any particular mode of transportation, and especially active modes of travel. This study instead primarily focuses on attitudes and norms as the motility dimensions of interest, and does not closely attend to skill or knowledge. However, since the interviews provided indirect evidence regarding bicycling skill (though not knowledge), a brief overview of skill as a dimension of motility is helpful.

In broad terms, motor skill development is a continuous, hierarchical process of growth that is strongly related to the process of aging, with most of the maturation process occurring, unsurprisingly, in youth (Haywood and Getchell, 2009). This general trend in motor skill development is borne out in the realm of bicycling, as several studies have demonstrated that young children (7 to 8 years old) lack the skills of their older peers (9 and older) (Ducheyne et al., 2013; Zeuwts et al., 2016). But in addition to age-related skill improvement, children with more experience riding a bicycle are also likely to have superior bicycling skills (Zeuwts et al., 2016), improved hazard detection (Zeuwts et al., 2016), and reduced likelihood of getting into a bicycle crash (Schepers, 2012), all of which are consistent with the power law rule of practice (Newell and Rosenbloom, 1980).

In addition to the work of bicycle safety researchers, travel behavior scholars have also examined the influence of bicycling skill as described by perceived behavioral control or the related construct of “self-efficacy” (Bandura, 1982). These constructs have been demonstrated to be associated with greater bicycling frequency (De Geus et al., 2008; Dill et al., 2014).

3.3.2 Influence of Personal Characteristics

Personal characteristics, especially gender and age, have also been shown to directly or indirectly influence children’s physical activity and travel behavior. A review of the physical activity literature demonstrated consistent patterns of lower activity levels in teens and among girls, who were less likely to be physically active in childhood and much less likely in adolescence (Sallis et al., 2000). This finding is mirrored in the realm of children’s travel to school, where girls are less likely to bike to school than boys (McDonald, 2012).

Personal characteristics are also associated with motility. Young women tend to hold more negative attitudes toward bicycling, especially in adolescence (Goddard and Dill, 2014).

These gender differences often extend into adulthood as well (Emond et al., 2009; Heesch et al., 2012).

3.3.3 Social Influences

In this paper, I also account for the moderating influence of the social sphere on motility, particularly parents and friends and peers. In the field of psychology, motives behind attitude change are generally classified as being normative (concern about how their attitudes and behavior will mesh with their understanding of typical or accepted behavior) and informational (interest in accurately understanding an entity or issue) (Cialdini and Goldstein, 2004). Despite early theorizing that informational influences would be more likely to elicit lasting attitude change, more recent evidence indicates that normative influences on attitudes are also durable (Chen et al., 1996). And modern interpretations of the theory of cognitive dissonance propose that in addition to the need for self-consistency, dissonance can arise when individuals do not act in ways consistent with socially generated (normative) self-standards (Stone and Cooper, 2001).

The findings regarding social influence on *travel* behavior and attitudes, more specifically, mirrors those from the field of psychology. Parents may play an indirect role in shaping their child's bicycling motility through the rules and examples they set that limit or restrict bicycling behavior (Broach and Dill, 2013). Friends' attitudes may increase in relevance to children's own behavior and/or motility (e.g. attitudes, norms) as a child enters their teenage years (Emond and Handy, 2012; Underwood et al., 2014).

Parents shape their children's travel motility in multi-faceted ways. Through their choice of house, neighborhood, and city in which to reside, parents influence their children's daily travel mode (Susilo and Liu, 2015), which may have the secondary effect of influencing motility.

This is undoubtedly the case in Davis, with its uniquely extensive network of on- and off-street bicycle infrastructure (see the “Setting” sub-section for further details). Furthermore, parents’ fears of traffic and crime risks, as a function of both the objective environment and parental perceptions, can serve to influence the rules that parents impose on their children’s travel (Broach and Dill, 2013; Stewart et al., 2012). These rules are typically relaxed as a child matures (McDonald, 2012). Even with Davis’ extensive bicycle infrastructure, parents may perceive that there are gaps or that the infrastructure is insufficient, and they may therefore regulate where and how their children travel. On a more mundane level, scheduling conflicts can constrain the way children are allowed to travel to school and other activities (Driller, 2013a; Stewart et al., 2012). Parents have different options to adapt to the logistical challenges of juggling family schedules – either opting to have their children travel independently by foot or bike or to chauffeur their children to school and other activities. These influences on children’s travel behavior may all play a role in the skills and knowledge they develop for bicycling but also may send unintentional signals about the normality and appropriateness of bicycling.

The role of friends and peers has not been as closely examined in the literature as the influence of parents, but those studies that have analyzed friend and peer influence have demonstrated its importance. Children may want to use a certain mode in order to travel with friends, or they may feel peer pressure to use or to avoid certain “cool” or “uncool” modes (Baslington, 2008). This effect appears to be particularly strong for active travel modes among girls, while boys appear to be indifferent to whether they feel that their peers think bicycling is cool (Goddard and Dill, 2014). Again, the influence on motility could therefore be indirect, as a consequence of any changes in travel behavior, or direct, if friends’ behavior and attitudes manifest as norms.

In contrast to social influence on attitudes, to my knowledge, little to no research in psychology or travel behavior has investigated the role of social influence on skill. I posit, though, that social influence could indirectly increase skill if it causes an individual to enact the relevant behavior (i.e. ride their bicycle) more often, and thereby enhance their skills.

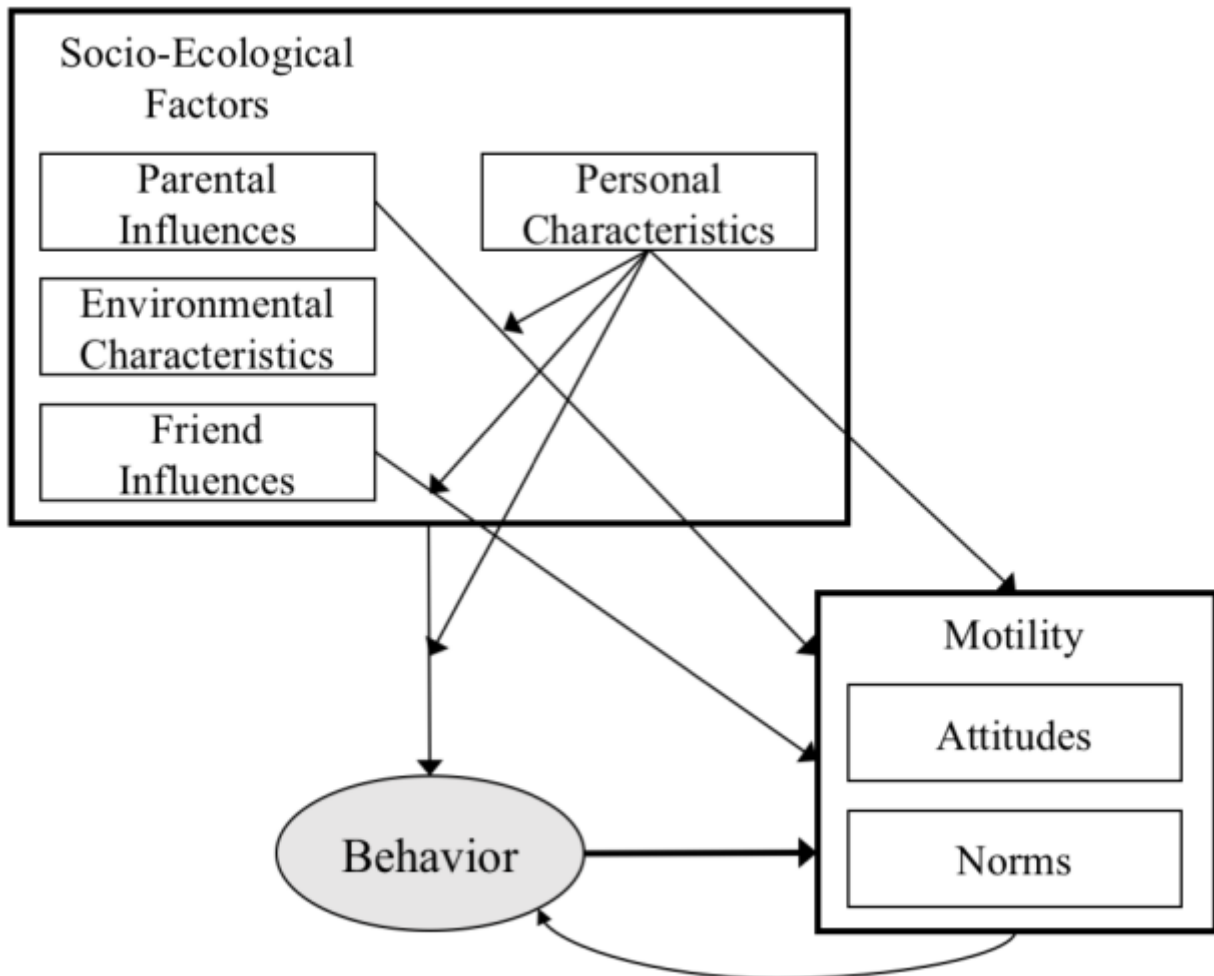
3.3.4 Conceptual Model

My conceptual model reverses the TPB to resemble the motility framework: bicycle behavior is an independent variable of interest, and the multi-dimensional construct of bicycling motility is the principal dependent variable (see Figure 3.2). I primarily attend to attitudes and norms as the underlying dimensions of motility, as the later rounds of interviews did not seek to systematically assess bicycling skills and knowledge. Though not the main focus of this paper, the conceptual model also includes causal arrows from motility to behavior, reflecting the idea that attitudes and norms also influence behavior, in addition to being shaped by behavior, in a reciprocal causal loop.

I include further independent variables from the personal and social spheres, as discussed in the previous sections. I also add the physical environment as another construct in my conceptual model, as it has a well-established relationship with travel behavior (e.g. distance to school, pedestrian and bicycle infrastructure are associated with active school travel - see (Stewart et al., 2012) for a review) and may therefore indirectly influence motility. Including these additional factors is consistent with the socio-ecological approach commonly used in the travel and health behavior fields (Sallis et al., 2008) and allows me to gain a richer understanding of motility and its determinants. All four independent factors (personal, parental, environmental, and friends' influences) are conceived as influencing bicycling behavior directly, while friends, parents, and personal characteristics also influence bicycling motility. Environmental

characteristics are not conceived as directly influencing bicycling motility, as the influence of the built environment on bicycling motility is likely to instead be mediated by bicycling behavior. Finally, personal characteristics, particularly age, are expected to moderate the influence of the other three independent variables on behavior and to moderate the influence of parents and friends on motility.

Figure 3.2. Conceptual Model of the Influence of Bicycling Behavior on Bicycling Motility, while Accounting for Additional Independent Variables (Parent Influences, Environmental Characteristics, Personal Characteristics, and Friend Influences).



3.4 METHODOLOGY

3.4.1 *Setting*

I investigate my research question through a prospective panel of interviews in a city with a reputation as the capital of bicycling in the US: Davis, CA (Buehler and Handy, 2008). The city of Davis is very flat, has a Mediterranean climate, and is home to roughly 65,000 residents.

Davis could be seen as a translation of a Dutch city in the US context: with over 50 miles of on-street bicycle lanes and 50 miles of off-street bicycle paths in its 10 square miles (Buehler and Handy, 2008), Davis residents can reach many destinations within a short distance and on safe facilities. In a striking resemblance to Dutch bicycling statistics, 30-50% of the city's children aged 5 to 18 bicycle to school (Fitch et al., 2016b), 50% of the city's university students bicycle to campus (Thigpen, 2015), and approximately 20% of UC Davis staff and faculty commute by bicycle (Thigpen, 2015).

In addition to a comprehensive and connected bicycle infrastructure network, the city of Davis, local advocacy groups, and parents promote bicycling through a number of programs. For example, the city's active school travel program participates in the national May is Bike Month effort and offers bicycle rodeos at elementary schools to teach basic bicycling skills. The local advocacy group Bike Davis runs promotional events like "Loop-a-looza", a bike tour to highlight the proximity of off-street bike paths to residential areas and schools. Parent volunteers also operate a scanning program, called Active4.me, which records and provides prizes for children's daily active school travel and sends alerts to parents when their child arrives at school (Thigpen and Hartsough, 2017).

Despite these promotional efforts, a substantial proportion of children are driven to school and other activities. This pattern suggests that bicycling infrastructure is a necessary but

insufficient condition for bicycling (Ahlport et al., 2008) and therefore permits me to study how personal and social factors influence children's bicycling motility and behavior.

3.4.2 Sampling, Interviews, and Analysis

In the first round of interviews in 2009, Maiss and Handy recruited participants for this panel study via flyers, convenience sampling, and newspaper ads (Maiss and Handy, 2011). The resulting sample of 20 children, aged 8 and 9, were evenly distributed around Davis and had nearly an even gender split. Driller and Handy followed up with the panel in 2012 (Driller, 2013a), which was refreshed and augmented to account for panel mortality to a new sample size of 25 children, who at this stage were all about 12 years old. In 2015, I conducted a third round of interviews with the participants, now aged 15. To account for further participant drop-out over time, I again refreshed the panel by adding five new participants, for a sample size of 24 children. Ultimately, 11 of the original 20 children in 2009 participated in all three rounds of interviews, and 8 children participated in 2012 and 2015. These 19 individuals, who participated in at least 2012 and 2015, form the basis for this study's panel analysis. The participants' sociodemographic characteristics are outlined in Table 3.1. Since most of the children in the sample were age 9 in 2009, 12 in 2012, and 15 in 2015, in the results section I collectively refer to all of the participants in these three rounds as 9, 12, and 15-year-olds, respectively.

The sample was approximately representative of the overall Davis population by measures of income, education, race, and gender (Table 3.2). The household incomes reported by the sample were spread fairly evenly across categories, though those households making \$100-200,000 and over \$200,000 a year were over-represented. The sample is also more highly educated than the general population of adults 25 and older in Davis, with all but 2 of the 19 parents receiving a four-year college degree or beyond. The sample was comprised of Caucasian,

Asian-American, and Hispanic parents, though one in twelve Davis residents do not identify as one of these three races. The gender split of the sample of children had a greater proportion of females compared to the overall ratio of males and females younger than 18 in Davis.

Interviews rather than surveys are preferred for these research questions for a number of reasons. This study features exploratory questions, such as those related to norms, and complex concepts that are nicely suited to the context of a personal interview, where the interviewer can clarify meaning (Clifton and Handy, 2001). The ability of the interviewee to elaborate and for the interviewer to press for details also allows for a more holistic understanding of the constructs of interest (i.e. better content validity) (Haynes et al., 1995). In so doing, this study complements the other quantitative analyses in this dissertation by providing deeper, richer stories in contrast to the broader but less in-depth information gained from the analysis of large survey datasets.

In this study, each round of interviews was semi-structured, using a script from which the interviewer could deviate slightly as appropriate (Fylan, 2005) (see Appendix A for the full interview transcript). Though each round's focus shifted slightly (e.g. Maiss and Handy studied mental maps (Maiss and Handy, 2011)), a core set of interview questions regarding bicycling attitudes and behavior were maintained in all three rounds. In the 2015 interviews, I supplemented this core with questions about parental attitudes and behavior, friends' attitudes and behavior, and subjective norms. I also issued a short survey to supplement the interviews and to better understand the representativeness of the sample compared to the Davis population (see Appendix B).

Each interview was audio-recorded, and a professional transcription service converted the interview recordings into text, thereby allowing me to study the interviews using coding analysis. For the first cycle of analysis, I used a structural coding approach, which “applies a content-

based or conceptual phrase representing a topic of inquiry to a segment of data that relates to a specific research question used to frame the interview” (Saldana, 2009). I applied a structural code (Table 3.3) to all three rounds of the panel, with the categories corresponding to the constructs in the conceptual model (Figure 3.2).

The other two interviewers and I asked questions about most of the constructs in all three rounds, with an important exception. No explicit questions about personal or injunctive norms were asked in 2009 or 2012, and we asked about descriptive norms in 2012, but inconsistently. In 2015, I added questions about peers’ travel attitudes and about participants’ perceptions of common “types” of bicyclists. This last question was exploratory, and was included in an attempt to ascertain whether the children felt that bicycling was harmonious or in conflict with their self-concept (Gatersleben and Haddad, 2010; Van Acker et al., 2016). Structural coding of personal norms (personal rules of behavior) was based on participants’ offered statements; we did not ask about personal norms in any of the interview rounds.

I then applied a longitudinal coding scheme to the structural codes in a second cycle of analysis. This coding approach linked panel members’ responses across the three rounds to examine how the children’s bicycling frequency was associated with their bicycle motility (attitudes and norms), as identified in the structural codes. I present the longitudinal coding results in both descriptive and explanatory fashions in the results section below.

Table 3.1. Characteristics of Panel Households

ID	Household		Parent		Child
	Annual Income	Residential Location	Educational Attainment	Race	Gender
A	NA	North	4-yr college degree	Caucasian	Male
B	≥ \$200,000	East	Graduate degree	Asian-Amer.	Female
C	\$100 - 200,000	Central	Less than 4-yr college degree	Caucasian	Female
D	≥ \$200,000	South	Graduate degree	Caucasian	Male
E	\$100 - 200,000	Central	4-yr college degree	Caucasian	Female
F	\$100 - 200,000	South	4-yr college degree	Caucasian	Female
G	\$100 - 200,000	North	4-yr college degree	Caucasian	Male
H	\$100 - 200,000	Central	Graduate degree	Caucasian	Male
I	≤ \$100,000	South	Graduate degree	Caucasian	Female
J	≤ \$100,000	East	Graduate degree	Caucasian	Male
K	≥ \$200,000	South	Graduate degree	Asian-Amer.	Female
L	NA	North	Graduate degree	NA	Female
M	\$100 - 200,000	West	Graduate degree	Caucasian	Male
N	≥ \$200,000	South	Graduate degree	Caucasian	Female
O	\$100 - 200,000	East	4-yr college degree	Caucasian	Female
P	≤ \$100,000	West	4-yr college degree	Hispanic	Female
Q	\$100 - 200,000	West	4-yr college degree	Hispanic	Female
R	≤ \$100,000	East	Less than 4-yr college degree	Caucasian	Female
S	\$100 - 200,000	South	Graduate degree	Caucasian	Male

Note: This table describes the participants' characteristics as of 2015.

Table 3.2. Sociodemographic Characteristics of the Sample and the Davis Population

Variable	Characteristics	Sample	Population ¹
Household income	Less than \$100,000/year	24% (4)	46%
	\$100,000 to \$200,000/year	53% (9)	35%
	More than \$200,000/year	24% (4)	20%
Parent educational attainment	Less than 4-year college degree	11% (2)	28%
	4-year college degree	37% (7)	29%
	Graduate degree	53% (10)	43%
Parent race	Caucasian	78% (14)	56%
	Asian-American	11% (2)	22%
	Hispanic	11% (2)	14%
	Other	0% (0)	8%
Child's gender	Female	63% (12)	46%
	Male	37% (7)	54%

¹ Data for the city of Davis' characteristics were obtained from tables B01001, B03002, B15003, and S1901 using the 2011-15 American Community Survey 5-Year estimates (U.S. Census Bureau, 2016).

Table 3.3. Structural Coding Categories

Categories	Sub-categories	Description
Bike Behavior	Bike Access	Whether the child has access to a functioning bicycle.
	Frequency	How often the child rides a bicycle.
	Purposes	Where and why the child rides a bicycle.
Bike Attitudes	Like Bicycling	How much and why the child enjoyed riding a bicycle.
	Dislike Bicycling	How much and why the child did not enjoy riding a bicycle.
Bike Norms	Image of Bicycling	Child's perception of how peers view bicycling to school, in general. (e.g. "cool", "green")
	Among Peers	Child's perception of whether school peers' like to ride a bicycle.
	Bicyclist Typology	Child's perception of stereotype(s) of bicyclists.
Friend Influences	Bicycle Behavior	How many friends ride their bicycle to school, and the extent and type of bicycling children engage in with their friends.
Parent Influences	Rules	Restrictions on where, with whom, how far, etc. their child could ride a bicycle.
	Travel Behavior	Parent's commute mode, bicycling frequency, driving frequency.
	Attitudes	Parent's personal attitudes toward bicycling and driving, and preferences for child's travel.

3.4.3 Limitations

The three rounds of interviews featured three different interview protocols and were conducted by three different interviewers, which could introduce unintended variation or biases in responses. However, the interview protocols were generally similar across the three rounds, and each round was overseen by the same principal investigator, Professor Susan Handy, which helped to provide the interviewers with similar preparation and to ensure that each interviewer understood the study's focus. These factors may have reduced the variation in interviewing content and style and thereby minimized any influence on how the participants responded.

Though this study has a small sample, which reduces its external validity, the qualitative nature of the interviews and the prospective panel design permits good internal validity. Through

interviews, I can more readily identify causal mechanisms and important contextual factors, while the panel design allows me to assess the influence of characteristics in one time period on attributes in a later period (i.e. time order).

I also note that there may be self-selection effects of the types of families who move to Davis, as they may be more pro-bicycling than families in other cities. The drop-out of panel participants might represent a source of bias if the probability of drop-out systematically varied with important characteristics of the participants. However, the children who dropped out were evenly split by gender and actually were somewhat more likely to bicycle frequently, resulting in more varied mode use among the remaining group of panel participants.

Cross-population generalizability of the exact results obtained in this study is likely to be weak, as Davis possesses unique attributes that encourage bicycling. However, I would argue that the more universal relationships identified in this study, between travel behavior and motility, are likely to generalize to other modes of travel and other contexts.

And the unusually bicycle-friendly environment of the city of Davis also has valuable practical implications to urban planning and policy in California and the US. California's SB 375, SB 743, and other smart-growth policies seek to encourage dense, infill development as well as facilitate sustainable transportation via regional transportation plans (Barbour, 2016). These outcomes are pursued as intermediate steps toward the ultimate goal of promoting alternative modes of transportation and limiting car vehicle-miles-traveled, thereby reducing the greenhouse gas emissions from transportation. Given Davis's uniquely comprehensive provision of bicycling infrastructure (Buehler and Handy, 2008), one could view the city as a preview of what these future outcomes could look like. Consequently, these results could be interpreted as

the patterns of travel behavior and motility that other California cities could witness in the coming years.

3.5 RESULTS

3.5.1 *Descriptive Analysis*

On aggregate, the panel participants slightly increased their bicycling frequency over time (Table 3.4). The children's bicycling purposes shifted as they aged, too. They rode their bicycles predominantly for fun at age 9, for functional reasons (e.g. school) at age 12, and for social purposes at age 15. In parallel with these behavioral shifts, the panel participants' attitudes toward bicycling shifted over time, from enjoying it for intrinsic reasons at age 9 and 12 to appreciating it for its functional and social aspects at age 15. Relatedly, characteristics participants disliked about bicycling shifted from worries about crashing, either on their own or with a car, at age 9 and 12, to the dislike of the effort associated with bicycling and the exposure to unpleasant weather. And at age 15, the participants generally believe that it is acceptable and normal for anyone to ride a bike, though some children identify sub-groups that are more likely to bike.

In the following section, I describe these findings in greater depth. For brevity's sake, I provide the number of participants reporting a particular characteristic in parentheses (e.g. "(3)" to indicate three participants). The inset, italicized quotations include a letter in parentheses, indicating the unique ID for that participant (e.g. "(M) *'It's just overall fun.'*") refers to a quote from the participant with the ID letter "M").

3.5.1.1 Behavior

At age 9, most participants (6) rode their bicycle frequently (once a week or several times a week), while a smaller number rode daily (3) or infrequently (2) (less than once a week). Three years later (after the addition of 8 new panel members), this panel was composed of more frequent riders: eight rode daily, seven rode frequently, and four rode infrequently.

Approximately the same was true at age 15, as nine rode daily, eight rode frequently, and two rode infrequently. Overall, the panel increased how often they rode their bikes, though in each round of interviews at least two participants rode their bicycle infrequently. This is the reverse of the age-related trend in bicycling seen elsewhere in the US, where bicycling frequency is typically at its highest among young children and declines as individuals age (Pucher and Buehler, 2008).

These aggregate shifts mask the overall consistency in bicycling frequency by individual. None of the participants increased from infrequent bicycling (the lowest frequency) to daily bicycling (the highest frequency) or vice versa. In fact, four of the eleven three-round panel participants maintained the same level of bicycling in all three rounds, and twelve of the nineteen full panel participants maintained the same level of bicycling at age 12 and 15. Five participants shifted their bicycling frequency between ages 9 and 12 (four increased, one decreased), and seven participants shifted between 12 and 15 (five increased, two decreased). Five participants (*E*, *F*, *Q*, *R*, and *S*) therefore stand out for bicycling infrequently in half or more of their interview rounds, six participants (*B*, *D*, *H*, *K*, *M*, and *P*) bicycled frequently in half or more of the interviews, and eight participants (*A*, *C*, *G*, *I*, *J*, *L*, *N*, and *O*) bicycled daily in at least half of the interviews. As a methodological side note, for the 8 participants who joined the panel as 12-year-olds in 2012, in the event of an even split between two frequency categories, I assigned

them to the lower of the two frequency categories. But more substantively, this consistency in bicycling frequency seems to extend beyond this study's sample, as one participant noted it as a general trend:

(O) *“The people that I knew that were biking in elementary school still bike.”*

At age 9, the participants provided a wide variety of reasons for bicycling, though biking for enjoyment took precedence. The most common response (9) was “for fun” – the intrinsic enjoyment of biking. Relatedly, seven of the participants said they biked in order to get to the park, where they presumably had fun. Five of the respondents biked to school, and four each biked to meet with friends (typically at their house) or to go shopping. Finally, three of the respondents mentioned biking downtown. Other trip purposes, including sports, summer camp, swimming pool, and restaurants, were mentioned by one or two participants. The minimum number of purposes provided was one (by one respondent), the maximum was eleven (excluding this apparent outlier, the maximum was five purposes), and the median was four purposes.

Three years later, fewer purposes for bicycling were provided and the most common purposes had shifted. Twelve participants biked to school, eight rode their bicycle to go shopping, while six biked to meet with friends and five each for fun or to go downtown. to sports, or to go downtown. Notably, only three to the park or to sports. The maximum number of purposes at age 12 dropped to six and median dropped to three, so the overall variety of trips being taken by the twelve year olds decreased slightly.

At age 15, the most common purposes shifted yet again. Thirteen participants biked to meet with friend and fourteen biked to get to downtown destinations, suggesting that social

outings were particularly important to this age group. Bicycling to school remained one of the most common purposes (14), while other purposes received substantially fewer mentions: bicycling to shop and to access the park or a swimming pool each received 4 mentions. At age 15, the minimum number of purposes remained at one, the median increased to four, and the maximum remained at six – a slight uptick in the overall variety of trips taken by the teenagers.

Overall, bicycling frequency was associated with the number of bicycling purposes. Perhaps unsurprisingly, those who bicycled more often were more likely to report a larger number of purposes. And over time, the participants increased how often they rode their bicycles and simultaneously shifted the types of trips they made by bike. While 9-year-olds overwhelmingly rode for the intrinsic enjoyment of bicycling, by 12 the same children were more likely to be bicycling to get to school and at 15 most of the panel cohort had added biking for social purposes to their repertoire.

Table 3.4. Children's Bicycling Behavior over Time

ID	Age 9 (2009)		Age 12 (2012)		Age 15 (2015)	
	Frequency	Purposes	Frequency	Purposes	Frequency	Purposes
A	Frequently	Fun, shopping, friends' houses, school, summer camp	Daily	School, restaurants, friends' houses	Daily	School, friends, other activities
B	Frequently	Fun, park, triathlons	Frequently	School, swimming pool, Target	Frequently	School, downtown
C	-	-	Daily	School, exploring, fun	Daily	School, downtown, restaurants, friends, shopping
D	Frequently	Fun, sports	Frequently	School, sports, friends' houses, restaurants, exploring	Frequently	Downtown, friends, sports, movie theater
E	Frequently	Downtown, farmer's market, fun, park, school	Infrequently	Downtown, summer camp, UC Davis	Infrequently	School, friends, library, downtown
F	-	-	Infrequently	Fun, friends, park, restaurants	Frequently	Downtown, friends, pool, park
G	Frequently	Fun, park, school, store	Daily	School, sports	Daily	School, sports, friends, downtown, swimming pool
H	-	-	Frequently	Downtown, friends, shopping	Daily	Downtown, friends, restaurants, school
I	Daily	School, doctor, downtown, friends' houses, grocery store, library, park, sports, restaurants, shop, movies	Daily	School, park, shop, grocery store, friends' houses, downtown	Daily	School, sports, downtown, friends, parks, anywhere
J	Daily	Fun, downtown, friends' houses, park, swimming pool	Daily	Sports, shop	Frequently	Park, friends, library, job, other activities

K	Infrequently	Fun, summer camp	Frequently	School	Frequently	Extracurricular activities, swimming pool, downtown, other activities
L	Daily	Friends' houses, park, school, shop	Daily	School, shop, friends' houses	Daily	School, downtown, friends, restaurants, shop
M	Frequently	Fun	Frequently	School, park	Daily	School, downtown, friends, swimming pool, other activities
N	-	-	Daily	School, shopping, grocery store, friends	Daily	School, coffee, downtown
O	-	-	Daily	School	Daily	School, grocery store
P	-	-	Frequently	Fun	Frequently	Shopping, park
Q	-	-	Infrequently	Fun	Frequently	School
R	-	-	Infrequently	Shopping	Frequently	School, friends, downtown
S	Infrequently	Fun, park	Frequently	School, shop, farmer's market, downtown	Infrequently	School, downtown, friends

Note: "Daily" = every day, "Frequently" = once a week or a few times a week, "Infrequently" = less than once a week. A "-" in a cell indicates that the question was not asked of the participant because they were not yet a part of the study.

3.5.1.2 Attitudes

Across all three rounds of interviews, the participants almost unanimously report liking to bike, overall (Table 3.5). Therefore, the real nuance in understanding the children's attitudes lies in the characteristics they cite as being reasons they like or dislike bicycling. As the children have aged, the characteristics of bicycling that they like changed. While 9 and 12-year-old children were more likely to enjoy intrinsic aspects (e.g. fun, movement, speed) of bicycling as well as the fun and exploratory elements, these same children at age 15 appreciated the functional characteristics of bicycling as a way to quickly, independently, and flexibly travel, both with friends and to meet friends, and as a way to relax. In all three rounds, the most common characteristics that participants disliked were the weather and effort associated with bicycling. Concerns of traffic and falling were somewhat prevalent at age 9 and 12, while concerns of appearance arose among some participants by age 15.

At age 9, among the 11-person panel, the most frequently-cited aspect of bicycling that the participants liked were related to the intrinsic enjoyment of biking as "fun" (6). Though their descriptions at this age were plain, they were clear:

(B) *"It's just fun."*

(G) *"It's fun to bike."*

Four also said they enjoyed it for the exercise; three said they liked biking for the physical, embodied experience (its movement and freedom); two reported enjoying being outside, seeing the scenery, and not being confined to a car; and two liked the speed of bicycling.

After the panel was augmented by an additional 8 participants at age 12 (bringing the panel size to 19), many of the same characteristics were mentioned again: speed (9), fun (7), the physicality of bicycling (5), and seeing scenery/exploring (3):

(A) *“I like seeing how fast I can go. I just like going fast, I don’t know.”*

(K) *“There's wind in your face and stuff, and it's nice and you can look around more than in a car because there's only a window. You can look around and you see all sorts of things.”*

(M) *“It's just overall fun.”*

One change was an increase in the number of children (3) noting the environmental benefits of bicycling as a reason they liked it:

(S) *“Well, it’s healthy for you and it’s healthy for the environment and stuff.”*

At age 15, the 19-person panel of children was much more likely to cite functional aspects of bicycling as reasons they liked to ride a bicycle. Flexibility, convenience, or practicality (15), independence (9), and speed (especially relative to walking) (9) were the most frequently-mentioned characteristics at this age. With parental permission, these children appreciated being able travel efficiently and quickly on their own without needing to schedule a car ride with their parents in advance and could do so despite not having a driver’s license.

Beyond not needing to coordinate with parents, many of these teenagers liked the convenience of leaving when they wanted, rather than potentially being restricted to leave at a certain time in order to match their parents' schedules.

- (A) *"It gives me a lot of independence because I don't know how to drive. ... And just being able to leave when I want without having to arrange, because having to have someone else drive you and having to have their schedule match. If I want to meet up with a friend, I have to align our schedules and our parent's schedules..."*
- (D) *"It allows me to go places where I don't need to rely on them to shuttle me around everywhere I need to go. I can just hop on my bike and go somewhere when I want to."*
- (G) *"I don't have to wait for my parents to be able to take me places so I can just go when I'm ready."*
- (I) *"I can just like leave whenever I want to. I don't have to wait on someone else 'cause I can just get myself somewhere any time I want."*
- (J) *"I just can hop on it anytime and just go anywhere."*
- (L) *"I like that I am not dependent on people, I kind of just go with my own schedule."*

They also began to attribute their enjoyment of bicycling to socializing (8) and relaxation (6).

(B) *“Being with your friends is kind of more fun. And I guess in general when you're with your friends more, and it wouldn't really matter where you're going because you're with your friends and you can like talk and stuff.”*

A small number of participants also labeled the physicality of bicycling (e.g. being in control, moving) (4) and the environment (4) as reasons for liking to bike.

Though most children reported a substantially larger number of qualities they liked than disliked about bicycling, almost all had at least one quality of bicycling that they said they disliked in each round of the interviews. At age 9, unpleasant weather (4) and the effort and slow speed of bicycling (4) were the most commonly-cited reasons for disliking to bike.

(E) *“If you have to bike really far sometimes it's kind of tiring and you have to stop at lights and stuff.”*

(I) *“When it's hot out I don't like biking.”*

(K) *“[When I] go for a long ride, my hands get sweaty.”*

(L) *“Your legs can get really tired from pedaling so long.”*

Fear of traffic and cars were mentioned by two respondents and concerns with falling were mentioned by one participant.

At age 12 (keeping in mind that the panel increased in size from 11 to 19 children), the effort and slow speed of bicycling (7) and unpleasant weather (5) remained common responses. Unlike at age 9, though, the children became more likely to report traffic/cars (4) and fear of falling (3):

(E) *“I'm scared of crossing the street.”*

(E) *“I just get scared that I'm going to fall off sometimes. That's why I don't like riding my bike alone.”*

(J) *“Interviewer: And is there anything that you dislike about riding a bike?”*

Child: Well, maybe the cars, but not really.

Interviewer: You don't really like biking next to cars?

Child: Yeah, no.”

Three years later at age 15, the 19-child panel provided unpleasant weather (9) as well as the effort and slow speed of bicycling (11) as the primary reasons for not liking to bicycle. Fear of falling was not mentioned, while fear of traffic remained present but uncommon (3). Concerns about appearance became prevalent (4), primarily related to helmets and their impact on hair style choices, as well as the need to choose certain types of clothing if riding a bike.

While unpleasant weather is a common source of dissatisfaction over time, at ages 9 and 12 several of the children had concerns regarding falling off their bicycle, suggesting that these children may not have been very confident in their bicycle handling skills, particularly on city

streets. Though skills and knowledge were not directly assessed in the interviews, these attitudinal responses point to low bicycling skill (i.e. perceived behavioral control or self-efficacy). By age 15, though, the slow speed of bicycling and the effort required were the main characteristics of bicycling that these children disliked, and fear of falling had completely disappeared, indicating bicycle handling proficiency.

Table 3.5. Children's Bicycling Attitudes over Time

ID	Age 9 (2009)			Age 12 (2012)			Age 15 (2015)		
	Like?	Likes	Dislikes	Like?	Likes	Dislikes	Like?	Likes	Dislikes
A	Yes	Fun, environment, exercise	Traffic	Yes	Environment, fast	Slower bicyclists, hill, turns	Yes	Time to think, exercise, environment, independent, flexibility	Slowness, extreme rain
B	Yes	Fun, no seatbelt		Yes	New bike		Neut.	With friends	Slow, hot
C	-	-	-	Yes	Fast, can sit down	Uncomfortable seat, hot	No	Practical, easy	Hills, tiring, helmet, too much biking
D	Yes	Fun, friends and family, ice cream, restaurants	Hot	-	-	-	Yes	Independent, convenience, only option	Doesn't ride in rain
E	Yes	Fun, fast, exercise	Slow, tiring	Yes	Feels good, environment, exercise	Traffic, cold, fear of falling off	Yes	Fast, can avoid strangers, environment, exercise	Cold, risk of crashes
F	-	-	-	Yes	Enjoyable, fast, easy, exploring, fun, in control, with friends	Occasional mechanical issues, cold, traffic/cars	Yes	Fast, independent, convenient, with friends	Hills
G	Yes	Getting outside, exercise	Hot	Yes	Fast	Carrying musical instrument	Yes	Independent, flexible, fast	Hot, distance/slow
H	-	-	-	-	-	-	Yes	Fast, flexible, easy to carry things, fresh air, independent, with friends, refreshing	Rain, hot, helmet hair

I	Neut.	Scenery	Hot, tiring	Yes	Fast, freedom	Biking in morning, rain, tiring	Yes	Easy to get around, flexible, independent, listen to music, biking slowly, with friends	Weather, slow
J	Yes		Fear of falling off	Yes	Freedom, moving, exploring	Traffic/cars	Yes	Simple and easy, flexible, environment	Slow
K	Yes	Fast	Hot, helmet	Yes	Fast, wind in face, scenery, fun	Uncomfortable seat, tiring	Yes	Flexible, independent, with friends, wind in face, notice scenery, down time	Weather, inconvenient
L	Yes	Fun	Tiring	Yes	Nice	Slow, tiring	Yes	Flexible, independent, low stress, fast, with friends	Helmet, tiring
M	Yes	Feels good, exercise, wind in face	Tiring	Yes	Fun	Fear of falling off	Yes	Flexible, independent, social, in control, easy	Tiring
N	-	-	-	Yes	Can multitask	Cold, annoying school bike partner	Yes	Fast, listen to music, relaxing, easy, with friends	Hot, morning, tiring, windy
O	-	-	-	Yes	In control, easy		Yes	Easy, convenient, no need for gas	Traffic danger
P	-	-	-	Yes	Fast, tricks	Locking it up	Yes	Fast, easy, convenient, better than alternatives	Locking it up
Q	-	-	-	Yes	Fun, with friends, fast	Helmet hair	No	For fun or recreation	Traffic danger, being

								seen by peers, sweaty, constrains clothing and hair choices	
R	-	-	-	Yes	Fast, fun	Hills	Neut.	Fast, nice when hot because breeze	Locking it up, mechanical issues
S	Neut.	Mobility/freedom	Fear of crash	Yes	Exercise, environment, different types of bikes	Slow, traffic/cars, fear of falling off	Yes	Cheap, environment, efficient, fast	Parent rules

Note: A “-” in a cell indicates that the question was not asked of the participant, either due to omission or because they were not yet a part of the study. A blank cell indicates that the participant did not provide a response to that aspect of the question.

3.5.1.3 Norms

I examined the presence of personal norms (Table 3.6), even though none of the interview explicitly asked about personal norms. Since participants offered these beliefs without prompting, it may suggest that any statements about personal norms consequently indicate that these beliefs are particularly strongly held.

At age 12, only three participants provided comments indicative of personal norms, all due to guilt over their travel choices' environmental impacts. These responses were given to questions about their attitudes toward traveling by car:

- (A) *“But then I’d feel guilty sitting in the backseat of the car, just watching the exhaust go out into the atmosphere.”*

- (K) *“I feel bad because like all the fumes and stuff, but nothing extremely bad that I don't like about cars.”*

- (S) *“I see a bunch of commercials on TV, on the channels that I watch, that say like, ‘stop.’ Or not this directly, but generally giving this message, like, ‘stop driving a car it pollutes the world.’ ... That’s the general message, is that driving cars is bad for the environment. And like global warming and stuff. So they encourage you to ride a bike so sometimes I feel bad when I think about all the people who are riding a bike to school. And that’s why I started riding my bike to school.”*

One of the participants explicitly mentioned influence from the media, though as I explore later, parents' beliefs as well as the Davis community's environmental ethos likely play an important role as well. One participant reported pride in the instances when he behaved in a way consistent with his personal norm by bicycling to school:

(S) *"It does give me a sense of pride to just go to school by myself. Occasionally I see my friends and I ride with them, and that's fun. I like to ride to school by myself, it makes me feel like I can ride my bike. And it makes me feel like I ride my bike often."*

Two 15-year-old respondents gave responses suggesting they had personal norms regarding travel behavior, again related to the environmental impacts of driving as opposed to biking. One respondent confessed feeling guilt over being driven:

(E) *"It is faster which is good but I do feel guilty doing it. ... because from the whole environment standpoint, it's not very good."*

The other admitted to a hybrid of personal and injunctive norms about children who lived within easy biking distance of school but chose not to bike:

(A) *"Well, if you lived in Davis and you're literally close enough where you can get to school easily and you didn't bike, then that might be looked, frowned upon a bit just because I mean, biking is considered the better alternative, if you can bike. In my opinion. ... Just something like, 'Oh come on...Yeah, you should be biking.'"*

It was unclear during the interview if this participant was referring to his own beliefs or the wider norms of his peers in this quote. Nonetheless, this child clearly expresses a sense of personal obligation to ride a bicycle if it is feasible.

I assessed injunctive norms (i.e. unwritten rules about how you should behave) at age 15 through questions about peers' personal attitudes toward bicycling, the image of bicycling at school, and the participants' perception of different "types" of bicyclists.

Participants viewed their peers as holding neutral or slightly positive attitudes toward bicycling: nine said that the average attitude toward bicycling was neutral, six said that their peers were at least neutral toward it, while four said that most of their peers liked to bike.

(A) *"I'd say at least the majority of people bike to school [and] they enjoy it. ... It's just sort of normal, it's like eating."*

(B) *"It's just kind of if you do it, you do it. If you don't, you don't."*

(C) *"It's just kind of there."*

(F) *"It's pretty like usual, you're not judged for biking to school. ... [it's] never been like 'oh you biked to school, like really?'"*

(H) *"No one's like, 'Oh gosh, they bike to school.' or 'What idiots!' or like 'Wow, they bike to school, look at them!'"*

(I) *“It's just kinda like, ‘Oh, you bike to school?’ There's nothing like... I don't think about it like that.”*

(L) *“It's sort of ‘whatever.’”*

(M) *“That was just like an accepted thing that that's what people did. ... I think most people like to ride their bike.”*

Several participants justified this perspective by suggesting that bicycling is part of the Davis lifestyle:

(D) *“I think biking is just kind of part of life in Davis.”*

(F) *“I think it's weird if you don't own a bike in Davis.”*

(S) *“It's just part of our lifestyle, I guess.”*

Finally, I asked about the children's perceptions of categories or stereotypes of bicyclists. This question was intended to probe the participants' understanding of whether bicycling was associated with certain lifestyles or was itself a “lifestyle expression”, and consequently to see if their perception was harmonious or in conflict with their characteristics. Thought of another way,

this question helps to understand what injunctive norms the children hold regarding bicycling: is it normal, or only an acceptable practice for certain people?

Most of the participants felt that there was not a single “typical” bicyclist, as there were too many different types of people bicycling to classify them. Some of the teenagers were stymied by the question, which could be revealing in and of itself, if their confusion stemmed from a sense of bicycling as a universal activity. Four participants said that anyone could be a bicyclist:

(I) *“I don't really think [there is a typical bicyclist]. I think a lot of... For me, I think, I see a lot of different types of people biking. So, I can't really like say there's a typical one because I see so many different types of people biking.”*

(L) *“Interviewer: And then what do you feel a typical bicyclist looks like?”*

Child: I don't know. Anybody in Davis. [laughter]

Interviewer: Anybody in Davis. So just somebody just wearing just normal clothes biking around?

Child: Yeah.

Interviewer: Okay, nice. And do you feel like they have certain things they care about, or do, or...

Child: Um, no I don't really think so.

Interviewer: No?

Child: No.”

- (S) *“Child: Yeah, it's not like anybody. It's not like a stereotype or whatever.*
Interviewer: Okay.
Child: There's nothing like that in my opinion.
Interviewer: Okay.
Child: And I'm sure many other people also think the same way.”

A particularly savvy participant reflected that the media portrayed bicyclists as hippies or hipsters, but then noted that her experience in Davis contradicted that image:

- (I) *“If you're watching TV or if you're on social media: ‘Oh, you ride a bike...’ And then there's this... they match you to be this artist, or kind of like a college student... I don't know.*
...
I think if I didn't ride... This is what I think of but I also think this is what other people who don't ride their bike think of more: in movies and TV shows, I definitely think that if it's [set] in New York and you're [an actor cast as] like a hipster kind of person you either take the train or you take [your bike], you don't drive a car.
...
I think that's what I think of even if I know it's not true.”

A minority of respondents (3) felt that all bicyclists were defined by their environmental attitudes and motivations or their “outdoorsy” lifestyle:

- (B) *“They might be just doing it to look at nature. People who want to be outdoors-y.”*
- (E) *“Maybe they care more about the environment and not too much about the way they look.”*
- (K) *“[A typical bicyclist is] probably someone that cares about the environment enough to take action? Because a lot of people go, ‘Oh, you know, ‘green cars’ and stuff.’ And they talk about all these things and then they don't actually do any of it. So, I think, I don't know, Davis is a better environment to encourage people to actually do the stuff they want to try. So, someone that's conscious about the environment.”*

The majority of teenagers (12) felt that anyone could be a bicyclist, but distinguished these everyday bicyclists from sub-categories of bicyclists. These sub-groups were drawn based primarily on activity types but in some cases life stage or lifestyle. The most frequently mentioned sub-group (11) was recreational bicyclists, clad in spandex gear and riding their bike for fitness or competition. Three teens also included environmentalists as an additional sub-group beyond everyday bicyclists, and one teen also mentioned students as a sub-group.

Those who distinguished between everyday and recreational bicyclists tended to feel that the former group was likely the larger of the two:

- (C) *“There [are] the racing people, with their racing bikes. And then there's just people who have their town bikes and then they just bike around. There's not really a specific image [for them] because it would be different things.”*

(D) *“Occasionally here you will see the people like their racing gear with their special helmet and like their glasses on and they're like busting down the street at 35. And it's like you see those people every once in a while but not too much.”*

(G) *“There is like hardcore bikers with their road bikes and they like shoes, they have suits and gloves and that kind of stuff ... But I don't know many people like that. A lot of people are just kind of normal bike style.”*

Table 3.6. Children's Bicycling Norms over Time

ID	Age 12 (2012)	Age 15 (2015)		
	Personal	Personal	Peers	Typology
A	Would feel guilty if driven to school.	Look down on those who live close to school but do not bike.	Neutral. Image of bicycling as normal.	Anyone + Recreational
B			Some like it, otherwise neutral. Half bike to school, half are driven. Image of bicycling is neutral.	Outdoorsy
C			Neutral, no image of bicycling.	Anyone + Recreational
D			At least neutral, considered a part of life.	Anyone + Recreational
E		Feels guilty being driven.	Most like to bike for independence. Considered normal because so prevalent.	Environmentalism
F			Most like to bike, because it is easy and independent. No image of bicycling because it is common.	Family bicyclists + Environmentalists
G			At least neutral, for independence.	Anyone + Recreational
H			At least neutral. No image of bicycling because it is common.	Anyone + Environmentalism + Recreational (depends on city)
I			Most are neutral, just the way it is in Davis.	Anyone (Media-portrayal as hippie/hipster)
J			Neutral, mode to school doesn't matter.	Anyone + Recreational

K	Feels guilty about driving.		Neutral.	Environmentalist
L			Neutral.	Anyone
M			Most like to bike, accepted as normal.	Anyone + Recreational
N			At least neutral, not enthusiastic. No image of bicycling but bike fashion.	Anyone + Environmentalist + Recreational
O			Most like to bike, but no image of bicycling	Recreational bicyclists + Students + Anyone
P			Neutral, because it is convenient, best way to get around Davis. No image because it is the norm	Anyone + Recreational (especially outside of Davis)
Q			At least neutral, no image	Anyone
R			Neutral, image of bicycling as uncool (compared to driving)	Anyone + Recreational
S	Feels guilty when driven, especially when he sees peers bike to school. Proud of biking to school.		Neutral, part of lifestyle.	Anyone

Note: The interview protocol did not include questions about bicycling norms in 2009. The participants were not directly asked about personal norms in either 2012 or 2015, and the participants were not asked about their perceptions of types of bicyclists in 2012.

3.5.2 *Exploratory Analysis*

In the following analysis, I first seek to answer the question: *What role do bicycling experiences play in developing bicycling attitudes and norms?* To do so, I begin by using the bicycling behavior categories I developed in the “Descriptive Analysis” section, in which I divided participants according to their typical bicycling frequency over the three rounds of interviews. I can categorize the children in such a way thanks to the remarkable consistency in each individual child’s bicycling frequency, which in no instance shifted more than one category away throughout the six years of this panel study. This categorization results in three groups: infrequent bicyclists (*E, F, Q, R, and S*), frequent bicyclists (*B, D, H, K, M, and P*), and daily bicyclists (*A, C, G, I, J, L, N, and O*). I then assess systematic differences in attitudes and norms between these three groups.

Subsequently, I examine the additional influence of parents, friends, the built environment, and personal characteristics on bicycling behavior and motility. This corresponds to my conceptual model, in which these factors contribute to bicycling behavior as well as motility.

3.5.2.1 *Attitudes and Attitude Change*

All three groups had similar bicycling attitudes at age 9 and 12. The biggest divergence seems to occur at age 15: for the most part, the infrequent bicyclists did not come to appreciate the independence and flexibility afforded by bicycling, while their peers who bicycled frequently or daily almost unanimously came to like that aspect of bicycling. This result may seem intuitive, as infrequent bicyclists are unlikely to experience the independence and flexibility provided by a bicycle if they do not ride it often enough. But its surface simplicity masks important

ramifications, as failing to gain an awareness of how bicycling can fit into a (young) adult life could possibly hinder later adoption of bicycling.

Dislikes of bicycling were also associated with bicycling behavior. Fears of falling or crashing were more likely to be reported by the infrequent bicyclists, suggesting that less bicycling experience reduced these children's bicycling skills, another important component of motility. At age 12, three of the five infrequent bicyclists mentioned fear of car traffic as a reason they disliked bicycling, whereas their peers were unlikely to list these fears at all. Similarly, two of the infrequent bicyclists mentioned fears of falling off their bike, while only one frequent bicyclist and no daily bicyclists identified this as a characteristic they disliked about biking. And though concerns about bicycle handling disappeared by age 15, two infrequent bicyclists still cited fear of crashing as a characteristic of bicycling that they disliked.

These two joint trends in attitudes among infrequent bicyclists – the increased likelihood of safety concerns and decreased likelihood of appreciating the independence associated with bicycling - could perhaps serve as a negative feedback loop. If these individuals' lack of experience makes them have poor bicycling confidence and self-efficacy (or even fear of bicycling), they are unlikely to gain the experiences that might lead them to enjoy the flexibility conferred by a bicycle.

3.5.2.2 Norms and Norm Change

Two infrequent bicyclists (and one frequent bicyclist) reported feeling guilty about being driven as a consequence of violating their personal norms by not behaving in line with the standards they set for themselves. In contrast, none of the daily bicyclists felt guilty about their travel, with one of the daily bicyclists *anticipating* feelings of guilt in a hypothetical scenario in which they were driven to school. Finally, an infrequent bicyclist (*S*) reported feelings of pride at age 12,

when he managed to align his behavior with his norms by biking to school during this time period. These results align with previous theoretical and empirical work, though ultimately do not provide strong evidence that individuals' bicycling experiences *contributed* to their norms. Rather, these children's personal norms seem to have been shaped through both explicit and subconscious messaging of parents, the community, and the media (see quotes in the "Norms" section).

The normative pressure provided by perceived peer attitudes toward bicycling was associated with personal bicycling behavior. The infrequent bicyclists were proportionally much more likely to feel that their peers liked to bike (2 of 5 infrequent bicyclists) compared to their frequent and daily bicyclist peers (1 of 6 and 1 of 8, respectively). This perception among some of the infrequent bicyclists may be a mechanism to understand why their peers are bicycling at higher rates than they do themselves, and may relate to their perceptions of what types of people ride their bikes.

The individuals who thought that bicyclists were typically defined by outdoorsy interests or environmental concerns were infrequent (2) or frequent (3) bicyclists, with the sole exception of one daily bicyclist. The daily bicyclists unanimously felt that "anyone", or anyone plus recreational bicyclists, could be a bicyclist. The tendency for infrequent and frequent bicyclists to see "bicyclists" as a particular sub-group of people, with distinct characteristics could be a subtle form of "othering", in which an individual ascribes characteristics to groups of people they feel are different than themselves (Johnson et al. 2004), and relates back to the concept of travel as a lifestyle expression (Van Acker et al., 2016). In other words, daily bicyclists could feel that they are a part of the overall group of "bicyclists", and therefore don't perceive there being any strongly distinguishing features that differentiate bicyclists from non-bicyclists. And in

contrast, frequent and infrequent bicyclists might perceive themselves as non-bicyclists, leading them to assign defining characteristics to the types of people who are bicyclists.

3.5.2.3 Parental Influences

Parents have the capacity to enhance or restrict their children's motility. Parents helped build their teen's motility through their own behavior, attitudes, and norms. All of the parents reported that they were very comfortable riding a bicycle, they enjoyed riding a bike, and they owned a bicycle.

If a parent biked regularly, their children were much more likely to bicycle on a daily basis as well: of the parents who typically biked more frequently than once a week in 2012 and 2015 (5), four of their children were daily bicyclists and one was a frequent bicyclist. In contrast, if a parent was a very infrequent bicyclist, their children were likely to bicycle infrequently or frequently: of the parents who biked less than once a week in 2012 and 2015 (7), four of their children were infrequent bicyclists and three were frequent. This association could manifest through multiple causal mechanisms. Seeing their parents bike could serve as a model to the children, and the parents' bicycling experiences could serve to inform their rules requiring their child to bike and could aid them in helping their child overcome common bicycling barriers.

Parents' bicycling behavior was also associated with children's bicycling attitudes at age 15. All of the 15-year-old children whose parents biked at least once a week in both 2012 and 2015 held positive bicycling attitudes; children with negative bicycling attitudes had parents who bicycled infrequently or very infrequently. In contrast, parents' bicycling behavior was not strongly associated with their children's injunctive norms, as assessed by the types of typical bicyclists described by their children.

Parents' personal norms could potentially influence their children's bicycling attitudes and norms, both directly and indirectly by swaying the children's bicycling behavior. As parents' personal norms were not directly elicited through the interview protocol (just as with the children), the presence of responses indicating personal norms likely indicates that these are strongly held beliefs. Evidence of parents' personal norms could come from any round of the interviews – I assume these norms are stable over the course of six years.

Similar to the children's evidence of personal norms, most adults tipped their hand by noting their guilt about driving:

- (A) *"I like being able to get places fast [by car]. It's very easy. I don't like using gas, I feel slightly guilty. You know, it's just nice to be able to carry stuff. That's the big thing as far as... because every so often I will do grocery shopping on a bike because I've got baskets, but I can't get six bags. So, carrying stuff around is a big thing for biking or driving."*
- (J) *"[I bike] less than once a week, realistically. I would like that to be more, but it's just not [feasible]."*
- (K) *"But I'm not very good about like biking to the store or, you know. I really should do that more often."*
- (L) *"I just feel like if I work at school (so I'm off in the afternoon) and I have these long summers and I feel like if I am out of milk or something, you know, I don't need to jump in the car go down to buy the milk and be back in 15 minutes. I don't have much else to do,*

so why not just get a bike ride and it is not going to take that much longer but I just feel like, you know, I want to do when I can.”

(M) *“I definitely feel guilty if I go pick up my daughter. It's like almost like I don't want to be seen. ... Totally feel bad about the environment.”*

Though these parents feel guilty, they justify the disconnect between their norms and their behavior by describing the car use as a more convenient way to meet their daily needs. In contrast, only one parent provided evidence of personal norms by citing their pride:

(I) *“I like to bike to West Sac to go to Raley Field. ... I like the idea that I can get to West Sacramento. ... I guess in that way I feel, not self righteous but I feel like that's awesome. That the infrastructure is there. It might not be as comfortable or as fun as or as easy as riding in a car but I see it as an accomplishment.”*

Parents who held personal norms of appropriate or desirable travel behavior were more likely to have children who were frequent (2 parents out of 6) or daily bicyclists (4 parents out of 8). In other words, none of the parents of infrequent (child) bicyclists mentioned personal norms for bicycling.

Parental can also limit teenagers' behavior through rules. A small portion of the parents curtailed their teenager's independent bicycling due to concerns with their teenager's safety from crime and traffic, which suggests that even the best bicycling cities have room for improvement. Rather than a global issue, parents typically identified key locations that caused them worry,

such as a bicycle underpass beneath a railroad track with low visibility or an intersection where a bike path intersected with an arterial road with insufficient protection for bicyclists. Parents who restricted their children's bicycle travel due to these fears limited opportunities for their child to continue building bicycling skills and attitudes.

In line with this study's conceptual model, the rules imposed by parents varied by the child's age. Though considerable variation existed across parents, the most common rules at age 12 related to the distances and locations the child was allowed to bike independently, whether they could bike alone, and to their knowledge of how to navigate. At age 15, rules shifted to govern when a child could bicycle, particularly at night. In 2015, the only parents to impose limits based on concerns about navigational knowledge or bicycling had children who bicycled infrequently (*F* and *S*), which is probably both a cause and a consequence of their rules.

3.5.2.4 Influence of Friends

The influence of friends' behavior, attitudes, and norms could not be as well explored as parents, since parents were directly involved in the interviews, but that does not mean that friends' influence is necessarily any less potent, particularly at older ages.

At age 15, the social element of bicycling rose to the fore. Through the interviews, it became apparent that friends likely reinforced positive bicycling attitudes and norms indirectly through the relatively mundane act of coordinating social gatherings with friends. If several friends were meeting downtown, and one friend was driven by a parent, the teenagers would complain that they were hindered from moving around downtown easily by bicycle because they would need to walk with their bicycle-less friend:

(I) *“Now it's like I would almost rather ride my bike if all my friends are riding their bike. ... I can't be the one, like, ‘Oh, sorry, I have to wait for my mom to pick me up.’ Like that kind of thing. Because, well, I hang out with my friends downtown or we'll go to a park or we'll go somewhere and it's really like easy, like, ‘Oh, I wanna go across town.’ We can just all bike there like we all have our bikes. And like biking with my friends is fun like we don't... I mean it's more fun than biking alone ‘cause it's just like hanging out with them. So, it's fun. [And] like, “Oh, we can bike here, and then we can go from there...” Like if someone has a ride then we'll have to like bike slowly while they walk or something.”*

(M) *“Child: [It's good if all friends bike] because if we do plan to do something after school then we can all get there together.*

Interviewer: Oh, okay. Where would you go with your friends?

Child: Last year, we would go to Nugget because that was really close to Holmes.

Interviewer: So it's better if all you biked?

Child: Mhm.

...

Interviewer: And if one of your friends walked or was driven without

Child: We would either, like bike slow or walk our bikes.”

(N) *“You can just count on everybody to like get a bike and just bike somewhere and you don't have to think about their lift or giving them a lift [in a car]. ... With biking you can*

do a lot more stuff. You can just go somewhere, places faster. Like, if a friend of yours got a car ride, it'd be less flexible because you have to wait for the parent or they had to walk. Or people double-bike, that's another thing. ... [Biking is] simpler."

As a consequence, they much preferred when all members of the group had bicycled to get downtown, and they did not want to be the one holding the group back from spontaneous creation or changes of plans.

3.5.2.5 Environmental Influences

Despite the widespread availability of bicycle lanes and paths overall in Davis, this infrastructure is not uniformly distributed: some neighborhoods are better connected or have access to more off-street bicycle paths than others. North Davis is considered to be one of the safest and most accessible neighborhoods, as it has a comprehensive network of off-street bicycle paths that connect to the nearby high school and elementary school. In contrast, South Davis is separated from the rest of the city by an interstate highway, and access to one of its two elementary schools requires crossing a five-lane arterial road.

Children who lived in North Davis (3) were all daily bicyclists. Children living in South Davis (6) were distributed equally among the three behavioral categories, suggesting its influence was not as severe as its reputation would predict. However, re-evaluation of this pattern in the following round of interviews at age 17 may find that South Davis children reduce their frequency of bicycling, as the elementary and junior high schools in South Davis are relatively accessible, while the main high school is relatively far away (roughly 4 miles).

3.5.2.6 *Influence of Personal Characteristics*

As described in the “Influence of Personal Characteristics” literature review section, in most US cities, young women are less likely to be physically active and to ride their bikes than young men. This association also does not hold in this Davis sample. Both sexes are well represented in each bicycling behavior group: infrequent bicyclists (1 male, 3 female), frequent bicyclist (3 males, 3 females), and daily bicyclists (3 males, 5 females). However, at age 15, young women were the only panel participants to report neutral (2) or negative (2) attitudes toward bicycling. This may be related to external, societal standards of appearance for young women that have no equivalent for young men, reflected in their reported concerns over the impacts of bicycling on perspiration, hair style, and clothing choice.

As for injunctive norms, all of the young men stated that anyone could be a bicyclist, and six of the seven boys also identified recreational bicyclists as a sub-type. Only one young man identified environmentalism as a possible defining feature of who bicycles. In contrast, a lower proportion of young women felt that anyone could be a bicyclist (9 of 12; 75%) or that recreational bicyclists were a typical group (5 of 12; 42%). They were more likely to identify environmental or outdoorsy lifestyles as motivating aspects for those who choose to bike (5 of 12; 42%). No major differences existed between young men and women with respect to perceived peer attitudes toward bicycling.

3.6 DISCUSSION

3.6.1 *Theoretical Contributions*

I find that children's bicycling attitudes and norms are associated with their bicycling frequency, parent and friends' behavior and attitudes, physical environment, and personal characteristics.

These findings provide a deeper understanding of motility and how it is developed.

In particular, at age 15, frequent and daily bicyclists almost universally voiced their appreciation of the independence and convenience provided by the mode. Infrequent bicyclists were less likely to note these characteristics as reasons for liking to bike, likely because they did not use it often enough or in sufficient settings for this benefit to become apparent. Though other research had previously identified these factors of autonomy as important elements in the choice to use active modes of transportation (Simons et al., 2013), this research re-confirms this finding and goes further by identifying the behavioral antecedents of these attitudes. And since these individuals were bicycling at high levels *before* they acquired their liking of the independence and convenience of bicycling, there is evidence from both the time order and association that their bicycle behavior caused the development of these attitudes. From a practical standpoint, whether these attitudes form at age 15 is especially relevant, since at this age most teenagers' mobility is restricted by their ineligibility to hold a full driver's license (see Chapter 5). Holding positive attitudes toward bicycling at this life stage is therefore likely to facilitate independent travel (and vice versa) rather than a dependence on chauffeured trips by parents.

Bicycling frequency was also associated with the norms held by the panel participants at age 15. The daily bicyclists uniformly perceived that anyone could be a bicyclist, while infrequent and frequent bicyclists were more likely to ascribe particular trip purposes or lifestyle orientations to bicyclists. Again, the time precedence of the children's bicycling behavior at ages

9 and 12 before their reported norms at age 15 provides solid evidence for a causal relationship, in support of the hypothesis that travel behavior helps shape motility. However, as noted in this study's conceptual model and supported by the travel behavior literature, it is likely that bicycling norms and attitudes influence behavior in return.

Previous research at both aggregate (Pucher and Buehler, 2008) and disaggregate (Underwood et al., 2014) scales suggests that bicycling rates decline when American children reach their teenage years. The results of this study demonstrate the opposite, showing that children in Davis, CA are as, if not more, likely to ride their bicycles as teenagers, at least until age 15. Furthermore, the common gender difference in bicycling behavior and attitudes did not manifest in the Davis context. Girls were as likely to continue bicycling and hold positive bicycle attitudes and norms as boys in this sample. Though the influence of the built environment is not the primary focus of this paper, these results inevitably point to the value of the comprehensive, safe bicycle network that Davis planners and elected officials have cultivated over the past decades (Buehler and Handy, 2008). In this setting, Davis children, both boys and girls, *can* and *do* elect to ride their bicycles at high levels (though girls may bicycle at a slightly lower rate than boys (Emond and Handy, 2012)).

The social influence of friends exemplifies the importance of positive feedback loops. Friends helped to reinforce bicycling behavior through the simple act of coordinating how they would meet. Groups of friends preferred if everyone arrived by bike, so that they could travel together to different destinations without slowing down for friends on foot who had been dropped off by a parent. And since the participants in the sample continued bicycling into their teens and girls were no more or less likely than boys to bicycle regularly at age 15, I suggest that

providing extensive, safe bicycle infrastructure could allow these social feedback loops to develop in other cities as well.

Evidence from Chapter 5 and other research suggests that travel choices at these ages have secondary effects on the timing of driver's license acquisition. This also fits into a "systems" interpretation of the results of this study and the findings of Chapter 4 in that early bicycling experiences build bicycling motility, allowing and encouraging further bicycling behavior in a positive feedback loop. In contrast, those who did not bicycle frequently as a child may not enter into this positive feedback loop, and may consequently be more apt to gain a driver's license as soon as possible to fulfill their mobility needs.

Further analysis of these interviews will focus on driver's licensing intentions and behavior, following the fourth round of interviews scheduled for when the teenagers are 17. These interviews will provide further insight into the trajectory of bicycling motility, evidence for whether the participants stayed true to their driver's licensing intentions, and possible interactions between driver's licensing and bicycle use.

3.6.2 Implications for Practice and Policy

My findings suggest implications for policymakers and planners wanting to facilitate bicycling among children. Children's active travel to school has declined precipitously over recent decades (McDonald et al., 2011). Given the compelling immediate benefits of active travel for children, including improved attention spans and academic performance (Spitzer and Hollmann, 2013) and health (Lubans et al., 2011), transportation scholars and practitioners have consequently sought to better understand the factors behind the decline (Stewart et al., 2012). But further justification for the value of walking and bicycling may come from considering the long-term consequences,

that is, the accumulation of experiences and the development of attitudes and skills that may influence children's later travel behavior as adults.

In this study, I focused on the development of bicycling motility among a longitudinal panel of Davis, CA children. The bicycling share of trips in the US is low among children and dives precipitously from that already low level among adults (Pucher and Buehler, 2008). In contrast, in the Netherlands, children and young adults younger than 25 make roughly one in three trips by bicycle, before decreasing slightly to roughly one in four trips among Dutch older than 25 (Pucher and Buehler, 2008). Dutch children not only ride their bicycles at 8 times the rate of their American peers, but the gap widens among adults, with the Dutch bicycling at rates 36 to 60 times greater than American adults. This research would suggest that the bicycle infrastructure provided by the Dutch, and by other countries in northern Europe, is a necessary but insufficient factor in these nation's high rates of bicycling. In addition to the safe environment provided by these facilities, the skills and knowledge obtained at a young age, paired with the positive attitudes and normalization of bicycling, combine to maintain bicycling among the countries' citizens.

And though Davis' extensive bicycle network may be an anomaly now, smart growth policies such as California's SB 375 and SB 743 seek to encourage infill development centered around transit, walking, and bicycling (Barbour, 2016) (though whether they succeed in this aim is unclear (Allred and Chakraborty, 2015)). In other words, these policies try to nudge cities to look more like Davis, though perhaps even denser and more transit-oriented than Davis. This study's results could consequently be interpreted as a peak into the future of other California cities and their citizen's travel behavior and motility development. And though these policies are intended to effect immediate change in car use among adults, this study's results imply that they

may have further trickle-down effects on the children who grow up in smart growth communities, if they develop bicycling motility that is durable enough to persist through later residential relocation and life changes.

3.6.3 *Methodological Contributions*

This study employs a qualitative analysis in the context of a longitudinal panel design. Qualitative research remains uncommon in the field of travel behavior, despite its strengths of internal and content validity. This strength is borne out in this study. While almost all children stated that they liked to bike, across all three rounds of interviews, the richest information related to the construct of bicycling attitudes came from the reasons *why* they liked and disliked. Semi-structured interviews are particularly strong at answering these types of questions (Fylan, 2005), while quantitative research, even relying on survey questionnaires, is less amenable. Similarly, exploratory questions, such as those about typical bicyclists, are most ideally suited to qualitative research, where the protocol can be adapted to each particular participant to ensure that they understand the complex concept at hand.

3.7 CONCLUSION

The results from this prospective panel of interviews, combined with previous evidence of the importance of bicycle facilities to bicycle use by children, suggests that bicycle infrastructure is a necessary but not sufficient condition for high levels of bicycling motility among teenagers. Rather, previous bicycling experiences and support from parents and friends serve as important components to build teenagers' bicycling motility. This study therefore contributes to the broader understanding of travel behavior by examining and demonstrating the influence of behavior on psychological elements like attitudes and norms, whereas the majority of studies on the travel

behavior-attitude relationship have investigated the reverse. This study has important practical implications: if we are to expect young adults to pick up bicycling during windows of opportunity later in their life, it is likely that their bicycling motility, built earlier in life thanks to a stock of bicycling experiences, will play an important role in whether they dust off their bike or not.

3.8 ACKNOWLEDGEMENTS

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4 THE INFLUENCE OF BICYCLING EXPERIENCES AND EXPOSURE ON SKILLS AND ATTITUDES: EVIDENCE FROM A BICYCLE-FRIENDLY UNIVERSITY

4.1 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 advantageous setting to examine how these life changes can bring about changes in travel attitudes, norms, skills, and knowledge – a suite of psychological elements called “motility.” In this study, I pool data from seven years of the University of California, Davis’ annual campus travel survey to create repeat cross-sections, cohorts, and 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 describe trends in UCD undergraduates’ pro-bicycling attitudes and bicycling skills and find that, on average, pro-bicycling attitudes decrease slightly over time while an average undergraduate’s bicycling skills increase substantially throughout college. I then use the retrospective panel data to estimate statistical models to analyze the influence of bicycling exposure and experiences on skills and attitudes. In contrast to the implications of the descriptive analysis, 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. Since this study finds that bicycling behavior helps build positive bicycling attitudes, it suggests that policy efforts be directed toward incentivizing even short-term bicycle use in order to shift perceptions and attitudes about bicycling, with the intent of fostering a positive feedback cycle between greater pro-bicycling attitudes and increased bicycle use.

4.2 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. First, it relies on the understanding that these life events are likely to bring about important changes in characteristics relevant for travel, such as a new child with different, unfamiliar needs or a new job with a new distance and route from home. A second, related premise is that, in addition to the changes in an individual's travel characteristics, life events also introduce a discontinuity in habitual travel behavior. The mobility biographies approach argues that these two elements, the objective changes in characteristics and the break in habits, 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. Long-time users of a particular travel mode (e.g. the bus) may take for granted the requisite skills and knowledge and the facilitating attitudes and norms that support their travel mode use. But 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 (Kaufmann, 2002).

In the U.S., universities provide an excellent natural experiment to examine the impacts of travel experiences and exposure to new ways of traveling on students’ motility who have typically. Incoming undergraduate students may be exposed to or adopt new modes of travel with which they have had little recent experience as a child (McDonald et al., 2011), such as bicycling, walking, or taking public transit. These modes are popular on college campuses as affordable, convenient means of transportation, 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: *(1) How do UCD undergraduate students’ bicycling attitudes and skills change over the course of their time in college?* and *(2) 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 data set and examine the influence

of bicycling exposure (living within a community where bicycling is normal) 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 panel statistical models.

4.3 LITERATURE REVIEW

4.3.1 Attitude-Behavior Theories

In this study, I rely on the concept of "motility" to provide an overarching construct for the combination of travel skills and attitudes. This concept hails from the field of urban sociology, but has some similarity to the widely-used Theory of Planned Behavior (TPB); the dimensions of motility (i.e. attitudes, norms, skills, and knowledge) align closely with the independent variables of the TPB. As such, I will begin with a review of the TPB before noting the different aims and focuses of the motility framework.

Building off of previous works by social psychologists in the 1960s and 70s, Icek Ajzen proposed the TPB as a theory to understand the link between perceptions and behavior (Ajzen, 1991). The core elements of the TPB are: (a) *attitudes* – favorable or unfavorable evaluative reactions to a behavior; (b) *subjective norms* - perceptions of whether people important to an

individual think they should or should not perform a behavior; and (c) *perceived behavioral control* – the extent to which people believe they have the skills and ability to enact the behavior (Dill et al., 2014). The TPB has been widely applied within the field of travel behavior research, primarily to describe mode choice as a function of the TPB elements (Bamberg et al., 2003; De Bruijn et al., 2005; Dill et al., 2014; Heath and Gifford, 2002).

More recently, Vincent Kaufmann coined the term “motility” (Kaufmann, 2002), inspired by the term’s use in biology and medicine to describe the capacity for movement of an animal or an organ, as in the motility of an eye (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. The concept of motility encapsulates the skills, knowledge, attitudes, and norms regarding travel that individuals build throughout their lifetime. Fewer studies of motility have been published than studies of the TPB, perhaps due to the TPB’s substantially longer tenure and more general application to the study of human behavior. As a result, Flamm and Kaufmann (Flamm and Kaufmann, 2006) have called for quantitative studies to examine the long-term consequences of motility-building experiences in youth; this study is one answer to that call.

In contrast to most applications of the TPB in travel behavior research, motility 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., 2016; Tardiff, 1977), consistent with the theory of cognitive dissonance (Festinger and Carlsmith,

1959). Given the available evidence that early travel experiences influence later travel behavior (Smart and Klein, 2017), the development of motility also provides a likely causal mechanism behind the observed association. This reciprocal relationship is also of great importance to the current study, as without a causal cycling from behavior to motility and back again to behavior, focusing on the influence of behavior on motility would be a mostly philosophical endeavor with few practical implications.

4.3.2 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. 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 may 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. A sampling of studies using the aforementioned examples demonstrate 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 et al., 2011), particularly car use (De Haas et al., 2016). But in more general terms, this 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.

Scant evidence exists for the relevance of this study's alternative mobility biographies focus: how transportation-related experiences in an individual's *childhood* and *young adulthood* shapes their motility (which may thereby influence their later travel) (Flamm and Kaufmann, 2006). One of the few quantitative studies to approximate the mobility biographies approach I propose here shows that socialization in youth plays an important role in the car use of young adults (Haustein et al., 2009). Another study, using qualitative evidence in the form of interviews with 54 adults, illustrated how attitudes and subjective norms toward bicycling shifted across the respondents' childhoods (Underwood et al., 2014). The authors further connect the respondents' childhood bicycle use and attitudes to their adult bicycling, in some cases in the face of negative subjective norms in childhood. Finally, Baslington (2008) proposes a theory of travel socialization based on several of her studies on childhood travel attitudes, finding that their perspectives on travel are shaped by their parents, peers, and the media (Baslington, 2008).

Just as few studies have examined the influence of childhood experiences, the effects of college experiences have seen little research, despite the fact that undergraduate students constitute the research subjects for a sizeable portion of the published research in the social sciences (Gordon et al., 1986) and that Americans are obtaining college degrees at an increasing

rate (National Center for Education Statistics, 2016). Ripplinger et al. conducted a three-wave panel at North Dakota State University, finding that despite having little previous exposure to transit, NDSU undergraduates were more likely to take local transit across their time in college (Ripplinger et al., 2008). In his 2011 dissertation, Rubin found that exposure to transit during childhood or college increased comfort and use of transit later in life (Rubin, 2011). Changes in behavior between high school and college have received some attention in the field of public health, where researchers have found that physical activity tends to decline after this transition (Bray and Born, 2004; Wengreen and Moncur, 2009).

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 established skill acquisition as an ongoing, hierarchical process of growth that is strongly related to the process of maturation in childhood and young adulthood (Haywood and Getchell, 2009). Additionally, the link between skill level and practice follows a log-log linear relationship (the relationship between the logarithm of a skill measure and the logarithm of a practice measure is linear), in what is termed the power law rule of practice (Newell and Rosenbloom, 1980). Bicycle safety scholars have found that bicycling skill development increases with age, consistent with the general findings in the field of human development: older children (9 and older) possess greater bicycling skills than their younger peers (7 to 8 years old) (Ducheyne et al., 2013; Zeuwts et al., 2016). But above and beyond age-related skill improvement, bicycle skills also follow the power law rule of practice: children with more experience riding a bicycle tend to have superior bicycling skills (Zeuwts et al., 2016) as well as better hazard detection (Zeuwts et al., 2016) and lower chances of getting into a bicycle crash (Schepers, 2012). 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.

Just as few travel behavior researchers have investigated the influence of travel behavior on attitudes or other dimensions of motility, the role of exposure to others using alternative modes of transportation has been similarly under-examined. 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”, “socialization”, or “spillover effects”, which has been shown to influence travel behavior (Bandura, 1971; Döring et al., 2015; Goetzke and Rave, 2011; Haustein et al., 2009).

Overall, the sparse knowledge base regarding the importance travel experiences and exposure in youth and young adulthood has not gone unnoticed. In a review of the research needs and challenges for better understanding bicycling use and behavior, Handy et al. (2014) singled out experiences and learning processes, such as how to ride and navigate a bike, as one of the more promising future research directions on bicycling use (Handy et al., 2014). Longitudinal data collection, as part of the mobility biography approach, can help tease out such relationships in ways that cross-sectional designs cannot; several literature reviews call for the collection of longitudinal data in the study of active travel (Heinen et al., 2010; Panter and Jones, 2010).

4.4 METHODOLOGY

This study employs longitudinal data analyses, using data collected at UCD over the past seven years, to first assess trends in attitude and skill change among undergraduates over time and then to statistically estimate the influence of bicycling experiences and exposure on bicycling motility.

4.4.1 Setting and Context

The city of Davis, home to about 66,000 people, initially built its reputation as a bicycling capital in the U.S. in the late 1960s, when the town elected a pro-bicycle city council and built the nation's first on-street bicycle lanes (Buehler and Handy, 2008). Despite a modest lull in bicycling in the 1990s and early 2000s, Davis' bicycle mode share continues to outstrip all other US cities by large margins. Depending on the school, between 10 and 50% of schoolchildren in Davis bicycle to school and approximately 50% of UCD undergraduates bicycle to campus on an average day (Fitch et al., 2016b; Thigpen, 2015). Davis adults also bicycle at high levels, as approximately 20% of UCD employees commute by bicycle (Thigpen, 2015). The city has also built a substantial network of bicycle infrastructure, with over 50 miles of on-street bicycle lanes and 50 miles of off-street bicycle paths within its 10 square miles.

Approximately 30,000 undergraduate and 7,000 graduate students attend UC Davis. 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. 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, have access to a uniquely extensive bicycle infrastructure network, and can use the wealth of bicycle services and resources (e.g. bike lock cutting service, bike classes) provided by the UCD Transportation Services department. In addition, many freshmen take up bicycling to campus, with roughly 70% of freshmen riding their bicycle on an average weekday (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 the research questions regarding the influence of personal bicycling experiences.

4.4.2 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) for nearly a decade. After a pilot effort in the 2006-07 school year, the CTS has been administered each year in the fall by a graduate student.

The CTS is administered online to students, staff, and faculty, with stratified random sampling from each of the eight main campus role groups to reduce survey burden while still obtaining representative results. The survey is sent out in late October or early November and accepts responses for two to three weeks, with an incentive for participation (typically a cash raffle or an equivalent prize) and a reminder email a week after the initial recruitment email is sent. The survey typically achieves a response rate of 10 to 15 percent of the invited sample. The

survey collects information on commute travel characteristics, including mode, distance traveled, and parking. Many of the questions are asked in the same way each year, allowing for robust cross-year comparisons by planners and researchers. The data is used for a variety of purposes, including long-range campus planning and program and policy evaluation.

Important features of the CTS helped engender this study. I use the most recent seven CTSs (see (Driller, 2013b; Gudz et al., 2016; Miller, 2012, 2011; Popovich, 2014; Thigpen, 2015) for reports and survey instruments) 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 panel data set. Their inclusion in this panel was conditional on them (a) receiving the survey, (b) taking the survey, and (c) providing their email address, so individuals' absence from any single survey may be due to any of those three reasons. Crucially, by constructing a longitudinal panel data set, I can 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) is also an important element of motility, it is difficult to operationalize in a generalizable way in a survey, due to its context-dependence, and was therefore excluded. Similarly, questions regarding social norms for bicycling were not asked in previous years of the survey and are consequently not assessed. All seven years of surveys asked about my dependent variables: bicycling skill (on a 4-point scale) and bicycling attitude (on a 5-point Likert-type scale). Importantly for my 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, such as gender and transfer status were also asked in each year (Table 4.1).

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 (see Table 4.2 and Appendix C). I designed this section to attain multiple goals. The primary intent of this section was to obtain a more complete panel of undergraduate student responses regarding their bicycling skills, attitudes, and behavior over three or more years. Undergraduates were 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), making this retrospective section particularly important to the goals of this study (see Table 4.3). Perhaps equally importantly, this retrospective section also captured the bicycling behavior and motility of transfer students. By their very nature, transfer students 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. The experiences and motility of transfer students are an important part of the quasi-experimental design of this study, a point I describe in greater depth in the “Statistical Analyses of Causes of Attitude and Skill Change” section and depicted in Table 4.3.

The retrospective section was designed to achieve other, secondary goals as well. Rather than only ask about the two primary attitude and skill questions that had been asked in previous editions of the CTS, I also asked about further dimensions of bicycling skills and attitudes. 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 based on

similar studies (Lois et al., 2015), all of which were subjected to rigorous pre-testing. Finally, the answers that undergraduates provided in the retrospective section could, in some cases, be compared to their prospectively supplied answers. I therefore used these instances to ascertain the reliability of the recalled responses.

As a final note, the data gathered in this retrospective section is used in the two statistical analyses, but not in the descriptive analysis.

4.4.3 Data Cleaning and Matching

I used the R statistical programming language to aggregate the seven CTS datasets and clean the data (R Core Team, 2016). To do so, I gave the variables of interest consistent names and ensured they were on the same scale (e.g. ascending rather than descending, numeric coding rather than character responses, etc.) across all seven years. I then reduced the data set to only include undergraduate students. For the cohort analysis I tracked the same class (e.g. students entering as freshmen in 2013) across all four undergraduate years, yielding four complete cohorts. To form the panel data set, I matched individuals across years of the CTS using unique IDs. The vast majority of individuals in the panel dataset have at least one or more years of missing data, which could be a consequence of not being randomly selected or of choosing not to take the survey.

4.4.4 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 employ three complementary descriptive analysis approaches to triangulate the overall trend of bicycle attitude and skill change among undergraduates over time. The first, a repeat cross-sectional analysis of the CTS

data, looks across the four undergraduate classes within each year, resulting in seven total cross-sections. In other words, I compare freshmen to sophomores to juniors to seniors to see how behavior, skills, and attitudes differ by class and thus time at UC Davis. This approach yields a large sample size ($n = 28,011$) and allows me to compare all seven years, but it provides differences in behavior across undergraduate classes rather than tracking individual change.

I also use a cohort approach, tracking a given class over time across all four years. I therefore have four complete cohorts, tracking the same class from freshman year through senior year over the 2010-2014, 2011-2015, 2012-2016, and 2013-2017 time spans. The cohort analysis has a smaller sample size ($n = 7,100$) than the repeat cross-section analysis, but it nevertheless retains a substantial number of respondents. The cohort approach also allows me to more readily detect possible history effects, which might occur if, for example, one cohort had the common experience of witnessing news coverage of a particularly bad bicycle crash. However, the cohort analysis still cannot assess individual change.

The final descriptive analysis, a prospective panel, consists of a much smaller number of individuals ($n = 1,648$), but allows me to trace individual change, unlike either of the previous analysis approaches. The prospective panel does, however, feature missing data, as many individuals only provided two or three years of responses with uniquely identifying information. I therefore ultimately have 3,498 observations (greater than 1,648 because of 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, so I simplified the panel analyses by looking at individuals' first and last responses as their official "beginning" and "end" points with respect to this analysis, an effective means of answering my 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.

Table 4.1. Campus Travel Survey Questions Asked All 7 Years

Questions		Answer Options	
Dependent Variables	How would you rate your ability to ride a bike?	<input type="radio"/> I cannot ride a bike at all because I do not know how <input type="radio"/> I can ride a bike, but I am not very confident doing so	<input type="radio"/> I am somewhat confident riding a bike <input type="radio"/> I am very confident riding a bike
	To what extent do you agree or disagree with the following statement: "I like riding a bike."?	<input type="radio"/> Strongly disagree <input type="radio"/> Disagree <input type="radio"/> Neutral or don't know	<input type="radio"/> Agree <input type="radio"/> Strongly agree
Independent Variables	What means of transportation do you usually use to travel to campus for school or work?	<input type="radio"/> Walk <input type="radio"/> Skate or skateboard <input type="radio"/> Bike or electric bike <input type="radio"/> Motorcycle or scooter <input type="radio"/> Drive alone in a car (or other vehicle)	<input type="radio"/> Carpool or vanpool with others also going to campus <input type="radio"/> Get a ride <input type="radio"/> Bus <input type="radio"/> Train or light rail <input type="radio"/> Other
	What year are you?	<input type="radio"/> Freshman <input type="radio"/> Sophomore <input type="radio"/> Junior <input type="radio"/> Senior	<input type="radio"/> Fifth-year senior <input type="radio"/> Post-baccalaureate <input type="radio"/> Visiting / exchange student
	Did you transfer to UCD from a college, university, or community college?*	<input type="radio"/> Yes	<input type="radio"/> No
	What is your gender?	<input type="radio"/> Male <input type="radio"/> Female	<input type="radio"/> Other <input type="radio"/> No answer

* Transfer status was not asked in the 2010-11 survey

Table 4.2. Additional Questions Included in the Retrospective Survey in 2016-17

Questions	Answer Options	
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?	<input type="radio"/> Uncomfortable and I wouldn't ride on it <input type="radio"/> Uncomfortable but I would ride on it <input type="radio"/> Comfortable	
Dependent Variables How strongly would you have agreed or disagreed [<i>with the following statements</i>]? <ul style="list-style-type: none"> • "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." 	<input type="radio"/> Strongly disagreed <input type="radio"/> Somewhat disagreed <input type="radio"/> Neutral <input type="radio"/> Somewhat agreed <input type="radio"/> Strongly agreed	
Independent Variables	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)?	<input type="radio"/> 0 <input type="radio"/> 5 <input type="radio"/> 1 <input type="radio"/> 6 <input type="radio"/> 2 <input type="radio"/> 7 <input type="radio"/> 3 <input type="radio"/> 8 <input type="radio"/> 4
	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)?	<input type="radio"/> 0 <input type="radio"/> 5 <input type="radio"/> 1 <input type="radio"/> 6 <input type="radio"/> 2 <input type="radio"/> 7 <input type="radio"/> 3 <input type="radio"/> 8 <input type="radio"/> 4

4.4.5 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 UC Davis) and (b) *riding a bicycle* (either at UCD or at a transfer student’s first college). The retrospective dataset used in these statistical models is comprised of 1,097 undergraduates and a total of 3,950 time points

(the number of observations for those 1,097 undergraduates). I use the retrospective survey responses in two panel models to estimate the influence of these variables over time: difference-in-differences (DID) and latent Markov models (LM) (also called latent transition models or hidden Markov models). I estimate both models because they can be thought of as representing upper and lower bounds, respectively, on the estimates of the causal relationships of interest, given their different representation of the causal process as “static” versus “dynamic” (Angrist and Pischke, 2008; Finkel, 2011a). The DID model is considered static, in that the lagged influence of previous states are not included in the model (i.e. your bicycling motility in the previous time step is not used to explain your bicycling motility in the current time step). 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 DID and LM models, I test the hypothesis that bicycling experiences will improve bicycling attitudes and skills, while exposure will improve bicycling attitudes but not bicycling skills.

4.4.5.1 Difference-in-differences

I estimate difference-in-differences statistical models to test the effects of bicycling exposure and experiences on bicycling attitudes and skills over the course of one year: between the beginning of respondents’ freshman year and the beginning of their sophomore year (see Table 4.3). I chose to only analyze these two years because they permit a natural experiment: the “control group” of transfer students are not exposed to high levels of bicycling during their first year at their community or junior college, while the “treatment group” of four-year UCD students witness first-hand the town and university’s bicycle culture in their freshman year. This analysis is not possible with prospective survey data since transfer students, by their very nature, do not answer

the UCD campus travel survey before they become a UCD student. I therefore rely on the undergraduate students' recalled bicycling attitudes, skills, and behavior during their freshman and sophomore years for this statistical analysis. Because I only use freshman and sophomore year data, the sample is comprised of 1,033 individuals and 2,066 time points (i.e. twice the number of individuals).

DID models are tools of econometric analysis, allowing economists to use observational data to evaluate the influence of policies as part of a natural experiment, such as differences in policy implementation between states (Angrist and Pischke, 2008). Using a continuous dependent variable in a linear regression model, the model's gambit is relatively straightforward: by including a control and a treatment group ($x_i = 0$ and $x_i = 1$, respectively), taking before and after measurements ($x_t = 0$ and $x_t = 1$), and specifying an interaction between the two, the treatment effect can be estimated via the following linear model:

$$y_{it} = \alpha + \gamma x_i + \delta x_t + \beta(x_i \cdot x_t) + \theta x_c + \varepsilon_{it}$$

The coefficient for the interaction term, β , is the association of interest as it can be interpreted as the "true" effect of the treatment, after accounting for the treatment group-specific effect (γ), the common time trend for both control and treatment groups (δ), and the influence of covariates (θ). In this study, I estimate three interaction terms, one for each explanatory variable of interest and a third for their combined influence: time and bicycle use; time and bicycle exposure; and time, bicycle use, and bicycle exposure. I include gender in the model as a time-constant covariate.

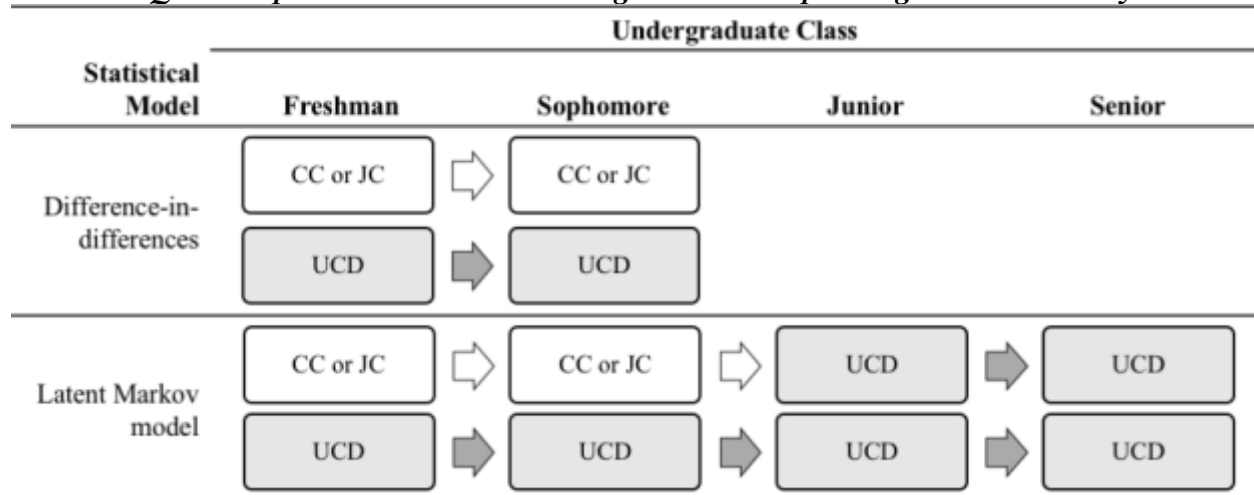
An important assumption driving this model is that the time trend is parallel or identical across control and treatment groups, and that the treatment group's deviation from this common time trend can be identified as the treatment effect. However, since the dependent variables in this study (bicycling attitudes and skills) are ordered categories, I choose to fit ordinal logistic regression models, with cumulative-log-odds links, rather than estimate linear models. And though an ordinal logistic regression is more appropriate for the dependent variables' scales, it is more difficult to interpret the DID model coefficients for such a model. This is due to nonlinear models' violation of the parallel line assumption, in that the marginal effect of any variable is not constant (as in linear models) and instead varies based on the values of other variables (McElreath, 2015). Karaca-Mandic et al. (2012) and Puhani (2008), though, argue that the sign, rather than the absolute value, of the interaction term in a nonlinear DID model can be correctly interpreted as the direction of the average treatment effect on the treated (Karaca-Mandic et al., 2012; Puhani, 2008).

I code the ordinal dependent variables on an ascending scale (i.e. from less positive to more positive pro-bicycling attitudes, increasing bicycling skill), so positive parameter estimates can be interpreted as being associated with higher attitude or skill. I also note that pro-bicycling attitudes were rated on a five-point Likert-type scale, while bicycling skill was assessed on a four-point scale, so the attitude model has four intercepts and the skill model has three. I estimate two Bayesian statistical models, one each for pro-bicycling attitudes and bicycling skill, using the panel data and the *rstan* and *rethinking* R packages (McElreath, 2016; Stan Development Team, 2014).

I only include individuals who provided complete responses to the retrospective questions of bicycling attitudes and skills during freshman and sophomore year (Table 4.3),

yielding a sample size of 2,066 observations across 1,033 individuals. In addition to the indicators of transfer status, bicycle use, and year, I include a set of explanatory variables to explore the influence of individuals’ characteristics and experiences on their pro-bicycling attitudes and bicycling skill (Table 4.2). In both models, I include undergraduate class variables to analyze individuals’ changes in attitudes and skill over time, as well as the personal characteristics of gender and transfer status.

Table 4.3. Quasi-Experimental Research Design and Corresponding Statistical Analyses



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 Latent Markov model 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.

Based on my study hypotheses, I expect the transfer coefficient to have a negative sign in the attitude model and a small or insubstantial value in the skill model, meaning that attending UCD (the “exposure” treatment) had a positive influence on attitudes but no influence on skills. I would expect a positive sign on the freshman bicycle use coefficient in both models, indicating that the bicycle experience treatment had a positive influence on skills and attitudes. And as is logically consistent, I would also expect the combined, interacted influence of these two

variables to be negative (the product of a negative relationship multiplied by a positive relationship) for the attitude model and to be insubstantial in the skill model.

4.4.5.2 *Latent Markov models*

In this study, I use a LM model to test how bicycle experiences and exposure influence undergraduates' bicycling motility via the latent classes estimated through their pattern of responses to the attitude and skill survey questions. Unlike the DID analysis, the LM model uses all of the respondents' data (between 3 and 5 years), which provides a measure of both within and between-subject controls for bicycling exposure (see Table 4.3). This analysis also analyzes skills and attitudes together as a joint measure of motility, using the full set of bicycling attitude and skill survey statements (see Table 4.2). One way to consider the survey items regarding bicycling skills and attitudes is as imperfect measures of an underlying, unobserved (or "latent") construct: *bicycling motility*. Latent variable models were developed to address measurement error by using the joint information provided by multiple observed variables to estimate unobserved constructs (factor analysis is a well-known example of this approach) (Collins and Lanza, 2010) (see Figure 4.1). This study uses latent class models, a version of latent variable modeling in which the latent variable is categorical and therefore comprised of multiple "classes" (rather than a continuous dimension, as in factor analysis). Latent Markov (LM) models (also called "latent transition models") can be seen as longitudinal extensions of a latent class model, using panel data to estimate how individuals may shift, or "transition", between the different classes over time (Bartolucci et al., 2013). These models earned the "Markov" moniker thanks to their relation to Markov models, in which an entity's probability of occupying a certain state depends on their state in the previous time period (Bartolucci et al., 2013).

I estimated the latent Markov models using Latent Gold software (Vermunt and Magidson, 2005). I estimated 10 LM models with nominal latent classes, starting with a 1-class model and working up to a 10-class model (see Figure 4.1 for the model form). The indicators for the latent classes of motility included the nine questions related to bicycling attitudes and skills asked in the retrospective survey (see Table 4.2), each included as an ordinal indicator. In each model, I included variables related to childhood characteristics in the model of initial class membership: 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). And to ensure that I obtained global rather than local maximum model solutions, I ran each model with a set of 10 random parameter starting values and found that only the models with 3 or fewer classes converged to a consistent global maximum. Of these 3 model solutions, I selected the 3-class model due to its superior AIC and BIC and given the classes' ease of interpretation (Collins and Lanza, 2010).

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. Finally, the initial-state model will provide evidence for whether childhood bicycle use predicts early adulthood bicycling attitudes and skills: I hypothesize both associations to be positive.

4.4.6 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 evaluate the extent to which this analysis decision distorts the “true” relationship between behavior and attitudes/skill.

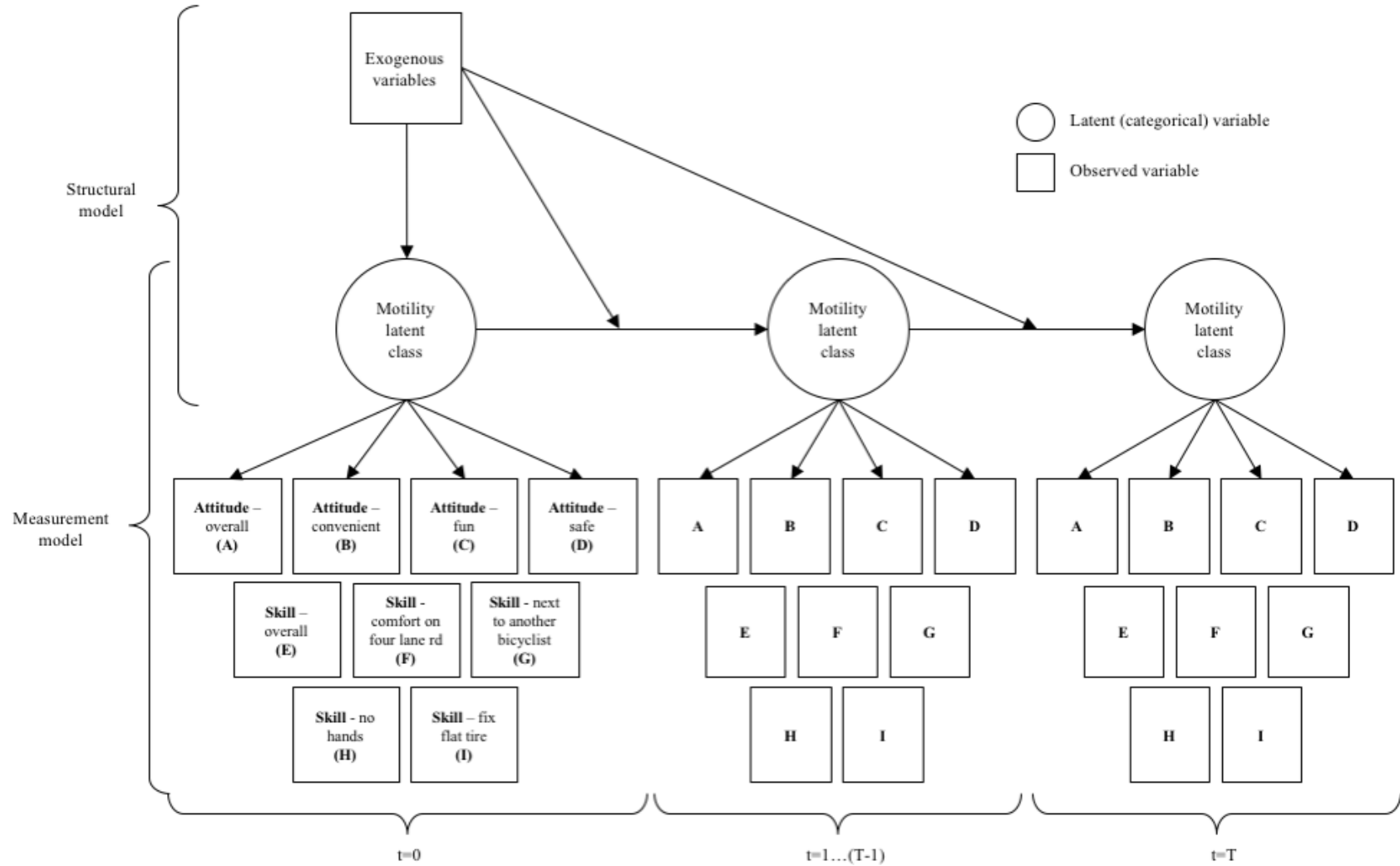
In some cases, the prospective and retrospective panels have different characteristic proportions than their prevalence in the broader cross-sectional and cohort data sets. In most cases the difference is slight, though transfers are an exception to this trend. The panel data has roughly double the proportion of transfer students as the repeat cross-section and cohort samples, which is somewhat surprising, since transfer students have fewer years to in which they might be invited to complete the survey. In all three data sets, undergraduate women are over-represented compared to their overall population proportion, due to their increased likelihood to fill out the campus travel survey. However, this should not substantially bias the model results, as this study is primarily focused on estimating causal relationships rather than seeking to describe the population proportions of these characteristics.

I sought to maximize the construct validity of the questions, particularly those related to the dependent and independent variables, 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 in the prospective panel by asking the additional questions about dimensions of bicycling attitudes and skills in the retrospective survey. 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 0.65, 0.39, and 0.72 for bicycling skills, attitude, and behavior, respectively, which indicate relatively high levels of reliability (Cohen, 1988) (see Appendix E for further details of the analysis of the measurement validity of the retrospective survey data).

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. To account for the possibility of selection bias, I asked about the respondents’ bicycling history before they attended UC Davis and 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.

Figure 4.1. Path Diagram of the Latent Markov Model Structure



4.5 RESULTS

4.5.1 Sample Characteristics

I summarize the characteristics of the samples for the three datasets used in this study in Table 4.4. Female respondents make up roughly 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 one in seven of the repeat cross-section and cohort data set, while they comprised a third and two-fifths of the prospective and retrospective panel data sets, respectively.

For all three 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 other two data sets (Table 4.4).

4.5.2 Descriptive Analysis

In the following figures and tables, 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? Unless otherwise noted, I screen out transfer students in this analysis, as they enter the dataset after freshman year and therefore distort the trends in differences and changes.

The repeat cross-section results show that, even in freshman year, approximately 90% or more of survey respondents indicate that they are at least somewhat confident in their bicycling

skills. Furthermore, the cross-sections consistently display a large increase in the samples' bicycling skill from freshman to sophomore year, and smaller increases in subsequent years. Though the trend is less dramatic, all seven of the repeat cross-sections exhibit declines in the samples' bicycling attitudes (i.e. on average attitudes become more negative), primarily between freshman and sophomore year, with little to no differences in subsequent years (e.g. sophomore and junior year attitudes are similar). Even during senior year, though, when negative attitudes toward bicycling are at their peak in most of the cross sections, 70% or more of the sample holds positive bicycling attitudes.

The cohort analysis replicates the repeat-cross section analyses almost exactly. Freshman tend to begin their college career with positive bicycling attitudes and possess confidence in their bicycling skill, and on average those attitudes decline slightly and their skills improve substantially in the following years. This analysis provides strong evidence that the results of the repeat cross-section are not due to history effects and instead reflect the typical experience of UCD undergraduates.

In the prospective panel, the vast majority of respondents began and ended with the same bicycling attitude (58%) and skill (78%) (see Table 4.5). However, of the panel respondents who changed their skill, twice as many reported increasing their bicycling skill (13%) than reported decreasing (6%). The reverse 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.

Table 4.4. Sample Characteristics of the Three Study Datasets

Variables		Combined datasets		
		Repeat cross-section and cohort	Prospective panel	Retrospective panel
Gender	Male	33	29	31
	Female	67	71	69
Undergraduate class	Freshman	21	33	28
	Sophomore	23	28	28
	Junior	24	22	28
	Senior	24	14	14
	Fifth-year senior	6	3	3
Transfer status	Four-year student	87	71	61
	Transfer	13	29	39
Usual mode to campus	Bicycle	54	51	59
	Other mode	46	49	41
Pro-bicycle attitude ("I like riding a bike")	Strongly disagree	5	5	9
	Somewhat disagree	7	8	11
	Neutral	14	16	21
	Somewhat agree	38	39	32
	Strongly agree	36	31	26
Bicycle skill ("How would you rate your ability to ride a bike?")	Cannot ride	2	3	4
	Not very confident	7	10	16
	Somewhat confident	22	23	25
	Very confident	69	64	55

Note: "Combined datasets" refers to the data collected and pooled across all the campus travel surveys since the 2010-11 school year, which includes all participants (included in the "Repeat cross-section and cohort" analyses, n = 28,011 and 7,100 respectively) and the subset of "Prospective panel" 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).

Figure 4.2. Changes in Bicycling Skill Across the Four Undergraduate Classes, by Repeat Cross-Section (All Seven Study Years), Cohort (the Four Complete Cohorts), and Panel

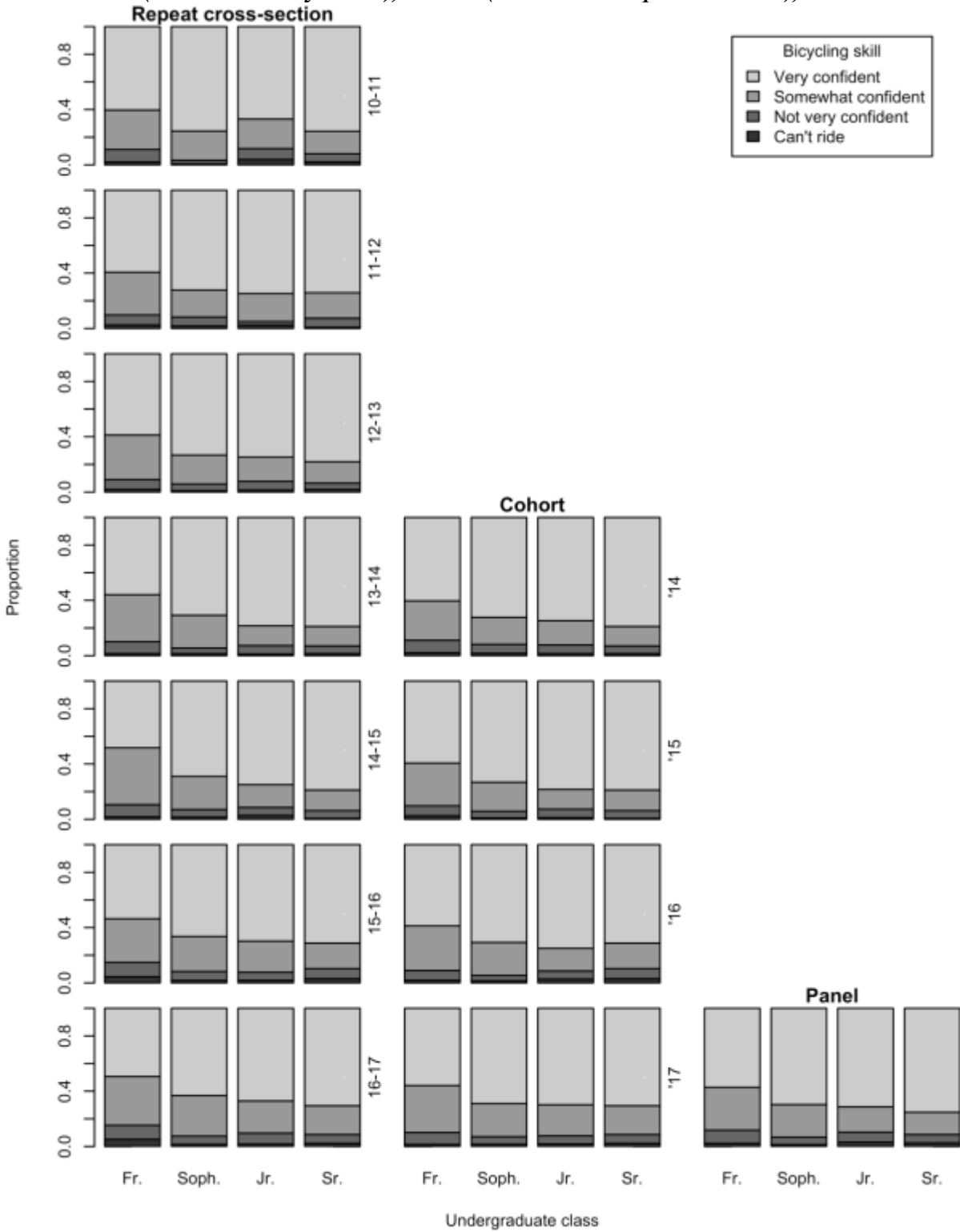


Figure 4.3. Changes in Attitudes Toward Bicycling Across the Four Undergraduate Classes, by Repeat Cross-Section (All Seven Study Years), Cohort (the Three Complete Cohorts), and Panel

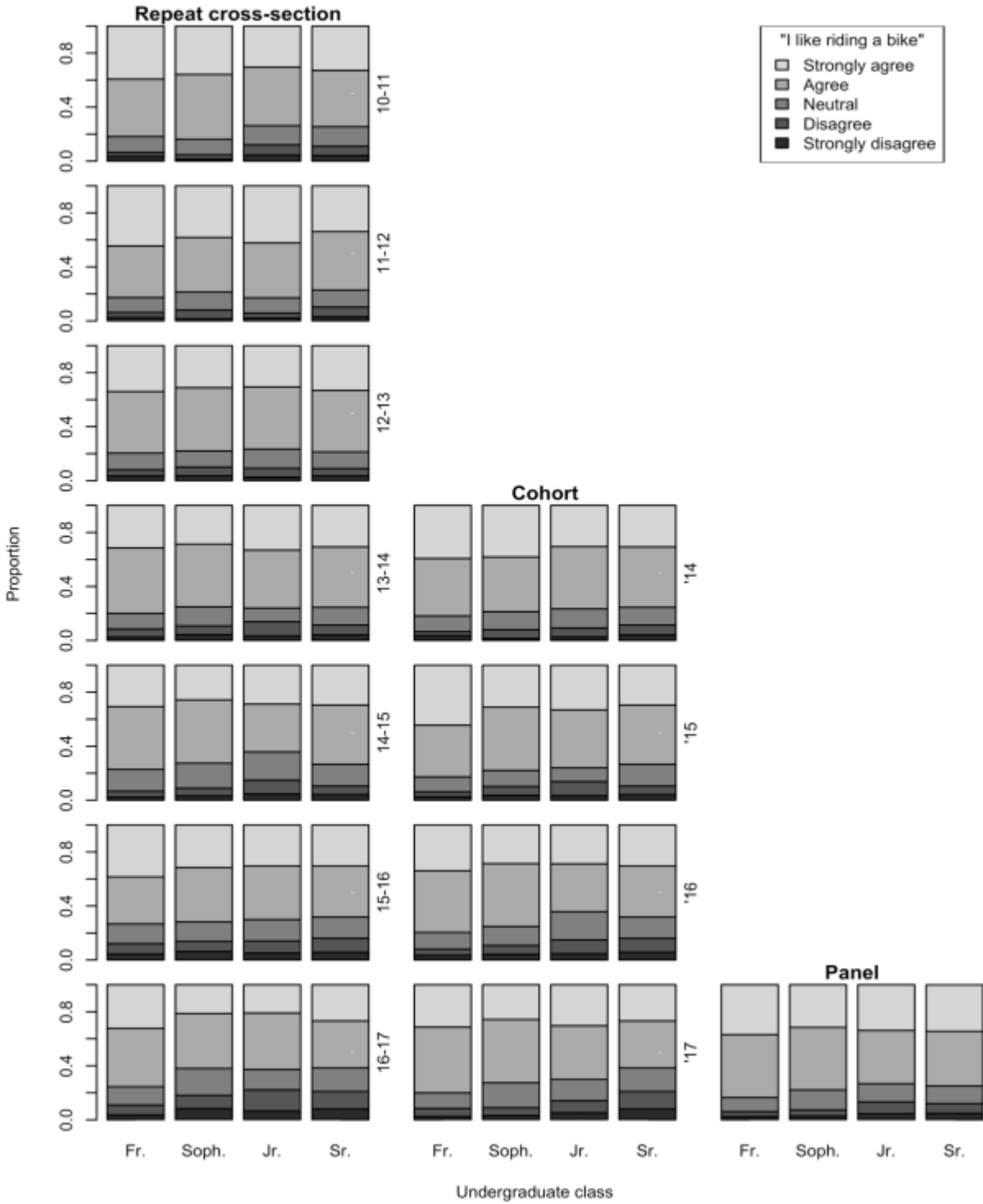


Table 4.5. Percent Change in Bicycling Skill and Attitudes between Individuals' First and Last Observations in Longitudinal Panel (n = 1,648)

		Change in Bicycle Skill						Row	
		-3	-2	-1	0	1	2	3	Totals:
Change in Pro-Bicycle Attitudes	-4	0	0	0	0	0	0	0	0
	-3	0	0	0	1	0	0	0	1
	-2	0	0	0	3	1	0	0	4
	-1	0	0	2	14	2	0	0	18
	0	0	0	3	48	7	0	0	58
	1	0	0	1	11	3	0	0	15
	2	0	0	0	1	0	0	0	1
	3	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0
Column Totals:		0	0	6	78	13	0	0	97

Note: Percentages sum to less than 100% due to rounding.

In sum, all three analyses of the CTS data consistently indicate an increase in undergraduates' bicycling skill across classes and over the course of their time at UCD (Figure 4.2). Within the panel data and on aggregate, the biggest different/increase in bicycling skill appears between freshman to sophomore years, with smaller differences/gains in subsequent years.

In contrast, my analyses display a decrease in pro-bicycling attitudes across undergraduate classes and over the course of individuals' college experience (Figure 4.3). Though in all four undergraduate classes, the majority of individuals hold pro-bicycling attitudes (either "Strongly Agree" or "Agree" they liked riding a bike), the share of individuals holding negative attitudes steadily, though moderately, increased over time.

4.5.3 Statistical Analysis

The descriptive results indicate that, on average, undergraduates' pro-bicycling attitudes tend to decrease over time while bicycling skills tend to increase, though the majority do not change on

these admittedly coarse scales. I now use the statistical models help to explain these patterns by assessing the influence of bicycling experience and exposure on attitudes and skills.

4.5.3.1 Difference-in-differences: Bicycling Attitudes

The difference-in-differences models of bicycling attitude and skill include a covariate (gender), the explanatory variables of interest (bicycle use and exposure), a time term to account for whether the observation was during freshman or sophomore year, and interaction terms to estimate the influence of the explanatory variables over time. Though the interaction coefficients listed in the model results in Table 4.6 are of primary interest, I will briefly interpret each coefficient below. And since these coefficients are difficult to interpret in isolation and as presented in the log-cumulative-odds scale, I have included a posterior probability plot for both the attitude and skill models to more clearly describe the strength and direction of the associations (see Figure 4.4 and Figure 4.5).

Gender has a strong and highly certain association with bicycling attitude, with the coefficient indicating that women are much less likely to report positive attitudes than their male peers.

The coefficient for the time term (“before” vs. “after”, freshman vs. sophomore year) is fairly small and has relatively high uncertainty, suggesting that the temporal trend in attitudes is negligible, though perhaps slightly positive. In contrast, the bicycle use coefficient indicates that use of a bicycle during freshman year is strongly associated with possessing a positive bicycling attitude. But because this is the non-interacted term, it should be interpreted as influencing freshman year attitudes, not as temporal change in attitudes between freshman and sophomore year. Lastly, being a transfer student is confidently though moderately associated with positive bicycle attitudes.

The negative coefficient for the first interaction term, bicycle use and time, can be interpreted as indicating that if an individual had usual ridden a bicycle to UCD as a freshman *and* was now a sophomore, they were less likely to hold positive bicycle attitudes. Though there is relatively high uncertainty in this estimate and interpretation of interaction terms is facilitated by tools like the posterior plots (see Figure 4.4), this particular coefficient provides initial, tentative evidence against the hypothesis that bicycle use would lead to more positive bicycle attitudes.

The second interaction term's coefficient describes the impact of being a transfer sophomore as being weakly negative. Though, weak, this association is in line with the hypothesis that attending UC Davis (and perhaps as a consequence of exposure to high levels of bicycling) results in more positive bicycle attitudes.

The third interaction term describes the interaction of time with both independent variables, effectively to test whether there are synergistic effects of both bicycling experiences and exposure. Contrary to my hypothesis, this interaction term indicates that the combined influence of being a transfer student and riding a bicycle is positive. In other words, a transfer student who bicycled is more likely to have a positive attitude toward bicycling than a UCD student (who bicycled).

Viewing the posterior predictive plot helps make these associations clearer, particularly the interaction terms (Figure 4.4). Each plot's x-axis includes freshman and sophomore year for a particular combination of the two independent variables (bicycle use and transfer status), while holding the covariate of gender at a value of 1. In other words, each plot displays the effect of a particular combination of bicycle use and transfer status for an undergraduate woman. Within each plot, any individual purple line is a random draw from the posterior distribution of the

model, and across the 1,000 random draws they give the aggregate impression of the relative certainty of the model's estimates. Their value on the y-axis represents the probability "cut points" of the ordinal logistic regression model. So, for example, the white space from 0 on the y-axis to the first group of purple lines indicates the probability of answering "Strongly disagree", the white space from the first group to the second group of lines indicates the probability of answering "Somewhat disagree", and so on. The slope of each boundary across the x-axis (left-to-right) therefore represents the influence of moving from freshman to sophomore year for that combination of independent variables. Downward slopes indicate increasing probability of positive attitudes, since the space above the purple line increases.

The top-left plot can be interpreted as the baseline case – the bicycling attitudes during freshman and sophomore year of a transfer student who did not ride a bicycle. The trend-line is almost flat, indicating that these individuals aren't likely to change their attitudes about bicycling between their first two years of college. In both years, "Neutral", "Somewhat agree", and "Strongly agree" (the top three white spaces) all have similar probability of given as a response.

From that top-left plot, looking down to the next row (bottom-left) gives a sense of the effect of riding a bicycle for a transfer student. This plot demonstrates that a transfer student who bicycled to college during their freshman year is more likely to have a positive attitude toward bicycling as a freshman (large space between the top purple line and the 1 value on the y-axis) *and* increases their probability of a positive attitude in their sophomore year, relative to other transfer students who did not ride a bicycle. However, as illustrated by the wide spread of purple lines, there is considerable uncertainty in this association.

The adjacent plot at the upper-right is a four-year student who did not regularly ride a bicycle. Though the slope is modest, these individuals have a small probability of acquiring a more positive bicycling attitude from freshman to sophomore year.

The plot in the bottom-right represents the combined effect of both individual variables: a four-year UCD student who rode to campus regularly during their freshman year. These individuals are very likely to hold a positive attitude toward bicycling, but on average their attitudes toward bicycling decline slightly from freshman to sophomore year.

4.5.3.2 *Difference-in-differences: Bicycling Skill*

As with the discussion of bicycling attitudes, I will first discuss the coefficient estimates of the skill DID model before interpreting the posterior probability plot.

As with attitudes, gender is strongly associated with bicycling skill. The estimate of the DID model indicates that women are substantially less likely to possess strong bicycling skills than their male peers, or at least are less confident in their skills.

The effect of time on bicycling is certain and positive. And just as with the attitudes model, the influence of bicycle use on skills is large, positive, and very certain. Lastly, transfer students are more likely to rate their bicycling skills highly compared to four-year students.

The first interaction term, bicycle use and time, indicates that sophomores who rode their bicycle regularly are somewhat more likely to have better skills, though the estimate is uncertain. The second interaction term, transfer status and time, estimates that transfer sophomore students are more likely to rate their skill poorly. Finally, the third interaction term suggests a moderate negative association between transfer sophomore students who regularly rode their bicycle and bicycling skill.

The upper-left plot of bicycling skill shows minimal probability of change in bicycling skill between freshman and sophomore year for a (female) transfer undergraduate who did not ride their bicycle (Figure 4.5). Transfer students who rode their bicycle regularly (bottom-left plot) were more likely to have high bicycling skills as a freshman and a small probability of increasing that skill in sophomore year. Four-year students who did not ride a bicycle (top-right plot) saw fairly large increases in perceived skill between freshman and sophomore year, and four-year students who rode a bicycle regularly had, on average, the most dramatic, positive shifts in the probability of being confident in their bicycling ability.

Table 4.6. Difference-in-Differences Model Parameter Estimates (log-cumulative-odds scale, $n = 1,033$)

	Pro-Bicycling Attitudes		Bicycling Skills	
	Estimate	SE	Estimate	SE
Intercept #1	-1.90	0.17	-2.77	0.19
Intercept #2	-0.99	0.16	-0.94	0.17
Intercept #3	0.20	0.16	0.42	0.17
Intercept #4	1.62	0.16	-	-
Female	-0.68	0.09	-0.99	0.10
Time	0.22	0.21	0.63	0.22
Bicycle Use	1.44	0.16	1.17	0.16
Transfer Status	0.68	0.16	0.60	0.17
Time * Bicycle Use	-0.40	0.24	0.41	0.26
Time * Transfer Status	-0.19	0.25	-0.56	0.26
Time * Bicycle Use * Transfer Status	0.82	0.44	-0.12	0.48

Note: All models converged with $\hat{R} < 1.01$, number of effective samples > 1000 (see Stan Development Team, 2016) for details of these two convergence metrics), and with Markov chains showing stationarity and good mixing for all parameters. Parameters that exceed the 95% confidence level are highlighted in bold.

Figure 4.4. Posterior Probability Plot of Pro-Bicycle Attitudes by Year (Freshman vs Sophomore), Bicycle Use (“Experience”), and Transfer Status (“Exposure”)

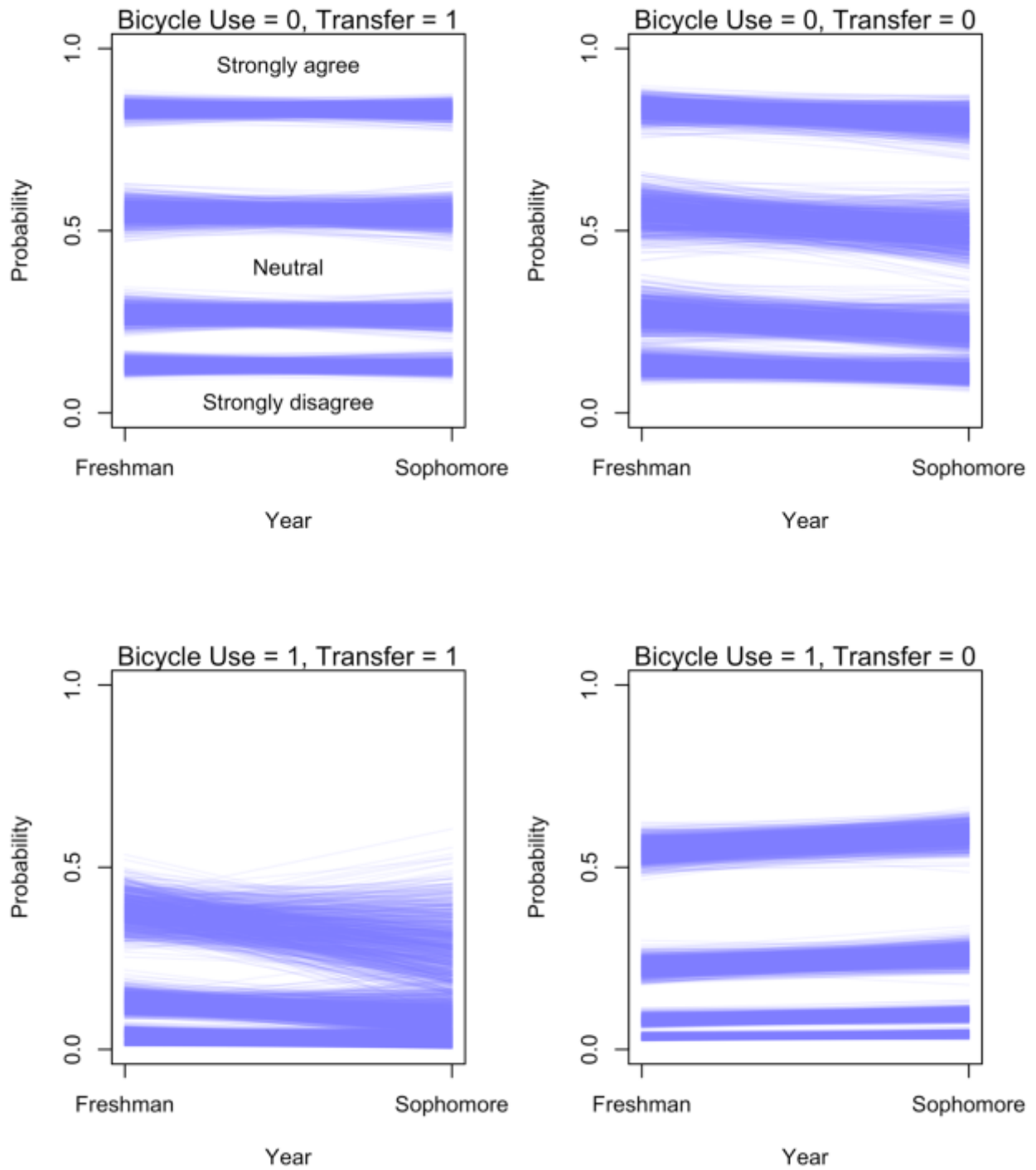
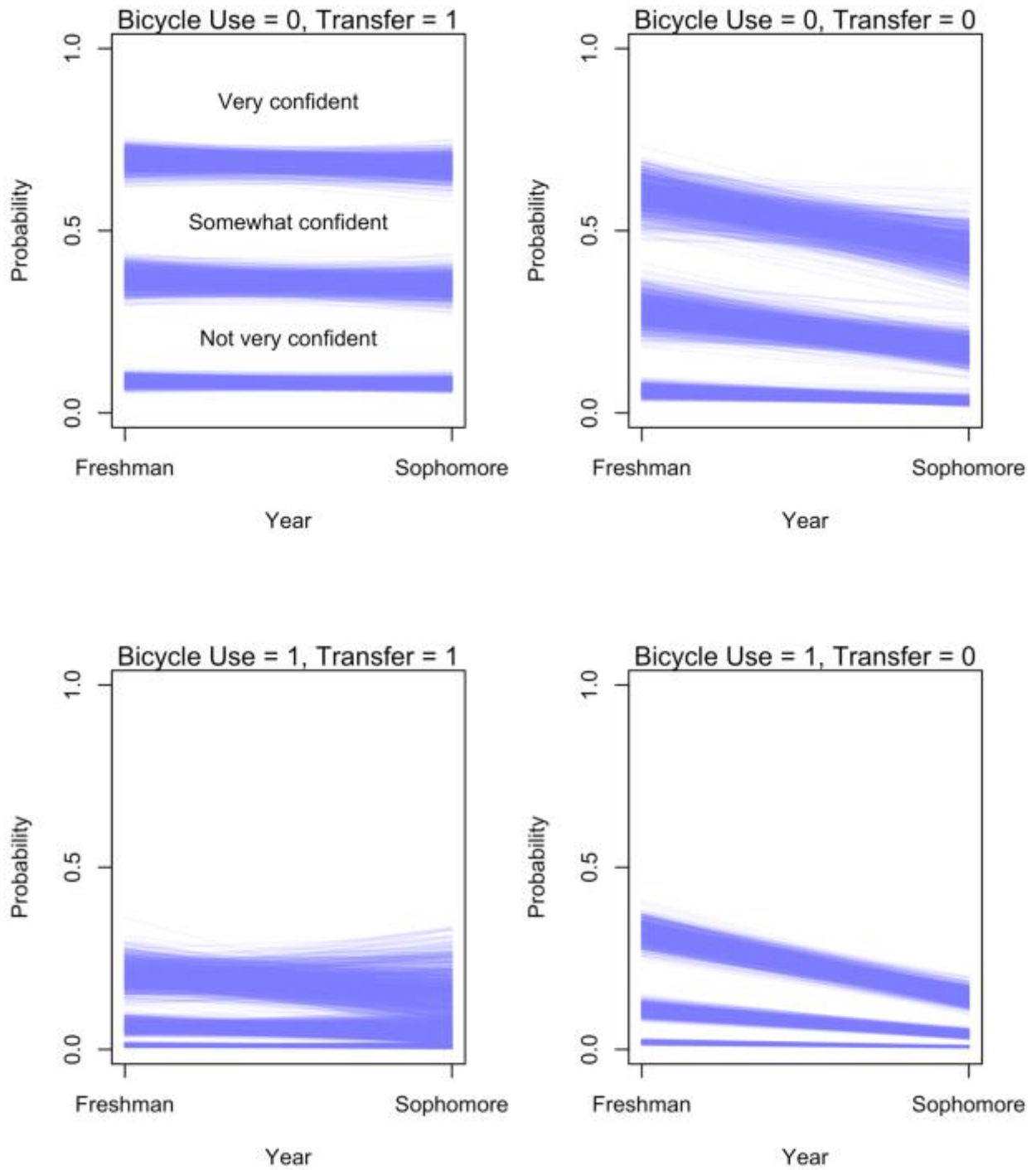


Figure 4.5. Posterior Probability Plot of Bicycle Skill by Year (Freshman vs Sophomore), Bicycle Use (“Experience”), and Transfer Status (“Exposure”)



4.5.3.3 *Latent Markov Model*

As mentioned in the methodology section, I selected the 3-class LM model as optimal. Table 4.7 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.

I labeled the lowest motility class, which comprised about twenty percent of the sample, as “Novice Bike-Phobes”, given their high probabilities of professing discomfort and low confidence in their bicycling skill as well as a strong aversion to bicycling overall. 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.

For the model of initial class membership, I included variables related to pre-college characteristics: regular bicycling during elementary school, regular bicycling during junior high and high school, and the individual’s gender (Table 4.8). The model’s coefficients 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. 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 4.9). 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*.

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.

Many of the undergraduate class coefficients were negative, and some were statistically significant, suggesting that once individuals progress past freshman and sophomore year, they are less likely to transition away from their previous year's motility class. The only exceptions to this trend were the positive (though mostly insignificant) coefficients for transitioning from Skilled Enthusiast to Novice Bike-Phobe and from Expert Aficionado to Skilled Enthusiast.

Table 4.7. Latent Class Profile of the Three-Class Solution (N = 1,097)

		Novice Bike-Phobe	Skilled Enthusiast	Expert Aficionado
Size (%)		21.5	51.3	27.3
Indicators				
Skill	Overall	Not very confident	Very confident	Very confident
	Comfort on 4-lane road	Uncomfortable and would not ride	Uncomfortable but would ride	Comfortable
	Next to another bicyclist	Strongly disagree	Somewhat agree	Strongly agree
	No hands	Strongly disagree	Somewhat agree	Strongly agree
	Fix a flat tire	Strongly disagree	Strongly disagree	Strongly agree
Attitude	Overall	Strongly disagree	Somewhat agree	Strongly agree
	Convenient	Somewhat agree	Somewhat agree	Strongly agree
	Fun	Neutral	Somewhat agree	Strongly agree
	Safe	Somewhat disagree	Neutral	Somewhat agree

Note: The responses listed in the table indicate the mode response for the relevant latent class.

Table 4.8. Initial Latent Class Membership Parameter Estimates

Parameters	Novice Bike-Phobe		Skilled Enthusiast		Expert Aficionado	
	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

Note: Parameters that exceed the 95% confidence level are highlighted in bold.

Table 4.9. Transition Parameter Estimates of Time (x + 1) Latent Class Membership

Time (x)	Transition parameters	Time (x + 1) Latent Class Membership					
		Novice		Skilled		Expert	
		Bike-Phobe	Enthusiast	Aficionado	Estimate	SE	Estimate
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.

4.6 DISCUSSION

4.6.1 Interpretation and Theoretical Implications

In the descriptive analysis, I observe changes in bicycling mobility along two dimensions: decreased pro-bicycling attitudes and increased bicycling skill between undergraduate classes, across cohorts, and within individuals’ college experiences. I then explore possible causes of

these trends using two families of statistical models. Together these models suggest that regular bicycle use, both in childhood and during college, is associated with increased pro-bicycling attitudes and skills. In contrast, the combined evidence indicates that exposure to high levels of bicycling at a bicycle-friendly university has little to no effect on skills or attitudes.

The association between bicycle use and skill is intuitive and also 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. Notably, higher bicycling experience during elementary school years is associated with being a member of the two high-motility classes, while 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 into expert bicyclists. A similar pattern holds in college, where individuals who ride a bicycle are more likely to gain skills and more positive bicycling attitudes.

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 explanations do not fully account for the aggregate pattern of decreasing attitudes across undergraduate classes (freshman to senior), though. One possible explanation for this trend is the novelty of bicycling for newcomers: students arrive as freshmen with optimistic views on bicycling, a symbol of UCD and the city of Davis, but the experience may not live up to their expectations. Alternatively, undergraduates may enjoy bicycling less after they move from on-campus to off-campus housing, a common pattern after students finish their freshman year, and consequently face a longer bicycle commute on city streets. Another possible cause for this aggregate trend is regression to the mean, as individuals with extreme answers may be more likely to return closer to the average response on a second occasion. 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 moderate, aggregate decline in pro-bicycling attitudes (though the pattern could also result from the reverse causal relationship, decreased attitudes to decreased bicycling, too).

In this study and context, the statistical models estimated that exposure to bicycling played little to no effect on bicycling attitudes (or skills, as hypothesized). Perhaps exposure (i.e. descriptive norms) may influence bicycling behavior but not attitudes – individuals may maintain their own personal attitude separate from the predominant social norm (Ajzen, 1991). Though exposure to high levels of bicycling played little to not role in changing attitudes or skills,

context still seemed to play a role. As evidenced in the DID models for both bicycling skill and attitude, transfer students who bicycled were more likely to begin their freshman year with high levels of skill and strongly positive attitudes than their UCD freshmen peers. This would suggest that in college settings where bicycling is not as safe or convenient as in Davis, those who are riding their bikes are those who are already highly skilled and pro-bicycle. The UCD setting, in contrast, may feel safer and offer greater accessibility, thereby providing an encouraging environment to students who are more tentative bicyclists to go for a spin. This finding fits with evidence from several different frameworks of bicycling behavior and behavior change, including the bicyclists typologies proposed by Geller and others (Damant-Sirois et al., 2014; Dill and McNeil, 2016), the Transtheoretical Model of Behavior Change (Nkurunziza et al., 2012; Thigpen et al., 2015), and others.

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).

4.6.2 Policy Implications

The majority of research into the relationship between bicycling attitudes and behavior has focused on the role of attitudes in guiding behavior (Handy et al., 2014). Given the now well-established association between positive bicycling attitudes and bicycling behavior, policy suggestions have consequently 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 adoption of bicycling by the general public?

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. But even if these specific results ultimately are relevant only to the college setting, the trend of decreasing independent mobility among American children suggests that they may have lower motility overall, but especially bicycling, walking, and transit motility. American high school students are more likely than ever to graduate without a driver's license (Sivak and Schoettle, 2011; Thigpen and Handy, 2016), a downward trend that began in 1980 and has continued since. At the same time, elementary school children in the US also bicycle and walk to school at about a quarter of the rate of children in the late 1960s (McDonald et al., 2011). 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. How might UCD and other campuses take an active role in increasing their students' motility – particularly bicycling but also walking and transit? 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. If these programs succeed in causing these sustainable modes to become a habitual behavior, my results indicate that these students would graduate with increased motility. The findings of this study should ideally be replicated in other bicycle-friendly settings (especially those that aren't university cities) as well as focus on other modes of travel beyond bicycling. Furthermore, studies of interventions that incentivize individuals to ride their bicycle on a trial basis should be undertaken.

But why should policymakers attend to the bicycling motility of college graduates? Combined with findings from mobility biography studies (Müggenburg et al., 2015), this study suggests that these young adults' enhanced bicycling motility will be less likely to pose a barrier to adoption of bicycling in other settings when a window of opportunity arises (e.g. moving, household changes, etc.). And if state and regional smart growth policies, like California's SB 375 and SB 743 bring about their intended effects of prioritizing infill development, the number of such windows of opportunity to bicycle may increase, in addition to opportunities to walk and use public transit. This study, combined with previous research, therefore implies that colleges can play a role in ensuring that these increased opportunities are seized by their graduates.

The results also indicate that children who bicycle in elementary and especially junior high or high school are more likely to hold positive bicycling attitudes and possess excellent bicycling skills. This lends additional supporting evidence to the value of programs, such as Safe Routes to School or May is Bike Month, that promote bicycling to school through both "soft"

encouragement efforts and “hard” infrastructure investments (Cairns et al., 2008a), beyond their immediate benefits (e.g. exercise). Yet if ten to fifteen percent of incoming freshmen at UCD are unable to ride a bicycle or do not feel very confident in their bicycling skills, perhaps policymakers can look to the mandatory bicycling education programs of nations like the Netherlands as inspiration for improvement. And beyond schools-level interventions, the role of parents may be just as important, if not more so, given parents’ critical influence over young children’s travel (McMillan, 2005). One possible angle for encouragement efforts would be to emphasize parents’ role as custodians and nurturers of their children’s development, as has been shown influential to mode choice in other research (Murtagh et al., 2012).

4.6.3 Methodological Implications

In addition to its substantive contributions, this study highlights important methodological considerations. By administering a well-designed survey over the course of a decade, the UCD Transportation and Parking Services (TAPS) department and the Institute of Transportation Studies have a rich dataset to evaluate campus programs and policies and to study travel behavior. Furthermore, UCD TAPS is able to cost-effectively obtain the data needed for its sustainability reporting and program evaluation by employing graduate students for survey administration, while the graduate students gain practical experience with survey design and the management of a complex research project. This partnership further benefits UCD transportation researchers through the regular inclusion of attitudinal questions as well as one-off research questions covering topics from skateboarding to social networks to bicyclist stress. UCD TAPS is unique in this regard, though; despite a plethora of college travel surveys across US campuses administered to understand travel demand (Volosin, 2014), little is known about how young people develop travel attitudes and skills during college or the driving forces behind these

personal changes. This may be due in part to the infrequent or irregular nature of many campus travel surveys, or perhaps to the types of questions asked, which are unlikely to focus on psychological factors, unless researchers are also involved. UCD TAPS provides a replicable model for how campus planners and researchers can cooperate to mutual benefit.

The long tenure of the UCD CTS also has drawbacks. In particular, survey administrators are incentivized to maintain existing survey questions or response options, as doing otherwise would break the survey's admirable continuity (Goulias et al., 1991). Fortunately, this has not been a substantial issue with the CTS, thanks to the thoughtful design of its early caretakers. Yet in the case of the CTS' bicycling skill question, an additional response option between "somewhat confident" and "very confident" might have helped survey respondents more accurately describe their level of confidence. However, an analysis of the measurement validity of the retrospective survey data found that respondents were typically proficient at providing answers retrospectively that matched their prospective responses (Appendix E). For campuses considering initiating an enduring travel survey, I therefore advise taking particular precautions with design of the first survey, given the inertia established by the survey questions in subsequent survey administrations.

Future work should more explicitly examine the reciprocal relationship between attitudes, skills, and behavior, ideally through panel models like the cross-lagged model estimated by Kroesen and his co-authors (Kroesen et al., 2017). It may also prove beneficial to examine the consequences of college travel experiences on adult residential location decisions and mode use choices, perhaps as part of a quasi-experimental research design across multiple universities.

4.7 CONCLUSION

Through a layered analysis of several years of the UCD campus travel survey, I find that on aggregate, most UCD undergraduates gain confidence in their bicycling skills by the time they graduate. Surprisingly, though, the overall trend of bicycle attitude change over time is very slightly negative; on average, students graduate with less positive attitudes toward bicycling than they began with as freshmen. To what degree are these changes due to a student's own experience bicycling versus exposure to the bicycling-oriented environment in Davis? According to my statistical analyses, bicycle use is tied to more positive bicycling attitudes and increased skill, while exposure to bicycling has limited influence, if any. This finding contributes to the literature on travel behavior and attitudes, as well as the fields of mobility biographies and motility, by highlighting the role of bicycling behavior in developing positive bicycling attitudes and skills in a setting and time in individuals' lives ripe with opportunity for experimentation and change. Given the value of bicycling to individuals and society, both in the present on college campuses and in the future as adults, campus transportation programs seeking to encourage bicycling may find success by experimenting with programs to encourage all students to ride a bicycle during college, either through education programs or promotions, in order to provide their students with valuable transportation motility.

4.8 ACKNOWLEDGEMENTS

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5 DRIVER'S LICENSING DELAY: THE IMPACT OF ATTITUDES, SOCIAL INFLUENCES, AND INTERGENERATIONAL DIFFERENCES AMONG RESIDENTS OF DAVIS, CA

5.1 ABSTRACT

Young adults currently obtain driver's licenses at a substantially lower rate than previous generations. In a handful of recent studies, scholars have evaluated this trend by investigating the association of various factors, primarily personal characteristics and the built environment, with driver's licensing. However, these studies have examined a limited set of possible explanatory factors and in some cases used only descriptive statistical analyses. To explore the causes of the licensing trend in more depth, this study uses retrospective questions asked of respondents to the 2014-15 UC Davis Campus Travel Survey, an annual online survey of students and employees at the University of California, Davis. I test the influence of an array of explanatory factors on driver's license *possession*, using a binomial logistic model, and on license *timing*, using multilevel survival analysis and censored regression models. The results show that delay in licensing is associated with travel attributes and attitudes, parental influences, and graduated driver's licensing policies. After controlling for these factors, the variables accounting for unexplained cohort influences had a small and uncertain effect on delay. Since I observe generational differences in eagerness to get a driver's license and find that driver's licensing attitudes substantially increase delay, this result suggests that cultural changes may be driving the decreased licensing trend. This generational shift in attitudes may have synergistic effects with policies designed to encourage smart growth and with the proliferation of innovative travel options that provide alternatives to car ownership and use.

5.2 INTRODUCTION

Recent media attention in the U.S. has focused on differences between the “millennial generation”, young adults born between 1981 and 1996 (Pew Research Center, 2014), and previous generations, particularly on their apparent apathy toward car ownership and their delay in driver’s licensing. This shift, if indicative of a permanent rather than transient behavioral change, could have dramatic ramifications for transportation safety and sustainability. According to the National Highway Traffic Safety Administration, motor vehicle crashes continue to be the leading cause of death among 15 to 20 year olds in the United States (National Highway Traffic Safety Administration, 2014). Since increased driving experience more dramatically improves driver safety than increased age and maturity (McKnight and McKnight, 2003), licensing delay to avoid graduated driver’s licensing (GDL) programs’ stringent requirements deserves serious scrutiny for its possible reduction in driver safety. However, licensing delay may also allow teenagers to gain valuable skills and knowledge for how to travel by bike and other alternative modes to the car, with implications for sustainable transportation now and as the teenagers age. For these reasons, it is important for policy makers to understand the causes of the licensing trend.

Though evidence of a shift in driver’s licensing abounds (Delbosc and Currie, 2013a), studies examining causal influences are still few in number. The main explanatory factors featured thus far in studies of driver’s licensing rates have focused primarily on socio-demographic characteristics and the built environment as explanatory variables. The influence of attitudes and the advent of cell phones and other information and communications technology have also received some attention as possible explanations. Some scholars have accounted for the impacts of GDL programs, which seek to reduce teenage driving fatality rates through a

program that gives these teenagers more time to learn how to drive in increasingly independent contexts (National Highway Traffic Safety Administration, 2008). However, as Williams et al. (2012) note, few have focused on parental influences, and even fewer have focused on the influence of previous travel experiences or the social environment. Another notable deficiency in many of the articles on driver's licensing is their omission of cohort effects. Including older age groups helps to provide a built-in comparison and enhances the contextual understanding of the factors behind the observed changes in driver's licensing rates.

This study investigates the factors influencing driver's licensing in the US. I include variables previously shown to influence driver's licensing delay, such as socio-demographic characteristics, technology, and the built environment, and contribute further to the understanding of driver's licensing delay by more deeply exploring cohort effects and including attitudinal variables related to the influence of parents, peers, and the social environment as well as variables related to personal travel patterns in high school. To do so, I used data from retrospective questions asked of respondents in the 2014-15 UC Davis Campus Travel Survey, an annual online survey of students and employees at the University of California, Davis. I asked questions of individuals from four generations to characterize how the current generation differs from previous generations. I use statistical regression models for the analysis, permitting a more complete and robust examination of the associations of interest than the simpler bivariate comparisons used in many of the previous articles on driver's licensing rates. The results suggest that the trend of decreased licensing is being driven primarily by parental influences, travel attitudes, travel attributes, and GDL policies.

5.3 LITERATURE REVIEW

The following section briefly examines the existing evidence for the factors associated with driver's licensing delay, noting which factors are well-established and which areas have room for further exploration. Since there were a wide variety of statistical approaches taken in these studies, and given the methodological extensions I provide in this paper, I also follow with a brief discussion of the statistical analysis approaches.

5.3.1 Findings

I divide the independent variables of interest into five broad groups: socio-demographics, the built environment and travel attributes (e.g. car or bus access), attitudes and norms, graduated driver's licensing laws (GDLs), and cohort and period effects. Fifteen of the 16 studies in this review included socio-demographic variables in their analysis, followed closely by the combined aspects of the built environment and travel attributes, which 10 of the studies covered (see Table 5.1). In contrast, fewer studies analyzed the role of attitudes and norms, GDLs, or cohort/period effects, and, notably, only one of the studies investigated all five influences.

5.3.1.1 Sociodemographic Characteristics

Many of the studies included gender as an explanatory variable, with most finding that women were less likely to hold a driver's license (Berg, 2001; Delbosc and Currie, 2014a; Hjorthol, 2016; Le Vine and Polak, 2014; Licaj et al., 2012; Noble, 2005; Raimond and Milthorpe, 2010). Another consistent finding was that minorities had lower levels of licensing (Brown and Handy, 2015; Shults and Williams, 2013; Tefft et al., 2014; Williams, 2011). These two characteristics are likely indirect indicators of the factors that influence licensing, such as personal preferences or income.

Studies also identified variables that more directly affect licensing. High personal or household income was associated with higher driver's licensing (Berg, 2001; Bohnet and Gertz, 2010; Delbosc and Currie, 2014a; Forward et al., 2010; Le Vine and Polak, 2014; Licaj et al., 2012; Noble, 2005; Tefft et al., 2014), as were higher levels of employment (Delbosc and Currie, 2014a; Hjorthol, 2016; Le Vine and Polak, 2014; Noble, 2005). Proxies for income, such as parental or personal educational levels, also were associated with driver's licensing (Brown and Handy, 2015; Hjorthol, 2016; Le Vine and Polak, 2014).

Though it is possible that individuals' interpersonal relationships and household characteristics could influence driver's licensing, few studies explored these characteristics and the evidence was frequently mixed. For example, living with parents was associated with increased licensing in one setting (Delbosc and Currie, 2014a) and decreased licensing in others (Le Vine and Polak, 2014; Licaj et al., 2012).

5.3.1.2 Built Environment and Travel Attributes

Characteristics of the individual's local built environment and their travel attributes were also examined across many studies. Larger city size and increased population density were consistently associated with lower rates of licensing (Berg, 2001; Bohnet and Gertz, 2010; Hjorthol, 2016; Le Vine and Polak, 2014; Licaj et al., 2012; McDonald and Trowbridge, 2009; Noble, 2005; Raimond and Milthorpe, 2010; Sivak and Schoettle, 2012a; Tefft et al., 2014). Lack of car access was also found to be a key barrier to licensing, both for access to a vehicle to practice with as well as a vehicle to use after gaining a driver's license (Bohnet and Gertz, 2010; Delbosc and Currie, 2014a; Hjorthol, 2016; Licaj et al., 2012; Williams, 2011).

The importance of access to other modes had mixed or counter-intuitive associations with licensing. Two studies found that public transit access decreased the probability of having a

driver's license (Berg, 2001; Bohnet and Gertz, 2010), one found no evidence of an association (Hjorthol, 2016), and a fourth found that it increased the probability of licensing (Le Vine and Polak, 2014). Brown and Handy (2015) found that access to a bicycle increased the probability of licensing, possibly a spurious relationship that could reflect the influence of income. The same study found that individuals who used a bicycle to ride to activities and destinations outside of school were less likely to hold a driver's license, which could be a reciprocal causal relationship.

5.3.1.3 Attitudes and Norms

Researchers have paid less attention to more subjective characteristics, such as attitudes and social influence. Despite the sparse evidence for or against the influence of social and parental influence on driver's licensing delay, further investigation is justified by the literature on travel socialization, which demonstrates the important role parents and peers play in influencing children's travel choices in the present as well as into the future (Baslington, 2008; Driller, 2013a; Johansson, 2005).

Some researchers have speculated that increased environmentalism may be behind the decline in licensing among millennials (Hopkins, 2016). Yet only one of the three studies to examine this factor found it to be associated with licensing (Forward et al., 2010), while the other three found no substantial relationship (Brown and Handy, 2015; Le Vine et al., 2014; Noble, 2005). Instead, the meanings that individuals attach to driver's licensing as a source of freedom and as a rite of passage to adulthood were more consistently found to increase the probability of holding a driver's license (Berg, 2001; Forward et al., 2010). Brown and Handy (2015) explored the role of attitudes toward different travel modes, finding that liking to ride the bus decreased the probability of licensing, while attitudes toward bicycling and being driven had no substantial association.

Studies have found the role of parents to be important in several ways. Parental encouragement increased rates of licensing in two studies (Berg, 2001; Forward et al., 2010), while parents who were willing to chauffeur their child to school and other destinations had the effect of dampening their children's probability of getting a license in another study (Brown and Handy, 2015). Beyond parental attitudes, Tefft et al. (2014) found that limits imposed by parents were not particularly influential in propensity to delay. In contrast, evidence for the importance of friends' attitudes toward driver's licensing is mixed, with one study finding that it was unimportant (Williams, 2011) and another finding friends' attitudes served as a normative pressure to increase licensing (Berg, 2001).

5.3.1.4 GDL Policies

GDL policies impose restrictions on novice drivers in an effort to increase their safety both before and after they acquire a full, unrestricted driver's license. Commonly, GDLs require that new drivers' first driving experiences occur in a supervised setting and that their early experiences driving without supervision occur without the distraction of friends or late at night (Preusser and Tison, 2007). As might be expected, more restrictive policies are associated with lower fatalities rates (Preusser and Tison, 2007). But evidence on the influence of GDL policies, which proliferated as the first millennials were reaching the legal driving age, on driver's licensing rates has suggested that the laws have less of an influence than suspected. Bivariate analyses of aggregate data suggest that delays in licensing preceded the introduction of GDL policies (Raimond and Milthorpe, 2010) and continued to fall after their introduction (Noble, 2005). Later articles, using descriptive analyses of self-reported reasons for delay, also suggest that young adults are not substantially influenced by GDL in their licensing decisions (Tefft et al., 2014).

5.3.1.5 *Cohort and Period Effects*

Many of the studies on licensing delay have been cross-sectional, looking only at individuals within the “millennial” generation, while a smaller number of studies have investigated cohort effects, which are defined as the effects of the “social, historical, and cultural events of any given era” on individuals’ development and behavior (Trzesniewski and Donnellan, 2010). In a series of bivariate comparisons, Noble (2005) used various aggregate data sources to examine potential causes of observed licensing delay across different cohorts, with the earliest cohort born starting in 1968. Delbosc and Currie (Delbosc and Currie, 2013b) used four cohorts of individuals, with the earliest group having birth years starting in 1964. Sivak and Schoettle (Sivak and Schoettle, 2012b) compared age groups using US Census data to show a continuing pattern of delayed licensing. In each study, cohort differences appeared to explain some of the variability in driver’s licensing rates, though only Delbosc and Currie (Delbosc and Currie, 2013b) used individual-level data and accounted for potential explanatory factors simultaneously in a statistical model. When designed carefully, cohort studies can account for both individual differences within a cohort as well as generational shifts in factors such as culture (Trzesniewski and Donnellan, 2010), broadly defined by Richerson and Boyd (Richerson and Boyd, 2005) as “information capable of affecting individuals’ behavior that they acquire from other members of their species through teaching, imitation, and other forms of social transmission.” In contrast, non-cohort studies can only analyze individual differences within a cohort, which precludes the analysis of how temporal changes, like shifts in the economy, attitudes, or culture, might contribute to patterns such as increased driver’s licensing delay.

Research into the influence of millennial-specific factors, such as technological innovations, thus far has returned conflicting results. Though some early literature found that use

of information and communications technology (ICT) was positively associated with delayed licensing (Sivak and Schoettle, 2011), more recent analyses have disputed this result (Le Vine et al., 2013; Tefft et al., 2014; Williams, 2011) and related work suggests that ICT generates social trips (Kroesen and Handy, 2015). And in a study of high school students in Northern California (Brown and Handy, 2015), the results even suggest cell phone owners are more likely to get a driver's license, though this could be an income effect.

5.3.2 Statistical Approaches

Several studies employed bivariate statistics to describe licensing patterns. Four of the six studies evaluated aggregate, nation-wide trends in licensing over time using existing data sources, while the remaining two employed custom disaggregate surveys to identify common barriers to driver's licensing (Forward et al., 2010; Williams, 2011). Though these exploratory papers suggest avenues for future analysis, inferring individual-level influences on driver's licensing from aggregate data is hazardous for a number of reasons, including the possibility of ecological fallacy.

Six of the studies estimated binomial logistic regression models. Five of the studies used the binomial logistic to examine the factors associated with the possession of a driver's license as the binomial dependent variable. The sixth study used the binomial logistic to evaluate the timing of driver's licensing, with two cut-off points framed as a dichotomy: possession of a driver's license within 12 months of state minimum age and driver's licensing before 18th birthday (Tefft et al., 2014).

Table 5.1. Characteristics of Previous Driver's Licensing Studies

Study	Analysis Approach	Dependent Variable	Data Source	Explanatory Variables ¹				
				SD	BE	ATT	GDL	COH
(Forward et al., 2010)	Bivariate Statistics	Possession of driver's license	Random sample of Swedish adolescents	X		X		
(Le Vine et al., 2014)	Bivariate Statistics	Possession of driver's license, by age	Great Britain National Travel Survey	X		X		
(Noble, 2005)	Bivariate Statistics	Possession of driver's license	Great Britain National Travel Survey	X	X	X	X	X
(Raimond and Milthorpe, 2010)	Bivariate Statistics	Possession of driver's license	Sydney Household Travel Survey	X	X		X	X
(Shults and Williams, 2013)	Bivariate Statistics	Possession of driver's license	Monitoring the Future survey of American teenagers	X				
(Williams, 2011)	Bivariate Statistics	Possession of driver's license	U.S. nationally representative random sample	X		X	X	
(Sivak and Schoettle, 2012a)	Linear Regression	Percentage of 20-24 year olds with driver's license	National statistics for 15 countries	X	X			
(Brown and Handy, 2015)	Binomial and Multinomial Logistic Regression	Possession and timing of driver's license	Students from 3 California high schools	X	X	X		
(Delbosc and Currie, 2014a)	Binomial Logistic Regression	Possession of driver's license	Melbourne, AUS household travel surveys	X				X

(Hjorthol, 2016)	Binomial Logistic Regression	Possession of driver's license	Norwegian National Travel Survey	X	X		X
(Le Vine and Polak, 2014)	Binomial Logistic Regression	Possession of driver's license	British National Travel Survey	X	X		
(Licaj et al., 2012)	Binomial Logistic Regression	Possession of driver's license	Lyon, FR Household Travel Survey	X	X		
(Tefft et al., 2014)	Binomial Logistic Regression	Possession of driver's license, by a certain age	Online panel of American 18-20 year olds	X	X		
(Berg, 2001)	Ordinal Logistic Regression	Level of driver's license	Sample of Swedish adolescents	X	X	X	
(McDonald and Trowbridge, 2009)	Rubin's Causal Model	Possession of driver's license, stratified by age	American National Household Travel Survey		X		
(Bohnet and Gertz, 2010)	Survival Analysis	Timing of driver's license	German Socioeconomic Panel	X	X		

¹ “SD” stands for sociodemographic characteristics, “BE” stands for built environment and spatial characteristics, “ATT” stands for attitudes, “GDL” refers to graduated driver’s licensing laws, “COH” refers to cohort/period effects.

One study employed multinomial logistic regression, examining whether a sample of high school students obtained a driver's license "early", "late", or "not at all" (Brown and Handy, 2015). This treatment views the timing of licensing as a potentially important indicator of individual constraints or preferences, but the sample of high school students used in this study constrained the researchers from using a more general statistical model of timing, such as survival analysis. Similarly, another study used an ordinal logistic regression to test how the explanatory variables influenced individuals' licensing level (Berg, 2001).

One study employed Rubin's causal model, a classic econometric approach, to determine treatment effects (in this case the influence of the built environment) through matching between treated and control cases on their covariates (McDonald and Trowbridge, 2009). While sophisticated, this approach is equivalent to the binomial logistic regression models in that it is focused on driver's license possession rather than timing of licensing.

Previous studies relying on available survey data have been limited to using binary measures of license possession rather than of license timing. When available, using a measure of the age at which individuals get their license is available has at least two advantages. First, from an information theory perspective, condensing age-specific data into binary or even several categories represents a loss of valuable information (Singer and Willett, 2003). Second, from a practical perspective, models of driver's licensing timing provide a more nuanced assessment of when and under what circumstances individuals obtain driver's licenses. This is important from a behavioral and policy perspective, as time spent without a driver's license as a young adult is likely to be time spent using or learning to use other modes of transportation, as evidenced in Chapters 3 and Chapter 4 in this dissertation.

Survival analysis is one of the primary statistical approaches to analyze the timing of events (Singer and Willett, 2003), with censored regression representing an alternative approach (Tobin, 1958). To analyze the timing of licensing, one study applied a survival analysis using a German household panel survey, which captured a 25 year period of individuals' lives (Bohnet and Gertz, 2010). This allowed the authors to explore how licensing patterns change across the life course, as influenced by characteristics such as gender and residential location. This appears to be the only study on licensing so far to use survival analysis.

5.3.3 Summary

Many of the studies that feature the most extensive set of explanatory variables analyze their relationship with driver's licensing using bivariate comparisons, limiting the robustness of their findings despite their consideration of many possible influences. And more generally, across both aggregate and disaggregate studies, the driver's licensing literature tends to use pre-existing data sources, such as national travel surveys. Consequently, driver's licensing scholars have been constrained from analyzing how subjective characteristics, such as attitudes, influence licensing.

I seek to add to the burgeoning literature on driver's licensing delay by:

- including a wide range of age cohorts;
- examining the role of attitudes, norms, and cohort effects while accounting for established characteristics – sociodemographic characteristics as well as the built environment and travel attributes; and
- using survival analysis and censored regression models to evaluate the added benefit of analyzing licensing by timing.

5.4 METHODOLOGY

To explore trends in driver's licensing, I administered a cross-sectional survey to a multi-generational sample. I asked retrospective questions about the timing of an individual's acquisition of a driver's license and various personal, social, and built environment factors at that point in the individual's life. Some potentially important factors track generations, particularly the availability of driver's training courses through the high school, cell phone availability, and the existence of graduated licensing laws.

5.4.1 *Data Collection*

Data for this study come from the 2014-15 edition of the annual UC Davis Campus Travel Survey (CTS), which was administered to a stratified random sample of 30,815 students, staff, and faculty over a period of three weeks (Thigpen, 2015). Over 4,200 individuals, about 14 percent of those invited, participated in the CTS. Although the main purpose of the CTS is to gather data on travel to campus, I included a special supplementary section that asked retrospective questions about the respondents' transportation situation during their first year in high school, focusing in particular on driver's licensing (see Table 5.2 or a full list of variables and Appendix D for the survey instrument). I augmented this primary data source with the GDL policy timeline collected by the Insurance Institute for Highway Safety (Insurance Institute for Highway Safety, 2015). GDL policies contain several core components, including supervision, passenger, and driving experience rules and restrictions. Information on gas prices, adjusted to the 2005 US dollar value, was also added to the data set (U.S. Energy Information Administration, 2011). The final, complete-case sample consisted of 1,586 individuals.

The CTS sample includes individuals from a wide range of ages, from 18 to 76, enabling the definitions of cohorts against which to compare the millennial generation (ages 18 to 34 at

the time of the survey). Although all the respondents now work or study at UC Davis, they spent their high school years in a variety of neighborhood types and geographic locations (Table 5.2), which suggests that this study's results could have reasonable external validity.

5.4.2 *Statistical Analysis*

I estimate three distinct models, using the statistical computing language R and the Stan modeling language (R Core Team, 2016; Stan Development Team, 2015), in order to compare the results with previous studies and to test the consistency of the findings across statistical approaches. The first model is a binomial logistic for comparison with previous studies on driver's licensing, and the remaining two models are a discrete-time survival analysis with right censoring and a left- and right-censored linear regression (also known as a "tobit" model (Tobin, 1958)) to examine the timing of licensing (see the "Statistical Models of Driver's Licensing" section for information on coefficient interpretation).

Survival analysis was originally developed in demographic and medical studies to study the timing and risk factors associated with death, which helps explain its name (Bohnet and Gertz, 2010). Because I collected the licensing age data on a year interval, I use a discrete-time survival analysis to examine how the risk of the study's focal event, driver's licensing, varies over time. I estimate a censored regression model as a complement to the survival analysis, as it allows me to specify censoring due to the legal constraints of a minimum licensing age ("left-censoring") and for individuals who have not obtained a driver's license as of the survey ("right-censoring") as part of a model that analyzes the age at which individuals get their driver's license. Researchers have not previously applied left-censoring in this context, but this approach may produce better estimates of the relationship between driver's licensing and the predictor variables (Tobin, 1958).

While the survival analysis and the censored regression models are the focal point of this paper's analysis of the timing of driver's licensing, I included the binomial logistic as a comparison, to examine the extent to which the licensing timing models are in line with the results of the license possession model (i.e. binomial logistic). This allows me to assess whether the associations derived from previous studies' binomial logistic models are in broad agreement with the alternative modelling approaches I take as to which factors most influence licensing.

In the sample, I used varying intercepts (also called random effects) to group the survey respondents by birth cohort and by childhood region, which helps account for shared, unobserved characteristics among those group members. Including these variables in the models either as categorical or continuous predictors, as is traditionally done, would ignore joint information shared between clusters since it effectively treats each cluster as a separate entity. Instead, multilevel models with varying intercepts account for shared characteristics by estimating an intercept for each cluster (i.e. birth cohort or region) but as part of a parent distribution of possible effects (McElreath, 2015).

With a larger dataset, it would be possible to estimate varying intercepts by state and by each birth cohort year, but I have sparse data for older individuals and for people from outside of California. I therefore chose to group birth cohorts by decade and by region (six groups of counties within California (California Department of Social Services, 2002) and a seventh group representing all other locations), which balances the requirements of the models while remaining faithful to the conceptual intent to capture the influence of unobserved factors caused by differences between cohorts and regions when the respondents were 16 years old.

Table 5.2. Description of Variables in the Model (N = 1,586)

Variable	Mean	Range	Survey items
Sociodemographic characteristics			
Gender	0.70	[0, 1]	“What is your gender?” (Male = 0, Female = 1)
Race	Black/Afr.-Amer. = 0.01; Asian = 0.22; White = 0.59; Mexican/Hispanic = 0.10; Amer. Indian = 0.01; Native Hawaiian/Pac. Islander = 0.01; Multiracial = 0.07		“Which of the following best describes your race?”
Parent educational attainment	0.64	[0, 1]	“During your first year in high school, what was the highest level of education completed by whichever parent/guardian had the most education?” (Bachelor’s or Graduate Degree = 1, Other = 0)
Built environment and travel attributes			
Neighborhood type	City nbhd. = 0.17; Suburban nbhd. = 0.57; Small town = 0.17; Rural area = 0.09		“How would you describe the place you lived during your first year of high school?”
CA Region	Bay Area = 0.34; So. California = 0.15; Los Angeles = 0.09; Cent./So. Farm = 0.07; North & Mntn. = 0.05; Central Valley = 0.14; Non-CA = 0.15		“What was your ZIP code at the home you lived in during your first year of high school?” (grouped by California regions for analysis, plus an “other” non-California region for those living outside of California)
Distance to school	6.0	[0, 80]	“About how many miles did you live away from your high school?” (reported in miles, but centered on the mean and standardized by the standard deviation for analysis)

Modes available	Walk = 0.50; Skate(board) = 0.09; Bicycle = 0.41; Car = 0.91; Bus/School bus = 0.49	“What options were available for you to get to school?” (Select all appropriate options)
Usual mode to school	Walk = 0.12; Skate(board) = 0.00; Bicycle = 0.05; Car = 0.67; Bus/School bus = 0.16	“How did you usually travel to school?” (converted to binary variable of car or other mode for analysis)
Primary car access	0.60 [0, 1]	“At the age you could drive in high school, did you have access to a car that you could primarily use?” (No = 0, Yes = 1)
Extra-curricular activities	3.38 [0, 5]	“How many days did you usually participate in after-school activities in school or elsewhere?”

Attitudes and norms

Driver’s license anticipation	0.30 [-2, 2]	“I wanted to get my driver’s license as soon as possible.”
Liked bicycling	0.17 [-2, 2]	“I liked riding a bicycle.”
Liked the idea of driving	0.93 [-2, 2]	“I liked the idea of driving.”
Liked riding the bus	- 0.75 [-2, 2]	“I liked riding the bus or public transit.”
Valued independence from parents	1.11 [-2, 2]	“I valued independence from my parents.”
Friends’ mode to school	0.71 [0, 1]	“How did your friends usually travel to school during your first year of high school? (Car = 1, Other = 0)
Friends’ driver’s license anticipation	0.85 [-2, 2]	“My friends got their driver’s licenses as soon as possible.”
Driving considered the coolest	0.69 [-2, 2]	“Driving was considered the coolest way to get to school.”
Community public transit use	- 0.38 [-2, 2]	“Lots of people took the bus in my community.”
Parents’ commute mode	0.95 [0, 1]	“During your first year of high school, how did you parents travel to work?” (Car = 1, Other = 0)

Parent allowed independent travel	0.73	[-2, 2]	“My parents/guardians allowed me to go places on my own.”
Parent chauffeured	0.90	[-2, 2]	“I could rely on my parents/guardians to drive me places.”
Parents encouraged driver’s licensing	0.73	[-2, 2]	“My parents/guardians encouraged me to get my driver’s license.”
GDL policies			
Unsupervised driving hour restriction	0.85	[0, 1]	Presence of an unsupervised driving hours prohibition (typically late night hours) at time of legal driving age.
Unsupervised passenger restriction	0.81	[0, 1]	Presence of a passenger restriction at time of legal driving age.
Cohort and period effects			
Age	25.2 9	[18, 76]	“In what year were you born?” (Their response subtracted from 2014 to yield their age) (Grouped by decade for statistical analyses)
Cell phone ownership	0.75	[0, 1]	“Did you own a cell phone?” (No = 0, Yes = 1)
Gas price	2.53	[0.29, 3.64]	National average of gas price (inflation-adjusted in 2005 dollars) when respondent was 16 years old.

Note: The mean and ranges reflect the trimmed, unweighted data set for use in the model, which features no missing values. The items with a range of [-2, 2] were asked on a five point Likert-type scale from “Strongly disagree” to “Strongly agree”.

5.4.2.1 Binomial Logistic Model

The binomial logistic model frames driver’s licensing as a binomial, “yes”/ “no”, decision or state. As noted in the literature review, this is the statistical modeling approach most commonly taken in the literature on driver’s licensing. For each individual i , the dependent variable Y takes on the value of 1 if they have a driver's license and 0 if they do not.

$$Y_i = \begin{cases} 1 & \text{if individual } i \text{ has a driver's license} \\ 0 & \text{if individual } i \text{ does not have a driver's license} \end{cases}$$

I then use the logit link to map the linear equation to the probability scale in the binomial likelihood.

$$\begin{aligned} Y_i &\sim \text{Binomial}(1, p_i) \\ \text{logit}(p_i) &= \alpha + \beta \cdot x_i \end{aligned}$$

5.4.2.2 Survival Analysis

In the right-censored discrete-time survival analysis, I estimate a hazard function, which represents the conditional probability that an individual will obtain a driver's license in a particular time period, given that the individual has not yet experienced the event. Individuals are right-censored if they have not yet obtained a driver's license. I identify the minimum legal licensing age experienced by the individual (which varies across states and has changed over time) as the "beginning of time," the point at which everyone in the sample was in the same state of not possessing a driver's license. Each individual i has one record per year j between when they became eligible to obtain a driver's license (e.g. 16 years old) and either (a) got a driver's license or (b) reached their current age without getting a driver's license. Individuals who obtain a driver's license before they reached their current age drop out of the sample after the year of their driver's licensing. The dependent variable Y is therefore formally defined as:

$$Y_{ij} = \begin{cases} 1 & \text{if individual } i \text{ has a driver's license in year } j \\ 0 & \text{if individual } i \text{ does not have a driver's license in year } j \end{cases}$$

I then model the hazard function as a binomial regression with a complementary log-log link on the linear model:

$$\begin{aligned} Y_{ij} &\sim \text{Binomial}(1, p_{ij}) \\ \text{cloglog}(p_{ij}) &= \alpha + \beta \cdot x_{ij} \end{aligned}$$

5.4.2.3 Left- and Right-Censored Linear Regression

The left- and right-censored linear regression model's likelihood reflects censoring from the left (i.e. below), due to driver's licensing laws restricting when an individual can legally obtain a driver's license, and from the right (i.e. above), for individuals who have not yet obtained a driver's license. This approach is also referred to as tobit modelling, though for clarity I use "censored regression" to label the model (Tobin, 1958). In contrast to the survival analysis, which analyzes driver's licensing as a conditional probability at each time period, the dependent variable in this case is the age at which an individual obtained their driver's license. I use a normal likelihood to reflect the continuous-scale timing of driver's licensing, despite the interval censoring imposed by the survey's phrasing, which asked respondents for the age (in whole numbers, an interval scale) at which they got a driver's license. The normal likelihood also has the added advantage over alternative likelihood distributions of permitting imputation of censored cases' future age of driver's licensing. I write the censoring of driver's licensing formally as:

$$Y_i = \begin{cases} \text{minimum licensing age}_i & \text{if licensing age}_i = \text{minimum licensing age}_i \\ \text{licensing age}_i & \text{if current age}_i \geq \text{licensing age}_i > \text{minimum licensing age}_i \\ \text{current age}_i & \text{if no license}_i \end{cases}$$

I model the age of licensing as a linear regression with the identity link:

$$\begin{aligned} Y_i &\sim \text{Normal}(\mu_i, \sigma) \\ \mu_i &= \alpha + \beta \cdot x_i \end{aligned}$$

For the censored observations, I use the cumulative normal distribution and the complementary cumulative normal distribution to increment the log likelihood of left-censored observations and right-censored observations, respectively (Stan Development Team, 2016).

5.4.3 Limitations

The 2014-15 UC Davis Campus Travel Survey sampled individuals who work or study at UC Davis, located in what is widely considered to be a uniquely bicycle-friendly city (Buehler and Handy, 2008). As a result, it is possible that Davis residents are more interested in bicycling than the average American. To address this potential bias due to over-representation of bicycle-oriented individuals, I surveyed undergraduates regarding their reasons for choosing UC Davis over other universities they could have attended: bicycling was the least selected of the seven options provided, academics and affordability being the two most frequently selected (Gudz et al., 2016).

I also assessed the out-of-sample generalizability of the sample to the population of California (see Table 5.3). The survey participants were much younger than the average Californian, as a consequence of the high proportion of undergraduate students in the sample. Due to this age disparity and to changing demographic patterns in California, I examined other sociodemographic traits for 18-24 year olds (the age group of undergraduate students), those aged 25 and older, and all age groups. Because UCD admits more young women than men, and due to women's increased proclivity to participate in the UCD Campus Travel Survey, the sample also has a greater proportion of women than California, for both the 18-24 age group and the 25 and older group. The survey sample is much more representative of the California population with respect to race, with the exception of the proportion of 25 and older individuals who are white in the sample versus the state, the overall under-representation of Black/African-

American individuals in the study, and the over-representation of Asian individuals among 18 to 24-year-olds and under-representation of Asian individuals over 25 years of age. The sample has a substantially greater proportion of Bachelor's and graduate degree-holders than the population of 25-year-olds in California, as a function of the survey setting in a major research university.

Household income is particularly relevant to driver's licensing (Berg, 2001; Bohnet and Gertz, 2010; Delbosc and Currie, 2014a; Forward et al., 2010; Le Vine and Polak, 2014; Licaj et al., 2012; Noble, 2005; Tefft et al., 2014), given the resources required to pass the license test as well as the facilitating effect of shared or primary car access. However, I cannot directly assess the household income of the respondents when they were in high school, as I chose not to include a question about household income during high school due to privacy and memory concerns. But since education is highly correlated with income (Goldin and Katz, 2007), I can tangentially examine the influence of household income levels through the information provided by respondents about the educational attainment of their parents at the time they were in high school. The sample has more families with greater educational attainment (29.7% with a Bachelor's degree and 32.1% with a graduate degree) than the average educational attainment of Californians aged 25 or older. Nevertheless, a substantial portion (38%) of participants had parents who had not received a Bachelor's degree or higher, suggesting that lower-income households were also well represented in the sample.

The previous evidence suggests that the sample is likely to be representative of the California population in some ways (race, attitudes about bicycling) but not in others (age, gender, educational attainment, parental education, household income). However, these differences are less of a concern with this study, as I seek to analyze the factors associated with driver's licensing delay, not estimate population-level patterns of licensing delay. In general, the

statistical analyses' estimate of associations should be relatively unaffected by sample representativeness, unless certain population segments (e.g. the poor or recent migrants) are excluded entirely or make up a very small proportion of the sample and these characteristics have strong effects on driver's licensing. Though this is possibly true of the survey sample, especially with certain races and age groups, it is also important to note that this study focuses on respondents' travel choices during high school. At this point, the overwhelming majority of participants (over 98%) were not yet living in Davis and thus not yet exposed to the unique Davis environment.

Table 5.3. Sociodemographic Characteristics of the Sample Compared to the Population of California (N = 1,586)

	Sample			California		
Age						
25 th percentile		19			15-19	
Median		21			35.8	
75 th percentile		26			50-54	
Characteristics by Age	<i>18-24</i>	<i>25+</i>	<i>Overall</i>	<i>18-24</i>	<i>25+</i>	<i>Overall</i>
Gender						
Female	74.1%	59.2%	69.7%	48.4%	50.9%	50.3%
Race						
White	48.6%	82.9%	58.6%	57.8%	64.0%	61.8%
Black/Afr.-Amer.	1.1%	0.9%	1.0%	6.7%	5.8%	5.9%
American Indian	0.4%	1.3%	0.6%	0.9%	0.7%	0.7%
Asian	28.6%	5.0%	21.7%	12.4%	14.9%	13.7%
Hawaiian/Pac. Islander	0.5%	0.4%	0.5%	0.4%	0.4%	0.4%
Hispanic	12.4%	4.5%	10.1%	-	-	-
Other/Multi-racial	8.5%	5.0%	7.4%	21.9%	14.1%	17.5%
Education						
Bachelor's degree	-	28.1%	-	-	19.8%	-
Graduate or professional degree	-	52.6%	-	-	11.6%	-

Given the absence of longitudinal data on travel attitudes, behavior, and other situational factors for high school students, I relied upon retrospective data. Retrospective surveys are

susceptible to selection bias as well as recall bias (Song and Chung, 2010). Though I could not directly estimate the measurement validity of the characteristics recalled by the respondents, I undertook a separate analysis of UCD undergraduate students' recall accuracy of characteristics from one to four years previous (see Appendix E). I find that the undergraduates' recollections of bicycling behavior and skill level were highly reliable, while their bicycling attitude was less reliably recalled, but still relatively reliable. This indirectly suggests that the answers provided by the participants in this retrospective survey would have relatively high reliability. Though perfect or near-perfect recall would be ideal, this high level of reliability is acceptable, given the empirical evidence demonstrating that people are prone to forgetting even distinctive, infrequent events such as hospitalizations or car crashes (Belli, 1998).

Despite the inevitability of recall error, I attempted to minimize biases introduced by the passage of time in several ways. For example, I restricted the analysis to those individuals who were born in the US to control for exposure to the American transportation system and culture. Older respondents may recall the year they received their driver's license as well as the other retrospective questions with less accuracy than younger respondents (Belli, 1998; Schoenduwe et al., 2015), but the symbolic importance of driver's licensing and driving to individuals of earlier generations (Davis et al., 2012) should help to minimize this recall bias (Teitler et al., 2006), as should its one-off, distinctive nature (Belli et al., 2001). The survey was also structured to aid recall, by beginning the retrospective section with questions regarding concrete, factual attributes (e.g. residential location) that could serve as memory "sign-posts" (Belli, 1998) that help the respondent recall other characteristics of their life during high school. I also anticipated recall difficulties with asking respondents about their parents' income when they were in high school. For this reason, and due to the inherent sensitivity of the topic, I omitted a question on parents'

income in the survey. In its stead, I included a question on parental education attainment, which is likely to correlate with income (Goldin and Katz, 2007).

5.5 RESULTS

I demonstrate using bivariate analyses that, beyond the well-documented decline in driver's licensing across generations, individuals' eagerness to acquire a driver's license has declined as well. I then report the results of the three statistical models, finding that travel attributes, attitudes, parental influences, and GDL policies have strong influences on license possession and timing. After controlling for the other variables in the model, the shared, unobserved cohort characteristics have almost no influence on driver's licensing. The sum of the evidence therefore suggests that generational changes in licensing attitudes play a key role in the observed decline in driver's licensing.

5.5.1 Bivariate Analyses

In addition to the descriptive statistics reported in Table 5.2, I also conducted bivariate analyses to identify important differences in travel attitudes and average licensing delay between different generations, using the R *likert* package to generate figures (Bryer and Speerschneider, 2015). The bivariate relationship between years of delay and generation, defined according to birth ranges (Pew Research Center, 2014), is particularly telling. The percentage of individuals with zero years of delay drops substantially over time, with 60% of the Greatest Generation ($n = 5$), 75% of baby boomers ($n = 97$), 74% of Generation X ($n = 103$), and 46% of millennials ($n = 1,381$) getting their driver's licenses within a year of the legal driving age.

Further exploration of bivariate relationships also indicates that some travel attitudes, though not all, systematically vary across the four generations included in this study. The

difference in eagerness to acquire a driver's license across generations is especially striking. Though a small sample size for the Greatest Generation results in a more uneven distribution across response categories than for other cohorts, the general trend over the generations is an increasing apathy towards driver's licensing (see Figure 5.1, which includes all attitudinal variables except those regarding the descriptive norms or parental influences). I also find increased apathy among millennials toward riding a bicycle and taking public transit, which mirrors recent findings that this generation is simply traveling less than previous generations (McDonald, 2015).

5.5.2 Statistical Models of Driver's Licensing

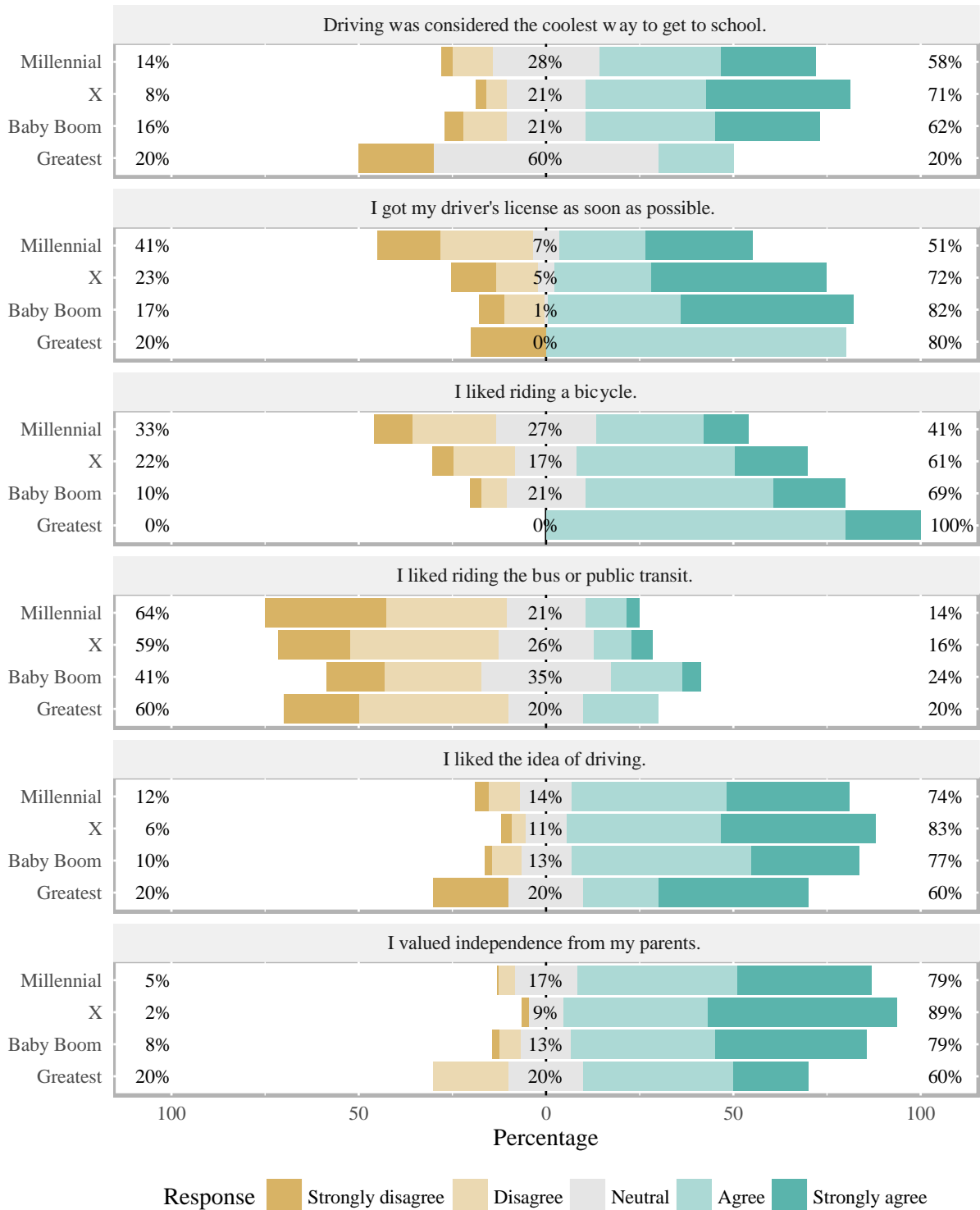
Before examining the models' results, I would like to note differences in interpretation between the three models. The binomial logistic regression tests whether the fact that an individual currently holds a driver's license is related to the suite of explanatory variables, while the survival analysis examines the conditional probability that a respondent will get a driver's license in a given year, conditional on not having gotten a license previously. Interpreting the coefficients for these two models is similar, in that a positive coefficient indicates an individual was more likely to have a license at the time of the survey (binomial logistic) or to get a license in a given year (survival analysis). In contrast, the censored regression focuses on the age at which an individual gets a driver's license, so a positive coefficient should be interpreted as an individual being less likely to get a license at a young age, or conversely more likely to delay getting a driver's license. Therefore, opposite signs for a coefficient between the two models of license timing, survival analysis and censored regression, indicate rough agreement rather than disagreement.

5.5.2.1 Sociodemographic Characteristics

All three models (Table 5.4) suggest that women are more likely to delay driver's licensing or not have a license, though these estimates are highly uncertain in the survival analysis and censored regression as well as the binomial logistic. Each racial category was included in the models except for "White", which was held out as a reference category. In the survival analysis and censored regression models, minority individuals were consistently more likely to delay than a White individual. The binomial logistic model, in contrast, showed mixed and highly uncertain evidence for an association between race and driver's license possession. The literature provides little reason to believe that the pattern observed in the models of driver's licensing delay represents a direct causal link, but this pattern could relate to income disparities among households of different races (Simms et al., 2009), which in turn might indirectly affect the likelihood the household could afford to purchase or share a car with their teenager, a relationship for which the evidence is stronger.

Participants with parent who had high educational attainment, a proxy for household income level, were more likely to own a driver's license and less likely to delay, a moderate, certain finding across all three models. This is consistent with the general finding in the literature that economic factors are tied to driver's licensing delay (Delbosc and Currie, 2014a; Le Vine and Polak, 2014; Shults and Williams, 2013).

Figure 5.1. Generational Differences in Travel Attitudes and Norms during High School (N = 1,586)



5.5.2.2 *Built Environment and Travel Attributes*

Included in the set of travel attribute variables are mode availability, usual mode to school, car access, and participation in extra-curricular activities. The binomial logistic model returned counter-intuitive results for the role of the built environment, suggesting that individuals who lived in a city, suburb, or town during high school were more likely to have a driver's license now than a rural peer, all else equal. In contrast, the survival analysis and censored regression were consistent for high school city and suburb dwellers, showing that they were more and less likely, respectively, to delay getting a license, though with substantial uncertainty for these estimates. This corresponds with the results of McDonald and Trowbridge (McDonald and Trowbridge, 2009), who found that young adults living in areas with high-density residential development were less likely to possess driver's licenses.

The region varying effects identified large differences in licensing: both models of license timing find that individuals from outside of California were much more likely to delay than their California peers. Though none of the California region varying effects' estimates had a high degree of certainty, there was variation across the regions, with individuals from Southern California (excluding Los Angeles), North and Mountain, and Central Valley counties somewhat more likely to get their driver's license quickly, in both models of license timing. This suggests that the region varying effects are capturing unobserved aspects of different regions, perhaps economic, demographic, or cultural, that influence license timing.

Distance from school returned a counter-intuitive result, perhaps due to collinearity with the neighborhood type question: individuals who lived further from school were very slightly more likely to delay licensing, though the estimates for all three models were very uncertain. In contrast, the models agreed that individuals who felt they lived within walking distance of school

were more likely to delay getting a driver's license, with high degrees of certainty in the survival analysis and censored regression. This could reflect the built environment of the respondent's community (independent of the location and neighborhood type variables that the models also included), or could indicate that individuals who have experience walking are more likely to be satisfied with that mode of travel and therefore have less impetus to get a driver's license. Access to other modes of travel to school had small and/or uncertain associations with timing of driver's licensing, though the binomial logistic model returned a large, certain estimate that car access (as a passenger) to school increased the likelihood of driver's license possession.

Respondents who bicycled to high school were less likely to delay licensing than users of other modes. The strongly negative influence of bicycle mode use on license timing raises the possibility that those who bicycled did not do so by choice and thus were eager to get their licenses once they were old enough, at least for those for whom driving to school would be a possibility. This association runs contrary to the results in Brown and Handy (2015), though it should be noted that Brown and Handy's sample included a large portion of teenagers from Davis, CA, where bicycling and income may be positively related and where bicycling may be a feasible and convenient alternative to the car for many teenagers (Buehler and Handy, 2008).

Car access at the minimum age of driver's licensing was a very strong predictor of both timing and possession, though surprisingly with slightly less strength than the association between bicycling to school and driver's license timing and possession. The causality could flow either way: those individuals who immediately got driver's licenses may have been more apt to purchase a car or have a car purchased for them, or those individuals who purchased a car or were otherwise given access to a car may have acquired a driver's license more quickly than they otherwise would have. At the very least, this association suggests that car access at the

respondents' legal driving age is an important factor in accelerating the process of gaining a driver's license.

The models concur that an individual who typically had many days of after-school activities was somewhat more likely to obtain a driver's license early. This is consistent with Brown and Handy (2015); the convenience afforded by a personal automobile would likely make travel for these individuals (and their parents) much easier, perhaps explaining their decreased probability of delay.

5.5.2.3 Attitudes and Norms

The models also test the associations between driver's licensing and attitudes about travel and independent mobility. The strongest and most certain association is with the respondents' recollection of their eagerness to acquire a driver's license: across all three models, those who wanted to get a license as soon as possible were (unsurprisingly) much more likely to hold a driver's license and less likely to delay. Consonant with Underwood et al. (2014), individuals who recalled enjoying riding a bicycle and using public transit were slightly more likely to delay than average, though this association is not observed as clearly in the binomial logistic model of license possession. Those individuals who valued independence from their parents were less likely to delay, though this association was relatively uncertain in the survival analysis and censored regression. And while eagerness to get a driver's license had a strong relationship with licensing, the association between liking the idea of driving and license possession or delay was tenuous. This suggests that teenagers want to get their license for symbolic reasons (Berg, 2001; Forward et al., 2010) or to gain access to a new mode, even if they weren't particularly excited about the act of driving.

I tested the influence of the social environment using variables pertaining to the respondents' friends and community during their high school years. The models did not find evidence for social influence via friends' behavior or attitudes. Neither friends' modes to school nor their eagerness to acquire a driver's license influenced the probability of an individual's delay. In contrast, the survival analysis found evidence for the influence of broader social norms about driving: individuals who felt that driving was considered to be the coolest way to get to school by their peers were somewhat less likely to delay driver's licensing, similar to Berg's (Berg, 2001) findings. These broader social norms also seemed to play a role for individuals living in communities they considered to be reliant on public transportation; across all three models these individuals were found to be slightly more likely to delay licensing.

The parental influence coefficients indicate that parents influence their teenager's behavior and decisions through the rules and examples they set, consistent with Johansson's (Johansson, 2005) findings. Individuals whose parents allowed them to travel independently were more likely to delay (though this association was only highly certain in the censored regression). Parents' attitudes toward driver's licensing (as reported by the respondent) was also of some importance: teenagers whose parents encouraged them to get a driver's license were less likely to delay, though this association is uncertain. All three models also find a negligible and uncertain association between parents' willingness to chauffeur their child to different activities and their probability of licensing delay. The models found moderate-to-strong, certain associations for individuals whose parent(s) usually drove a car to work and higher probability of driver's license possession and timing.

Table 5.4. Coefficient Estimates for Driver's Licensing Possession and Timing (N = 1,586)

Variables	Binomial Logistic		Survival Analysis		Censored Regression	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Intercept	3.66	0.71	-0.48	0.3	17.24	0.99
Gender	-0.43	0.3	-0.06	0.07	0.28	0.23
Race: Black/African-American	-1.84	0.65	-0.67	0.3	1.26	0.71
Race: Asian	0.29	0.31	-0.19	0.08	0.51	0.24
Race: Mexican/Hispanic	-0.73	0.37	-0.57	0.11	1.35	0.32
Race: American Indian	0.45	0.88	-0.29	0.34	0.29	0.76
Race: Native Hawaiian/Pacific Islander	0.71	0.81	-0.22	0.37	0.24	0.76
Race: Multiracial	-0.34	0.42	-0.2	0.11	0.38	0.33
Parent educational attainment	0.88	0.29	0.21	0.07	-0.4	0.21
Neighborhood type: City	0.74	0.47	-0.01	0.14	0.45	0.39
Neighborhood type: Suburb	1.09	0.44	0.2	0.12	-0.23	0.34
Neighborhood type: Town	0.53	0.48	0.15	0.13	0.35	0.37
Distance from home to school	0.27	0.17	0.01	0.03	-0.01	0.1
Modes available: Walking	-0.32	0.31	-0.22	0.08	0.52	0.24
Modes available: Skate(board)	-0.56	0.38	-0.11	0.11	0.04	0.33
Modes available: Bicycle	-0.2	0.33	0.07	0.08	-0.06	0.24
Modes available: Car	1	0.42	0.14	0.12	-0.36	0.34
Modes available: Bus/School bus	-0.13	0.29	0.03	0.07	-0.26	0.22
Usual mode to school: Car	-0.34	0.38	0.01	0.11	-0.15	0.3
Usual mode to school: Bicycle	1.6	0.67	0.49	0.16	-1.16	0.46
Usual mode to school: Bus/School bus	0.28	0.47	0.2	0.13	-0.37	0.39
Primary car access at 16	1.01	0.33	0.5	0.07	-1.11	0.23
Extra-curricular activities after school	0.19	0.07	0.05	0.02	-0.18	0.05
Wanted to get their driver's license as soon as possible	1.09	0.17	0.5	0.03	-1.5	0.09
Liked bicycling	-0.2	0.12	-0.1	0.03	0.18	0.09
Liked the idea of driving	0.19	0.13	-0.01	0.03	-0.15	0.11
Liked riding the bus	-0.11	0.12	-0.05	0.03	0.19	0.09
Valued independence from parents	0.27	0.15	0.06	0.04	-0.15	0.13
Most friends driven to school	0.14	0.29	-0.03	0.08	0.13	0.24
Friends got their driver's license as soon as possible	0.04	0.13	-0.05	0.03	0.12	0.11

Driving was considered the coolest way to get to school	0.02	0.13	0.1	0.03	-0.03	0.11
Wide-spread public transit use in their community	-0.16	0.12	-0.03	0.03	0.21	0.1
Parents' commute by car	1.2	0.44	0.02	0.15	-0.13	0.4
Parents allowed independent travel	-0.06	0.11	-0.04	0.03	0.22	0.09
Parents chauffeured to activities	-0.14	0.14	-0.02	0.03	0.03	0.1
Parent encouraged driver's licensing	0.13	0.13	0.05	0.03	-0.16	0.1
GDL - unsupervised driving hour restriction	-0.01	0.69	-0.29	0.24	0.61	0.56
GDL - unsupervised passenger restriction	0.15	0.64	-0.56	0.24	-0.31	0.52
Cell phone ownership	-0.23	0.36	-0.16	0.09	0.28	0.28
Gas price	-1.23	0.22	-0.02	0.06	-0.02	0.19
Time	-	-	-0.09	0.01	-	-
Sigma	-	-	-	-	3.06	0.09
Varying effects' standard error by decade cohort	-	-	0.25	0.15	0.5	0.38
Varying effects' standard error by US region	-	-	0.3	0.13	1.2	0.56

Note: The three models' coefficients are on different scales. The binomial logistic regression coefficient estimates are log-odds ratios, the survival analysis coefficients are hazard odds ratios, and the censored regression coefficients are on the natural scale (i.e. continuous). The outcomes of the models also have different substantive meaning, but a positive coefficient in the first two models (binomial logistic and survival analysis) is roughly equivalent to a negative coefficient in the third model (censored regression).

5.5.2.4 GDL Policies

Both models of license timing found that GDL policies increase the probability of licensing delay. However, evidence for the influence of *particular* restrictions of GDL policies was mixed, likely due to strong collinearity (i.e. GDL policies tend to be adopted as a bundle of restrictions). Notably, the binomial logistic model returned null associations between GDLs and license possession, while the survival analysis and censored regression models estimated coefficients with larger magnitudes. This suggests that previous studies may have under-estimated these policies' influence due to their statistical methodology (Noble, 2005; Raimond and Milthorpe, 2010; Tefft et al., 2014). This seems logical, as GDLs may delay driver's licensing but don't prevent it from occurring after the age at which the GDL restrictions no longer apply – often at age 17 or 18 (Insurance Institute for Highway Safety, 2015). However, only one of the GDL

coefficients has a high degree of certainty: the influence of passenger restrictions in the survival analysis.

5.5.2.5 Cohort and Period Effects

The influence of novel technological advances, changing economic conditions, and other exogenous time-related factors are considered cohort or period effects (since I am looking at the influence of these characteristics at age 16, cohort and period effects are effectively the same thing). Note that I have given GDL policies, also a cohort effect, its own treatment in the previous section for sake of clarity between direct impacts on licensing and mediated or moderated influences on licensing. I examined two factors that are strongly correlated with cohort: cell phones, and gas prices.

An individual who owned a cell phone as a high school student was more likely to delay obtaining a driver's license or not have one at all, though the estimates in all three models are uncertain. Older cohorts did not have cell phones available, so this result speaks more directly to the effect of cell phone ownership on younger cohorts. This association suggests that cell phone use and travel demand serve as mild substitutes rather than complements, in contrast to the findings of Tefft et al. (2014) and Brown and Handy (2015), though this deviation could be due to the collinearity between cell phone availability and cohort membership.

According to the censored regression and survival analysis models, the influence of inflation-adjusted gas prices when the respondents turned the minimum licensing age had little to no effect on timing of licensing. In contrast, the binomial logistic model found that higher gas prices had a strong negative effect on possessing a driver's license.

The survival analysis model also includes a time term to account for increases or decreases in licensing probability as an individual ages. The coefficient is small and negative,

indicating that, conditional on having already delayed getting a license, individuals become increasingly likely to continue to delay as time passes, all else equal.

Finally, the cohort varying effects terms indicate that after controlling for the above-mentioned variables, a small amount of difference remains between age cohorts (see Figure 5.2). The varying effects in both the survival analysis and the censored regression models are moderate, and in both cases the estimates have large uncertainty.

5.5.2.6 Model Fit

I assess the three models' goodness of fit using McFadden's rho-squared, a statistic ranging between 0 (worst) and 1 (best) that can be interpreted as a measure of the additional proportion of information accounted for by the full model compared to a benchmark model (Mokhtarian, 2016). I used a "market-share" model, estimated just with an intercept, as the benchmark model for comparison. McFadden's rho-squared was designed for discrete choice models, and interpretation of the statistic is difficult even when applied to these models, since the value of the statistic is dependent on the study context, especially the relative distribution of the market share of the alternatives. And though McFadden's rho-squared can be estimated for other types of models (including survival analysis and censored regression/tobit models), the statistical literature indicates that these figures should be interpreted with even more caution (e.g. survival analysis McFadden's rho-squared statistics can theoretically exceed 1 and censored regression McFadden's rho-squared statistics are typically very low) (Veall and Zimmermann, 1994). Furthermore, the three models do not all use the same likelihood function, which may make it difficult to compare their goodness-of-fit statistics. Due to these factors, I report all three models' McFadden's rho-squared statistics but focus primarily on the goodness-of-fit of the binomial logistic regression.

The binomial logistic model has an unadjusted McFadden's rho-squared statistic of 0.46 with a market-share base, the survival analysis has a 0.27, and the censored regression has a 0.04. Though guidelines vary regarding the levels at which this goodness of fit statistic can be deemed "good" or sufficient, the binomial logistic model's rho-squared value exceeds 0.3, a benchmark heuristic for the market-share base (Mokhtarian, 2016). This suggests that the binomial logistic regression explains a substantial proportion of the information in the data relative to the naïve, null model. Based on previous empirical work, the low McFadden's rho-squared value for the censored regression was anticipated (Veall and Zimmermann, 1994).

5.6 DISCUSSION

My results demonstrate that modeling *possession* of a driver's license yields small but important differences compared to the models of driver's license *timing*. When compared to the models of license timing, the model of license possession understated the delay in licensing among minority individuals and those exposed to GDL policies, found associations with neighborhood type contrary to the literature, and overstated the role of gas prices. In addition, generational differences in licensing attitudes also appear to play a key role in the decline in licensing. These associations have important implications for equity as well as traffic safety and urban planning policy.

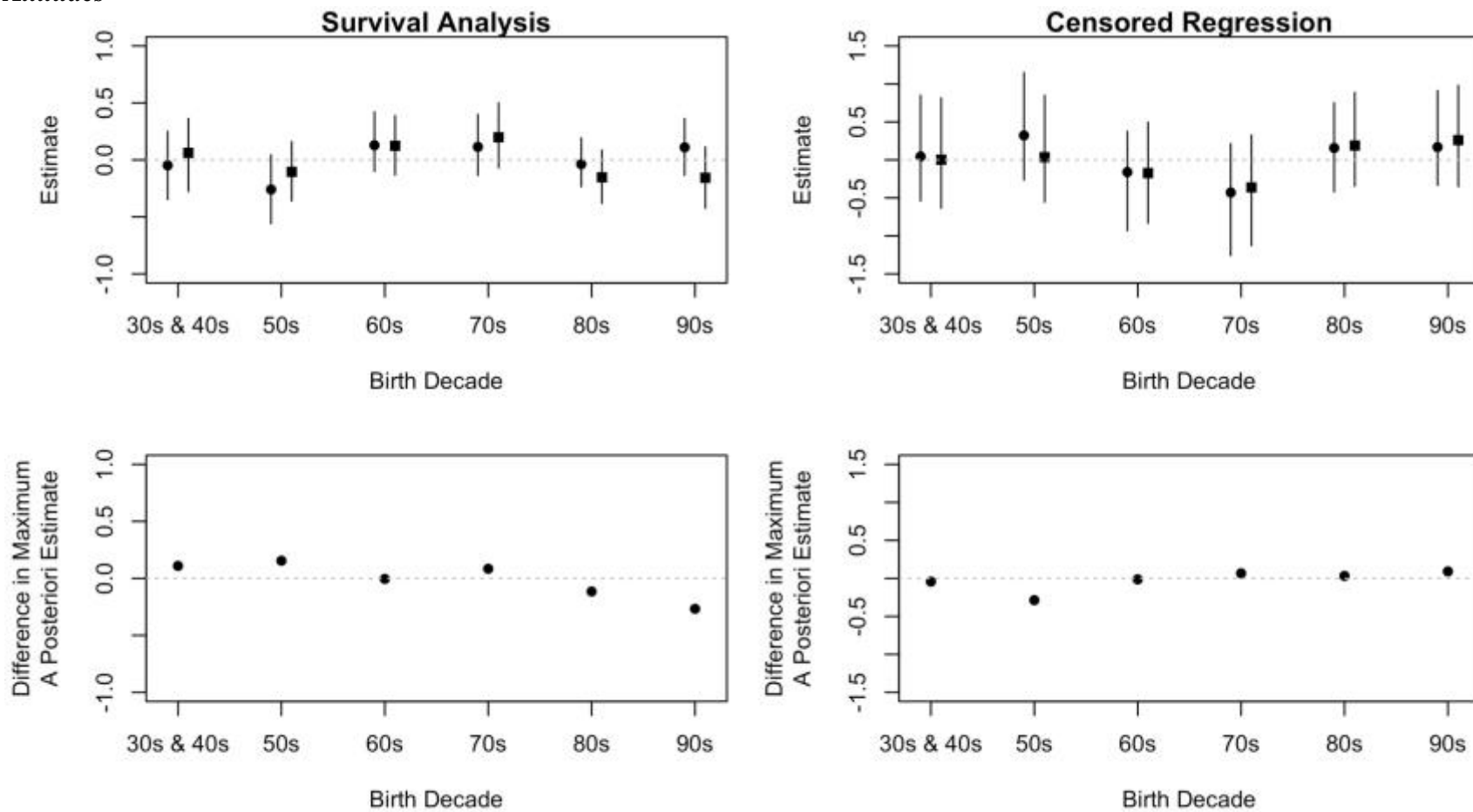
Finding moderate effects of GDL on delay runs contrary to the literature, in which previous studies found little evidence that these policies influenced license possession. My results suggest that young people are delaying licensing (either to avoid GDL requirements or because the license is less valuable to them without the ability to drive with young passengers and/or at night) and then obtaining a license soon thereafter. Although both experience and maturity influence driver safety (Mayhew et al., 2003), experience has been found to be the more

important of the two (McKnight and McKnight, 2003). Therefore, perhaps GDLs are having a split effect: teens who go through GDL-required training gain experience in safe settings, while those who wait out the GDL may be more prone to crashes. The latter effect, if strong enough, might argue against GDL policies. Yet simultaneously, waiting to avoid the GDL requirements may yield co-benefits of increased time spent developing skills and knowledge for how to travel by other modes like transit or bicycle, as suggested by Chapter 3 and Chapter 4 of this dissertation. And as both the model indicates and other studies corroborate (Hjorthol, 2016), decreased licensing among individuals at an early age makes them more likely to delay further, presumably traveling instead by alternative modes of transportation. Though further evidence should be gathered regarding the travel patterns of those who delay licensing, policymakers will want to carefully weigh the possible benefits and downsides of the delays caused by GDL policies.

This study also notably finds that cultural change may also be at play: eagerness to acquire a driver's license proved one of the most potent predictors of licensing in the model, and this eagerness has declined across generations (Figure 5.1). Furthermore, the cohort varying effects' 95% confidence intervals all cross 0, indicating that after accounting for the other variables in the model (including attitudes), the unobserved characteristics shared by each cohort do not provide much additional explanatory power. This "cultural change" hypothesis (not necessarily related to environmental attitudes (Le Vine et al., 2014)) is supported by re-estimating the survival analysis and censored regression models without personal attitudes (i.e. "I wanted to get my driver's license as soon as possible.", "I liked riding a bicycle", "I liked the idea of driving.", "I liked riding the bus or public transit.", and "I valued independence from my parents.") and comparing the cohort varying effects of this reduced model with the full model.

When I remove personal attitudes from the model, the varying effects for those born in the 1980s and 1990s (millennials) shift in the direction of increased delay (more negative in the survival analysis and more positive in the censored regression), while the estimates for those born prior to the 1980s stay steady or shift in the direction of decreased delay (see Figure 5.2). In other words, even after accounting for all the other explanatory variables, personal attitudes still show a marked and influential difference by generation, with millennials less likely than previous generations to possess influential attitudes such as wanting a driver's license as soon as possible. In contrast, the influence of macro-economic factors, operationalized through the inclusion of gas prices at age 16, had small, uncertain effects on license timing, *ceteris paribus*. These findings adds further nuance to evidence from other studies that suggests that changed or delayed life stages or economic circumstances among millennials may be the true driving force behind driver's licensing delay (Delbosc and Currie, 2014b).

Figure 5.2. Varying Effects by Cohort for the Survival Analysis and Censored Regression Models, With and Without Personal Attitudes



Note: In the first row of plots, the round point represents the varying effect estimates with personal attitudes included in the model, and the square point represents without personal attitudes included in the model. The second row of plots displays the difference in the *Maximum A Posteriori* cohort varying effect estimates between the model without personal attitudes and the model with personal attitudes (i.e. the effect of dropping personal attitudes from the model).

This study also contributes to the sparse evidence regarding parent and social influence on driver's licensing. Broader social norms of licensing as "cool" or "uncool" seemed to have a greater influence on licensing delay than the behavior or attitudes of friends specifically, matching previous studies' findings (Berg, 2001). Unlike eagerness to license, though, these social norms do not appear to vary systematically across generations (Figure 5.1). This study also confirms previous findings that parental encouragement speeds up teenagers' licensing. The inverse also seemed to hold true: if parents allowed their teenagers to travel independently prior to the minimum licensing age, they were somewhat more likely to delay, suggesting that they could fulfill their mobility needs via other modes. Like the effects of GDL policies, this could also be an important avenue for teenagers' development of the skills and knowledge necessary to travel by alternative modes to the car.

Despite the notable differences between the timing and possession models regarding the influence of GDL policies and a few other variables, overall the three models yield comparable results more often than they disagreed, suggesting that most of the literature's previous findings would hold up if re-analyzed by license timing rather than license possession. For example, the importance of travel attributes and attitudes is re-affirmed in this study. It is worth highlighting that, in fact, some of these variables had greater influence on license timing than the more headline-grabbing characteristics such as GDL policies. Since how an issue is framed or posed can influence both behavior and policymaking, the findings regarding travel attributes and attitudes should ideally be given equal attention alongside the findings that focus on more novel aspects or traits.

Though some of the results of the timing models matched those of the possession model, the statistical approaches of survival analysis and censored regression warrant further replication.

To enable replication, future surveys must include questions that yield information-rich variables: rather than ask, “Do you have a driver’s license?” (yes/no), instead query: “At what age did you get a driver’s license?”, which contains the former question as a subset of its information. Given the additional richness in understanding licensing behavior and its relevance to policymaking, this easy adjustment could yield further insights. And while this adjustment could be easily applied to both large public surveys and original surveys, adding attitudinal questions to original surveys would allow a better understanding of how subjective factors influence this important mobility decision.

5.7 CONCLUSION

This retrospective study confirms previous findings regarding the influence of travel attributes on driver’s licensing and suggests that popular and intuitive explanations, such as the proliferation of cell phones, may not fully explain the observed differences in driver’s licensing rates. GDL policies have also been put forth as an explanation for the increased delays in licensing, and the results show that these programs play an important role in licensing delay, contrary to previous research (Tefft et al., 2014). In the sample, parents also influence their children’s licensing decisions, particularly through the permission of independent travel. The effects of gas prices and unobserved cohort characteristics are small after controlling for these and other explanatory factors. However, the importance of attitudes, as estimated even in the final model, paired with the observed differences in attitudes across generations (see Figure 5.1), provides evidence of broader cultural change.

Understanding the factors underlying the trend toward decreased licensing is important for more accurately forecasting and then planning for future travel demand, but it is also important for efforts to shape future travel demand. If, for example, the goal is to reduce

dependence on driving, the results provide some guidance. The association between growing up within walking distance from school and licensing delay, found in this study and others, suggests that innovative land use policies such as California's Senate Bill 375, which encourages reduced per-capita VMT through coordinated land use and transportation planning to achieve "smart growth," could have effects beyond directly reducing VMT. If more children are raised in the denser, more accessible urban settings that result from these policies, more may delay getting a driver's license for longer, contributing both to the development of multimodal habits that carry into adulthood and to the development of a multimodal culture more generally. In addition, the growth of ICT-based mobility services, such as Uber and Lyft, could complement these land use policies by helping transition teenagers into lifestyles oriented away from car ownership in their early adult years. Marketing approaches could also potentially serve a useful purpose in encouraging a trend toward reduced automobile dependence and the emergence of a multimodal culture (Cairns et al., 2008b). Through these pathways and others, the trend toward delayed licensing is likely to have long-term cascading effects on the US transportation system.

5.8 ACKNOWLEDGEMENTS

Thank you to Prof. Joan Walker for your creative suggestion to consider left-censoring in the censored regression model. Thank you also to Prof. Susan Handy for your thoughtful input and assistance in designing the survey instrument and in analyzing the data.

6 CONCLUSION

6.1 THEORETICAL CONTRIBUTIONS

In this dissertation, I examine the question: *How do individuals' travel experiences influence their motility?* In my study of bicycling among the longitudinal panel of children from Davis, CA, I find that experiences with bicycling are associated with higher levels of bicycling motility at later time points: increased likelihood of possessing positive bicycling attitudes and perceiving bicycling as a normal mode of transportation that anyone could undertake. Likewise, in my longitudinal study of UC Davis undergraduates, students who bicycled frequently as a child and those who bicycled during college were more likely to belong to a high-motility class. These two studies therefore provide confirmatory evidence for the reciprocal relationship between behavior and motility, and they provide case studies for how motility development occurs with respect to bicycling.

These results provide a possible causal mechanism in the study of mobility biographies. If a key life event provides the window of opportunity for travel behavior change, then motility may provide the elements necessary to sustain the new behavior. The influence of motility could exert itself if an individual already possesses sufficiently strong attitudes, norms, skills, or knowledge for alternative modes of travel, and the key event provides sufficient disruption in travel habits to allow the individual to adopt new travel patterns. But ultimately, the motility-behavior relationship is a chicken-and-egg problem: how do you develop travel motility without travel experiences, and how do you travel without supportive motility? And it therefore begs the question: how do you get people to use a mode for which they have little motility? Passively waiting for key events to enact wholesale changes in travel behavior will almost certainly be

insufficient; could low-cost, uncomplicated policy efforts, such as free transit passes (Fujii and Kitamura, 2003) or other behavioral promotions, get the positive feedback loop of motility and behavior underway?

My study of driver's licensing delay provides insight into the factors that influence the motility-enhancing decision to obtain a driver's license, which could be considered a necessity in many US contexts. The results point to: the relevance of policy – graduate driver's license laws are moderately associated with delay in acquiring a driver's license; the influence of travel attributes – individuals in walkable communities were more likely to delay; and the potential for a culture change surrounding the American rite of passage of driver's licensing – an enthusiastic attitude toward getting a driver's license is a key predictor of licensing, and millennials are less likely to hold enthusiastic attitudes toward licensing.

The combined findings of these dissertation studies point to the importance of early travel experiences and the reinforcing, positive feedback loops that develop from these early stocks of experience. Evidence from Chapter 3 demonstrates that children who began bicycling regularly at a young age are most likely to hold positive attitudes toward bicycling in their early and mid-teenage years. These positive attitudes, especially regarding the independence and flexibility of bicycling, were associated with teenagers choosing to bicycle frequently during these same years – suggestive evidence for a positive feedback loop. This pattern of mutual reinforcement between attitudes and behavior likely extends to the decision to acquire a driver's license (Chapter 5), with those who choose to delay or abstain from driver's licensing likely to continue building their bicycling (or other) motility. And the benefits of bicycling experiences in youth extend into young adulthood, with those who bicycled frequently as a child more likely to belong to high-motility classes (Chapter 4).

6.2 POLICY IMPLICATIONS

6.2.1 *Motivation*

My findings suggest implications for policymakers and planners wanting to facilitate bicycling and other active modes of transportation among children. Children's active travel to school has declined precipitously over recent decades (McDonald et al., 2011). Active travel among children has compelling immediate benefits, including improved attention spans and academic performance (Spitzer and Hollmann, 2013) and health (Lubans et al., 2011), which has led transportation scholars and practitioners to consequently seek to better understand the factors behind the decline (Stewart et al., 2012). But my results provide further justification for the value of walking and bicycling by considering the long-term consequences: the accumulation of experiences and the development of attitudes and skills that may influence children's later travel behavior as adults.

At the same time as rates of active schools travel among young schoolchildren declined in the US, American high school students also became more likely than ever to graduate *without* a driver's license (Sivak and Schoettle, 2011), a downward trend that began in 1980 and has continued since. This life stage is also when bicycle rates tend to decline among American teenagers (Pucher and Buehler, 2008; Underwood et al., 2014). But if teenagers are eschewing a driver's license, bicycling and other modes of active, independent travel would seem poised to fill in the gap in these teenagers' mobility needs.

But why should policymakers pay attention to the bicycling motility of teenagers and young adults? When considered from a life course, or mobility biography (Müggenburg et al., 2015), perspective, the bicycling motility that young adults develop thanks to their early

bicycling experiences could help them to adopt or re-adopt bicycling in other settings when a window of opportunity arises (e.g. moving, household changes, etc.).

My research suggests possible avenues for planners and policymakers to encourage bicycling and to take advantage of the ongoing phenomenon of driver's licensing delay, via traditional policy tools and new policy avenues.

6.2.2 Traditional Policy

6.2.2.1 Safe Routes to School

The results of my studies indicate that children who bicycle in elementary and especially junior high or high school are more likely to hold positive bicycling attitudes and possess excellent bicycling skills. The justification for programs like Safe Routes to School or May is Bike Month, that promote bicycling to school through both “soft” encouragement efforts and “hard” infrastructure investments (Cairns et al., 2008a), could be further strengthened beyond their immediate benefits (e.g. exercise) by considering the long-term consequences of the travel experiences they facilitate. But there is likely room for improvement. Ten to fifteen percent of incoming freshmen at UCD are unable to ride a bicycle or do not feel very confident in their bicycling skills, which suggests that if bicycling is a policy priority, decision-makers should look to bicycling nations like Denmark, Sweden, or the Netherlands for guidance. For example, in the Netherlands, all primary schools implement bicycling education programs for young children before they graduate and move on to secondary school. These types of education programs could be a possible tool to import to the US context in order to explicitly improve children's bicycling motility.

6.2.2.2 *Bicycle Infrastructure and Smart Growth*

Davis, CA, the setting for all three studies in this dissertation, is a small city of roughly 60,000 people, with a well-deserved reputation as the bicycling capital of the US, thanks not only to its uniquely comprehensive network of bicycling infrastructure (Buehler and Handy, 2008) but also to its high rates of bicycling among children (Fitch et al., 2016b), students attending UC Davis (Gudz et al., 2016), and adults (Buehler and Handy, 2008). But over the past decade, other US cities have been seeking to catch up to the standard provided by Davis. The fifty largest US cities are installing bicycle infrastructure at a rapid pace, doubling the average availability of this amenity from 0.9 miles of bicycle facilities per square mile in 2007 to 1.8 in 2016 (Milne and Melin, 2016). If this trend continues, bicycling infrastructure networks will become increasingly extensive and connected, coming to more closely resemble the network of Davis, CA.

In addition to its reputation as a bicycling Mecca, the city of Davis stands out as one of the densest urban areas in the United States (U.S. Census Bureau, 2012). Recent smart growth policies such as California's SB 375 and SB 743 seek to encourage dense, infill development centered around transit, walking, and bicycling (Barbour, 2016) (though whether they succeed in this aim is unclear (Allred and Chakraborty, 2015)). In other words, just as with US cities building out their bicycling networks to Davis-like extents, these policies try to nudge cities to look more like Davis.

My dissertation studies may therefore be interpreted as a peek into the future of other California cities and their citizen's travel behavior and motility development if they become places where a lack of bicycling infrastructure and of nearby, accessible destinations are no longer a barrier to bicycling adoption. Though policies to build bicycle infrastructure and encourage infill development are intended to effect immediate change in car use among adults,

this study's results suggest that they may have further trickle-down effects on the children who grow up in smart growth communities, who may develop bicycling motility that can persist through later residential relocation and life changes. However, not everyone living in a bicycling paradise chooses to ride a bicycle, as evidenced by the results of my panel of Davis schoolchildren (Chapter 3) and of undergraduate students (Chapter 4). But as a consequence, those individuals have weaker bicycling motility. However, perhaps the more striking implications of my research are the positive feedback loops that emerge for those individuals who began bicycling frequently at a young age (likely thanks to the comprehensive provision of safe bicycling infrastructure and the availability of accessible destinations, among other factors). These individuals were very likely to maintain their frequent use of a bicycle, as well as build and maintain positive bicycling attitudes and perceptions of bicycling as a normal activity. Davis therefore provides a template for planners and policymakers to use to understand how extensive bicycling networks and high density can build high levels of bicycling in a community as well as to appreciate the social and behavioral processes that serve to maintain those high levels.

6.2.2.3 Graduated Driver's Licensing Laws

The intent behind Graduated Driver's Licensing laws (GDLs) is to provide young drivers with experiences behind the wheel in safe, supervised settings before gradually giving them greater independence. There is strong evidence that they achieve this goal (Preusser and Tison, 2007), at least among children who participate in the steps of the GDL process. However, if teenagers wait until they turn 17 or 18, they are exempted from the GDL process (Insurance Institute for Highway Safety, 2015). My dissertation provides evidence that GDL policies may be providing moderate discouragement for teenagers to get their driver's license at age 16 (Chapter 5). This suggests that for some teenagers, GDL policies "back-fire" by encouraging them to avoid the

time spent gaining driving experience under restricted, safer circumstances. This would be a troubling trend, since evidence suggests that driving experience is more important to safe driving than age/maturity (McKnight and McKnight, 2003). Therefore, perhaps GDLs have a split effect: teens who go through GDL-required training gain experience in safe settings, while those who wait out the GDL, and therefore immediately begin driving in unsupervised settings, may be more prone to crashes. The safety ramifications of this possible pattern might encourage GDL policy advocates to consider extending the age of exemption. But at the same time, those who wait to get their driver's license (to wait out the GDL requirements) benefit from the increased time spent developing skills and knowledge for how to travel by other modes like transit or bicycle, as suggested by Chapter 3 and Chapter 4 of this dissertation. And as the survival analysis model in Chapter 5 indicates and other studies corroborate (Hjorthol, 2016), decreased licensing among individuals at an early age makes them more likely to delay further, presumably traveling instead by alternative modes of transportation. Though further evidence should be gathered regarding the travel patterns of those who delay licensing, policymakers will want to carefully weigh the possible benefits and downsides of the delays caused by GDL policies.

6.2.3 New Policy Avenues

The majority of research into the relationship between bicycling attitudes and behavior has focused on the role of attitudes in guiding behavior (Handy et al., 2014). Given the now well-established association between positive bicycling attitudes and bicycling behavior, policy suggestions have consequently tended to emphasize the possibilities of market campaigns and other techniques to change attitudes, with the intent to therefore change behavior. However, this research investigates the reverse, the behavior-to-attitude relationship, and in finding that bicycling behavior is associated with improved attitudes toward bicycling, perhaps leads to

simpler, more straightforward policy interpretations. Rather than change people's attitudes about bicycling in order to get them on a bike, what if policymakers instead focused on getting people to ride bicycles, even for a short span of time, in order to change their bicycling attitudes, norms, and skills? And given the reciprocal nature of the bicycling behavior-attitude relationship (Kroesen et al., 2017), could this tactic therefore result in greater adoption of bicycling by the general public?

6.2.3.1 The Role of Universities

As mentioned previously, American high school students are less likely to have traveled by active modes to school and to have acquired a driver's license than their peers of previous decades. If incoming undergraduate students are therefore more likely to arrive on college campuses with fewer experiences with independent travel and with non-automobile modes of transportation, these institutions could play an important part in facilitating the development of young adults' sustainable transportation motility. Most universities already have the necessary ingredients to make this feasible, as car use is often discouraged through travel demand management programs, due to limited land, the expense of providing car parking, and high employment densities (Toor and Havlick, 2004). The results of this dissertation suggest that in addition to their existing travel demand management efforts, 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. If these programs succeed in causing

these sustainable modes to become a habitual behavior, my results indicate that these students would graduate with increased motility.

6.3 FURTHER RESEARCH

This research establishes a link between previous travel behavior and later motility. The findings of this study should ideally be replicated in other bicycle-friendly settings (especially those that aren't university cities), and future studies should focus on other modes of travel in addition to bicycling. Furthermore, studies of interventions that incentivize individuals to ride their bicycle (or walk or take transit) on a trial basis (in the vein of (Fujii and Kitamura, 2003)) should be undertaken to understand the changes in participants' motility that occur as a consequence.

Further research should also continue where this dissertation leaves off, by examining the longer-term influences of previous experiences (and the motility that consequently develops) in childhood or young adulthood on travel behavior as an adult. Answering this research question is notoriously difficult, as robust prospective panel data spanning such a long period is almost non-existent, with few exceptions (Smart and Klein, 2017). However, quasi-experimental approaches using retrospective survey questionnaires could seek to establish this long-term relationship.

An unanswered question from this dissertation is how individuals who delay licensing travel during their years without a license. Research into this question may require purposive sampling of locations or populations with low licensing rates in order to efficiently identify and recruit participants, which would also fit into a qualitative approach to the question, such as interviews or focus groups.

Another possibly fruitful line of inquiry would be to simultaneously estimate the reciprocal influences of behavior and elements of motility (e.g. attitude, skill), to more clearly describe the dynamic relationship and ascertain which direction of causality is stronger. This

research would contribute to theoretical understanding of travel behavior and psychology and also provide helpful guidance for practitioners seeking to increase the use of alternative, sustainable modes of travel.

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APPENDIX A – INTERVIEW PROTOCOL USED IN LONGITUDINAL PANEL OF DAVIS CHILDREN AND PARENTS

Note: This interview protocol was used as part of the study in Chapter 3. In the protocol, I included shortcuts for the interviewer: [he/she], [parent], [teen], etc. to indicate that the interviewer should fill in the name or appropriate pronoun; (*e.g. ...*) to indicate that the interviewer should elaborate if the interviewee is reluctant to respond; *Reference yy (Teenager Qxx)* or *Reference yy (Parent Qxx)* to indicate that the interviewer should refer to the survey responses provided by the teenager and parent while conducting the interview.

Thanks for agreeing to participate in this interview. This interview is one of 25 that we are doing for this study. We are looking at the factors that influence attitudes toward transportation as well as travel behavior. I hope to keep this interview conversational – bouncing back and forth between you and your teen, if [he/she] is willing to participate. I would like to assure you that all of your responses will be confidential. We will not identify you in anyway in our reports. With your permission, I will tape our conversation, so that we can transcribe your comments word for word. I expect this interview to last for about an hour.

Have you signed the consent form? Do you have any questions about the consent form? Do you have any other questions before we get started?

Do you have any commitments that might limit the amount of time we have to speak today?

This question is for both of you:

1. What do you like about living here? What don't you like? (*e.g. people, bicycles, university, etc.*)

This question is for [parent]:

2. What initially attracted you to Davis? (*e.g. job, schools, etc.*)
3. In general, how comfortable do you feel letting [your teen] go places in Davis on his/her own?
 - a. Is there anything unique about Davis that makes you feel more/less comfortable about [your teen] going places independently? (*e.g. bike paths, park space, traffic characteristics, sense of community, lack of crime, etc.*)
 - b. Do you feel more comfortable letting [your teen] travel independently at certain times of day?

4. Do you let [your teen] go anywhere in Davis on their own?
If not:
 - a. Where are they allowed to go on their own? Why? (*e.g. traffic, strangers, etc.*)
5. Have you and [your teen] lived anywhere else before Davis?
If so:
 - a. Where?

These questions are for [teen]:

6. *Reference school mode (Teenager Q8-9)*
 - a. Why do you use this mode(s)?
 - b. How do you think you will get to high school?

These questions are for [parent]:

7. Do you agree? Why will they use that mode?
8. *Reference family characteristics (Parent Q1):*
 - a. How do your other children get to and from school?
 - b. Do your other children influence how [your teen] gets to school?

These questions are for [teen]:

9. *Reference extracurricular mode (Teenager Q11)*
 - a. Why do you use this mode(s)?
 - b. How do you think you will get to after school activities in high school?

This question is for both of you:

If one or both of the subjects has a bicycle (Teenager Q2, Parent Q7):

10. Is your bicycle in working condition? Any problems? (*e.g. no fenders, shifting, brakes*)

This question is for [teen]:

11. Tell me about your bicycle. (*What kind of bicycle is it? What color or decorations? Do you have a basket? A bell? A rack? How many gears?*)
12. How long have you had your bicycle?
13. What do you like about your bicycle? Dislike? (*Would you be sad if it was stolen?*)
14. *Reference bicycling frequency response (Teenager Q5)*
 - a. How often would you like to bicycle?
 - b. Do you think you ride more or less than you used to?
15. What types of places do you bike to? (*Library? Store? Park? Friend's house? Downtown? With family?*) (*Focus on teenager*)
 - a. Where?
16. *Reference bicycling attitudes (Teenager Q3-4)*
 - a. What are things you like about riding a bike? (*e.g. going fast, scenery, biking with friends*)
 - b. What are things you dislike about riding a bike? (*e.g. sweaty, tiring, helmet, dangerous*)
 - c. Have you ever had a bad experience on a bike? (*e.g. flat tire, accident*)
 - i. Did the experience change how you feel about bicycling?

This question is for [parent]:

17. Reference bicycling attitudes (*Parent Q8-9*):
 - a. What are things you like about riding a bike? (*e.g. health, scenery, saves money, biking with friends*)
 - b. What are things you dislike about riding a bike? (*e.g. sweaty, tiring, dangerous*)
 - c. Have you ever had a bad experience on a bike? (*e.g. flat tire, accident*)
 - i. Did the experience change how you feel about bicycling?
18. Reference bicycle frequency (*Parent Q10*):
 - a. What types of places do you bike to?

If not bicycling, this question is for [teen]:

19. Have you thought about riding your bicycle to school?

If yes:

- a. Why don't you ride your bicycle?

If not:

- b. Why not?

These questions are for [parent]:

20. In general, would you like to see [your teen] bicycling more?
 - a. Why or why not?

These questions are for [teen]:

21. How do most of your friends get to school?
 - a. How does this make you feel? (*e.g. do you wish you could travel with more of your friends?*)
22. Do your friends like to ride their bikes?
 - a. Has that feeling changed over time?
23. Do you feel like other people at school like to ride their bikes? (*i.e. kids in general*)
 - a. What is the image of bicycling?
 - b. Has that image or feeling changed over time?
24. What does a typical bicyclist look like?
 - a. What do they wear?
 - b. What do they care about?
25. Have you participated in any bicycling events like Bike Loopalooza, Bike to School Day, May is Bike Month, or a bike parade?
 - a. Did participating in this event change how you felt about biking?
 - b. Did it change how much you biked?
26. Does your school do anything to encourage bicycling? What?
27. What do you think about your parents' rules about where you can go on your bike? (*Too strict, good? Requirements? Restrictions?*)
 - a. If it was up to you, would you like to bike more than you do, or less, or is it about right?
28. Do you like going places by yourself – either walking or bicycling?
 - a. Why or why not?
 - b. Is there anything that makes you feel uncomfortable - or nervous - about going places by yourself in Davis?

29. How do you usually get around by yourself?
 - a. How often?
30. How do you feel about being driven to places in a car?
 - a. What do you like or dislike about being driven to places in a car? (*e.g. too long, faster than other ways of getting around, listening to music, AC*)
31. Driving is just around the corner. Are you planning to get a driver's license?
 - a. Yes:
 - i. Why are you looking forward to getting a driver's license?
 - b. No:
 - i. Are there any particular reasons you aren't planning to get a driver's license?

These questions are for [parent]:

32. Do you want [your teen] to get a driver's license?
- If older siblings:
33. Did your older children get driver's licenses? How did they get to school?
 34. Do you feel [your teen]'s older siblings have set an example or model?

These questions are for [teen]:

35. How do you think you will feel about driving to places in a car? Are you looking forward to being able to drive?
 - a. What do you think you will like or dislike about driving to places in a car? (*e.g. easier to meet friends, listening to music, scary*)
 - b. Are there particular places or activities you look forward to driving to?

This question is for [parent]:

36. Reference driving frequency (*Parent Q11*):
 - a. In general, how do you feel about driving?
 - i. What do you like or dislike about it? (*e.g. hours spent in the car, other drivers, break between home and work*)

These questions are for [teen]:

37. Will you have access to a car?
 - a. Will you share the car or will you be the main user?
 - b. Do you already have a car? If not, who will buy the car?
 - c. What responsibilities will you take on? Who will pay for gas? Insurance?

These questions are for [parent]:

38. Do you plan to have any rules for [your teen]'s driving?
 - a. Distance limits? Supervision? Other?

These questions are for [teen]:

39. How do your friends feel about being able to drive?
 - a. Are they excited? Intimidated? Uninterested?
 - b. Are they planning to get a driver's license? Have they started?

If differences:

- i. Why do you feel differently than your friends?
- 40. How do other people at school feel about being able to drive? (*kids in general*)
 - a. What is the image of driving?
 - b. Has that image or feeling changed over time?
- 41. What does a typical driver look like?
 - a. What do they care about?
- 42. Do you ever talk about cars with your friends?
 - a. Do you notice that boys/girls are more interested in cars?
- 43. In general, do you notice a difference between the way girls travel and the way boys travel? What differences do you notice?
 - a. Do boys/girls get into their bikes?
 - b. Different bike styles?
 - c. Different clothes? Helmets?
 - d. Following the rules of the road?
- 44. Do you think you'll keep bicycling as you get older? Why or why not?
 - a. When you're an adult, do you think a bicycle will be a part of your life? (*How much and how often? Certain types of trips?*)
- 45. Do you think you will drive a car as you get older? Why or why not?
 - a. When you're an adult, do you think a car will be a part of your life? (*How much and how often? How many cars? Certain types of trips?*)

This last question is for both of you:

- 46. Is there anything else either of you would like to tell me about traveling around Davis?

That's my last question. Do you have any questions for me?

Thanks very much for your time. You have made an important contribution to this study. Please be sure to contact us if you have any questions. Before I leave I have one question for [teen]. In a few years we will be checking back with the people in this study. Would it be ok if we contact you then? You can say no later.

APPENDIX B – INTERVIEW SURVEY USED IN LONGITUDINAL PANEL OF DAVIS CHILDREN AND PARENTS

Note: This interview protocol was used as part of the study in Chapter 3. I have included both the parent and teenager surveys in this appendix. Their answers were primarily used to determine the study’s sample generalizability, and the survey was administered prior to the interview.

Parent Survey

1. Who are the members of your household? Please give first names, gender, and age, starting with yourself.

Person	Gender	Age

2. What intersection is nearest to your home?
 Your street: _____
 Nearest cross street: _____
3. How long have you lived at your current address? _____ year(s); _____ month(s)
4. How long have you lived in Davis, CA? _____ year(s); _____ month(s)
5. How many cars does your household have regular access to? _____

6. How many bicycles does your family have regular access to? _____
7. Do you know how to ride a bicycle?
- Yes, I know how to ride a bicycle
 - No
8. Do you own a bicycle?
- Yes, I own a bicycle
 - No
9. 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
10. To what extent do you agree or disagree with the statement: "I like riding a bicycle"?
- Strongly agree
 - Agree
 - Neutral
 - Disagree
 - Strongly disagree

If you own a bicycle:

11. On average, how often do you ride your bicycle?
- Every day
 - A few times a week
 - Once a week
 - Less than once a week
 - Never

If you own a car:

12. On average, how often do you drive a car?
- Every day
 - A few times a week
 - Once a week
 - Less than once a week
 - Never

13. How do you usually get to work?

- Car
- Bicycle
- Bus
- Train
- Walking
- Other: _____

14. What high school will your teenager attend next year? _____

15. What is your race or ethnicity? You may pick multiple categories.

- Hispanic
- Caucasian
- African-American
- Asian-American
- Pacific Islander
- American Indian or Alaskan Native
- Other _____

16. Think about your annual household income from all sources. In which of the following ranges does this income fall into?

- Less than \$40,000
- \$40,000-\$59,999
- \$60,000-\$79,999
- \$80,000-\$99,999
- \$100,000-\$119,999
- \$120,000-\$139,999
- \$140,000-\$159,999
- \$160,000-\$199,999
- \$200,000 or more

17. What is the highest grade or year of school you have completed?
- Never attended school or only attended kindergarten
 - Grades 1 through 8 (elementary school)
 - Grade 9 through 11 (some high school)
 - Grade 12 or GED (high school graduate)
 - College 1 year to 3 years (some college or technical school including Associate's Degree)
 - College 4 years (college graduate with a Bachelor's degree)
 - Graduate degree (Masters or Doctorate-level degree)

This is the end of the survey. Thanks!

Teenager Survey

1. Do you know how to ride a bicycle?
 - Yes, I know how to ride a bicycle
 - No

2. Do you own a bicycle?
 - Yes, I own a bicycle
 - No

3. 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

4. To what extent do you agree or disagree with the statement: "I like riding a bicycle"?
 - Strongly agree
 - Agree
 - Neutral
 - Disagree

Strongly disagree

If you own a bicycle:

5. On average, how often do you ride your bicycle?

- Every day
- A few times a week
- Once a week
- Less than once a week
- Never

If you ride a bicycle:

6. When you ride your bicycle, how much of the time do you ride:

	Never	Sometimes	Most of the time	Always
Alone?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With friends?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With an adult?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. What school do you currently attend? _____

8. How do you usually get to school?

- Car
- Bicycle
- Bus
- Walking
- Other: _____

9. How do you usually get home from school?

- Car
- Bicycle
- Bus
- Walking
- Other: _____

10. How many days a week do you participate in after-school activities?

- 0 – I don't participate in after-school activities
- 1
- 2
- 3
- 4
- 5

If you participate in after-school activities:

11. How do you usually get to after-school activities?

- Car
- Bicycle
- Bus
- Walking
- Other: _____

12. What high school will you attend? _____

13. When were you born? Month: _____ Day: _____ Year: _____

This is the end of the survey. Thanks!

**APPENDIX C – 2016-17 UC DAVIS CAMPUS TRAVEL SURVEY QUESTIONS USED
IN UNDERGRADUATE LONGITUDINAL PANEL ANALYSIS**

Note: I have only included the questions that were used in the analysis in Chapter 4. For the complete 2016-17 UC Davis Campus Travel Survey instrument, see (Heckathorn, forthcoming).

Q01. What is your primary role at UC Davis?

- Undergraduate student (including Postbaccalaureate)
- Graduate student
- Faculty
- Staff
- Visiting scholar
- Post doc
- Recent graduate
- Retiree

Q02. What year are you?

- Freshman
- Sophomore
- Junior
- Senior
- Fifth-year senior
- Post-baccalaureate
- Visiting/exchange student
- Other

Q03. Did you transfer to UC Davis from a college, university, or community college?

- Yes
- No

Q04. What means of transportation do you usually use to travel to campus for school or work? (If you usually use more than one mode of transportation, please select the one you usually use for most of the distance).

- 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 (either as driver or passenger)
- Get a ride (someone drops you off and continues on elsewhere)
- Bus
- Train or light rail
- Other

Q05. We'd like to ask about your opinions with respect to travel. There are no right or wrong answers; we want only your true opinions. To what extent do you agree or disagree with the following statements?

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
I like riding a bike.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Riding a bike is fun.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Riding a bike is convenient.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Riding a bike is safe.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I know how to fix a flat bicycle tire.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am comfortable biking alongside another bicyclist.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I can confidently ride a bicycle without my hands on the handlebars.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q06. How would you rate your ability to ride a bike? In particular, we are interested in whether you know how to ride a bike, regardless of whether it is practical or desirable for you to do so as a means of transportation to campus.

- 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

Q07. 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

Thinking back to how you traveled when you were younger

Next you will be asked about your travel behavior and attitudes during your first years of college. Please answer the following questions for the **START** of each year.

[for **non-transfer** Juniors, Seniors, and Fifth-year Seniors OR Seniors and Fifth-year Seniors who do not specify transfer status]

[for **transfers** – replace first two rows with “Beginning of your **first/second year at college (not at UC Davis)**”, then add a third row with “Beginning of your **first year at UC Davis**” for seniors]

Q08. What means of transportation did you usually use to travel to campus for school or work?

	Walk	Bike	Drove a car, rode a motorcycle, or was part of a carpool	Bus	Train or light rail	Other
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q09. How would you rate your ability to ride a bike?

	I couldn't ride a bike at all because I did not know how	I could ride a bike, but I was not very confident doing so	I was somewhat confident riding a bike	I was very confident riding a bike
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q10. In general, how comfortable would you have been 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
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q11. How strongly would you have agreed or disagreed with the statement: “I like riding a bicycle.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q12. How strongly would you have agreed or disagreed with the statement: “Bicycling is fun.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q13. How strongly would you have agreed or disagreed with the statement: “Bicycling is convenient.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q14. How strongly would you have agreed or disagreed with the statement: “Bicycling is safe.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q15. How strongly would you have agreed or disagreed with the statement: “I know how to fix a flat bicycle tire.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q16. How strongly would you have agreed or disagreed with the statement: “I am comfortable biking alongside another bicyclist.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q17. How strongly would you have agreed or disagreed with the statement: “I can confidently ride a bicycle without my hands on the handlebars.”?

	Strongly disagreed	Somewhat disagreed	Neutral	Somewhat agreed	Strongly agreed
Beginning of your first year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Beginning of your second year at UC Davis	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[for all undergraduates] **In the following questions, we would like to get a sense of your experience with bicycling growing up.**

Q18. What was your home ZIP code during your first year of high school? (e.g. 95616)

Q19. 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)?

_____ years (0 to 8)

Q20. 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 your neighborhood)?

_____ years (0 to 8)

**APPENDIX D – 2014-15 UC DAVIS CAMPUS TRAVEL SURVEY QUESTIONS USED
IN DRIVER’S LICENSING STUDY**

Note: I have only included the questions that were used in the analysis in Chapter 5. For the complete 2014-15 UC Davis Campus Travel Survey instrument, see (Thigpen, 2015).

Q01. What is your gender?

- Female
- Male

Q02. Do you currently have a driver’s license?

- Yes, a CA driver’s license
- Yes, a non-CA driver’s license
- No

[if no to driver’s license]

Q03. Have you ever had a driver’s license?

- Yes
- No

[if yes to driver’s license]

Q04. At what age did you get your driver’s license?

[numeric write-in] years old

Q05. What was the earliest age that you could get a driver’s license where you lived?

[numeric write-in] years

[numeric write-in] months

Q06. How would you describe the place you lived during your first year of high school?

- City neighborhood
- Suburban neighborhood
- Small town
- Rural area
- Other: _____

Q07. What was your ZIP code at the home you lived in during your first year of high school?

Please write your answer here: _____

Q08. About how many miles did you live away from your high school?
Please write your answer here: _____

Q09. What options were available for you to get to school?
Please choose **only one** of the following:

- Walk
- Skate or skateboard
- Bicycle
- Ride in a car
- Bus or schoolbus
- Other: _____

Q10. How did you usually travel to school?
Please choose **only one** of the following:

- Walk
- Skate or skateboard
- Bicycle
- Ride in a car
- Bus or schoolbus
- Other: _____

Q11. How did your friends usually travel to school during your first year of high school?
Please choose **only one** of the following:

- Walk
- Skate or skateboard
- Bicycle
- Ride in a car
- Bus or schoolbus
- Other: _____

Q12. During your first year of high school, how did your parents travel to work?
Please choose **only one** of the following:

- Walk
- Bicycle
- Car
- Bus or other public transit
- Other: _____

Q13. At the age you could drive in high school, did you have access to a car that you could primarily use?

Please choose **only one** of the following:

- Yes

- No

Q14. How many days did you usually participate in after-school activities in school or elsewhere?

Please choose **only one** of the following:

- 5
- 4
- 3
- 2
- 1
- Rarely/never

Q15. During your first year in high school, what was the highest level of education completed by whichever parent/guardian had the most education?

Please choose **only one** of the following:

- Some high school
- High school
- Some college
- Associate degree
- Bachelor degree
- Advanced degree
- Don't know
- Other: _____

Q16. Did you own a cell phone?

Please choose **only one** of the following:

- Yes, a basic cell phone
- Yes, a smartphone
- No, but I had friends with cell phones
- No, cell phones did not exist

Q17. We'd like to ask about your experiences and opinions with respect to travel *during your first year in high school*. To the best of your recollection, to what extent did you agree or disagree with the following statements?

	Strongly disagree	Disagree	Neutral or don't know	Agree	Strongly agree
My parents/guardians allowed me to go places on my own.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I got my driver's license as soon as possible.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked riding a bicycle.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I could rely on my parents/guardians to drive me places.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Driving was considered the coolest way to get to school.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the idea of driving.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
My parents/guardians encouraged me to get my driver's license.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The traffic congestion getting in and out of school was a major hassle.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I valued independence from my parents.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lots of people took the bus in my community.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
My friends got their driver's	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	Strongly disagree	Disagree	Neutral or don't know	Agree	Strongly agree
licenses as soon as possible.					
I liked riding the bus or public transit.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[if student]

Q18. The following question asks about your current plans for life after you graduate from UC Davis.

[if student]

Q19. Of the following options, where would you most like to live after you graduate from UC Davis?

- City neighborhood
- Suburban neighborhood
- Small town
- Rural area

Q20. The following questions refer to your current travel options, attitudes, and experiences.

[if does not have a license and is student]

Q21. You indicated you do not have a driver's license. To what extent do you agree or disagree with the following statements explaining why you do not have a driver's license?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I don't need a license to do what I want to do.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The costs of driving a car are too high.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
There are plenty of other available transportation alternatives.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
It is not important to me to have a driver's license.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
My parents are against it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am concerned about the safety of driving.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Electronic communications (email, texting, Facebook, etc.) reduce my need for driving.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am concerned about the impact of driving on the environment.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[if does not have a license]

Q22. Do you plan to get a driver's license?

- Yes
- No

[if does not have license and is student]

Q23. Which three of the following factors would most likely lead you to get a driver's license?

- Having more money
- Having a job in a location without other transportation alternatives
- Living in a location without other transportation alternatives
- Graduating from college
- Moving to a different city/location
- Getting married or in a long term relationship
- Getting divorced or ending a long term relationship
- Having a child
- Being less busy so that I have the time to get a license
- Other _____

Q24. In what year were you born?

[Numerical write-in]

Help text: e.g. 1980

Q25. Which of the following best describes your race?

Please choose **only one** of the following:

- Black or African American
- Asian
- White
- Mexican or Hispanic
- American Indian or Alaska Native
- Native Hawaiian or other Pacific Islander
- Multiracial
- Other: _____

APPENDIX E – ANALYSIS OF RECALL ACCURACY AMONG UNDERGRADUATE STUDENTS AT THE UNIVERSITY OF CALIFORNIA, DAVIS

ABSTRACT

Though panel data has substantial advantages over cross-sectional data in the study of travel behavior change, it also introduces new logistical and methodological challenges to researchers. Retrospective surveys have the advantage of addressing many of these challenges, though the measurement validity of recalled answers remains an important concern. In this study, I assess the measurement validity of recalled characteristics related to bicycling: usual use of a bicycle to commute, bicycling attitude, and bicycling skill. I use data collected prospectively in the 2012-13, 2013-14, 2014-15, and 2015-16 UC Davis Campus Travel Surveys and retrospectively in the 2016-17 UC Davis Campus Travel Survey in my statistical analysis. I find that prospective answers are strongly associated with recalled responses, that the passage of time has weak, uncertain influence on recollection, and that present attributes attenuate the relationship between prospective and retrospective answers. I conclude that the recalled answers display a sufficient degree of correspondence to prospectively-collected response to have faith in analyses using retrospective survey data (at least those that do not query characteristics beyond 4-5 years). I suggest that further research be done on the measurement validity of retrospective survey data to contribute to the knowledge base on this important methodological topic.

INTRODUCTION

For travel behavior researchers and transportation planning practitioners, collecting longitudinal panel data offers distinct advantages to alternative research designs. Panel survey data provides information on individual travel behavior change, which often is of greater interest and value than the information provided by cross-section or repeat cross-section designs regarding aggregate population trends. Observing the same individuals or households over two or more time periods also permits more persuasive causal arguments, thanks to the ability to observe time order (cause preceding effect) and the ability to (mostly) control for the possible influence of spurious factors (Kitamura, 1990). Panel data also allows researchers to better describe the processes of travel behavior change, such as time-lags between cause and effect or the presence and strength of reciprocal relationships (Finkel, 2011b).

Despite these strengths, panel analyses face practical and methodological challenges. Acquiring and maintaining a representative sample is difficult, given the increased probability of initial non-response, panel attrition, panel fatigue, and panel conditioning. And as a consequence of these common defects, researchers typically need to augment their panel in order to “refresh” the sample and maintain representativeness (Kitamura, 1990). Similarly daunting are the related logistical difficulties of maintaining, locating, and surveying the panel, which requires greater time and expense than traditional cross-sectional surveys. These challenges might be overcome, at least in part, by relying on *retrospective* surveys, which promise to minimize survey burden, maximize response rates, and collect consistent data.

Yet retrospective surveys introduce challenges of their own, as they may be prone to errors and biases that affect measurement validity (Belli, 1998). Research in the field of sociology and in the realm of survey methodology has identified several factors that influence

the accuracy of recall, including the amount of time elapsed between the focal time period and the present, the abstractness or complexity of a topic, as well as the salience and social desirability of the concept and the level of motivation of the participant (Belli, 1998; Teitler et al., 2006). Furthermore, individuals may use their current state as an anchor for their recollections, with evidence from a study of unmarried women's cohabitation patterns that respondents projected their current status backward onto their recollections of the past (Teitler et al., 2006).

In two of the studies in this dissertation, I rely on retrospective survey data for my analyses. I ask for survey participants' bicycling behavior, attitudes, and skills between 1 and 4 years in the past, in my study of bicycling motility (Chapter 4). In my study of driver's licensing (Chapter 5), I ask about survey respondents' travel behavior, attitudes, personal characteristics, and other attributes at age 16, which is at least 2 years ago, on average 5 years ago, and at most 58 years ago for the participants in my sample. In this appendix, I compare prospective and retrospective data from the study of bicycling motility to assess the extent and nature of recall error and bias. Does recall accuracy depend on the construct, such as whether it is a psychological characteristic or a concrete behavior? How does increasing time elapsed from the focal time period influence recall accuracy? How do present-day behavior, attitudes, or skills influence the recollection of those same attributes? I expect that (a) behavior would be more accurately recalled than less concrete constructs such as skills and attitudes, (b) more recent characteristics will be recalled more accurately than those that are more temporally distant, and (c) respondents will be more likely to emphasize change relative to their current state. In the following appendix, after a brief review of the literature and overview of the data collection and

analytical methodology, I present the results and interpret their implications for the reliability of the data for my two dissertation studies and for travel behavior research more generally.

LITERATURE REVIEW

Though panel data has the general virtue of providing the elements necessary for scientists to make robust causal claims about dynamic processes, certain fields have their own distinct uses of and history with longitudinal data. Through surveys, interviews, and ethnographies, sociologists and anthropologists painstakingly record information over many years about individuals lives in order to better understand life histories, their variation, and how individuals' behaviors are affected by internal characteristics (e.g. age, gender) (Mcelreath and Koster, 2014) and external factors (e.g. economic forces, social interaction) (Beheim et al., 2014).

In the field of travel behavior, panel studies are few and far between (Tourangeau et al., 1997). When they have been implemented, they have often been used to evaluate new transportation-related technologies or policies, such as the impact of high occupancy vehicle lanes or public transit fare changes (Golob et al., 1997; van Wissen and Meurs, 1989). In other instances, travel behavior panels have been implemented to understand routine travel behavior (Thøgersen, 2006), and there are some examples of transportation researchers (re-)using panel data, originally collected for other purposes, to good effect (Macfarlane et al., 2015; Smart and Klein, 2017). And in the sub-field of mobility biography research, researchers have often leaned on retrospectively recalled travel and life histories (Schoenduwe et al., 2015) to understand how life events as diverse as job changes, marriage, and purchasing a car can influence travel behavior (Müggenburg et al., 2015).

These retrospective surveys are particularly relevant, as this dissertation relies on retrospectively recalled data in two studies. However, to my knowledge, no travel behavior study has evaluated the measurement validity or reliability of travel recollections using a gold standard of prospectively collected data for the same individuals. Such assessments are rare in other fields as well. In sociology, researchers have compared prospective and retrospective data from the same individuals to determine the reliability and validity of participants' recollections of cohabitation and of marital events (Peters, 1988; Teitler et al., 2006). In the study of cohabitation, the authors used statistical models to analyze whether an individual revised their estimate up or down, relative to not at all (Teitler et al., 2006). Peters (1988) used a statistical model to examine whether marital events were reported consistently or not, and in what direction. Though the modeling choice will vary by study context and variable type, the approach taken by these authors can be problematic if the respondent provides a boundary/limit response (e.g. not cohabitating), in which case their recollection can only stay the same or go up. These approaches also ignore the extent of the revision (e.g. no cohabitation to marriage vs. no cohabitation to occasional cohabitation).

METHODS

The data used in this analysis comes from the retrospective survey in the 2016-17 UCD Campus Travel Survey (CTS) and from the prospective panel data collected in the previous four campus travel surveys (2012-13 through 2015-16), as described in greater detail in Chapter 4. Though approximately 1,100 survey participants provided retrospective answers to the questions in the 2016-17 CTS, only a fraction of those participants had taken the survey in previous years, yielding a sample size of 232 observations with complete responses to all variables included in

this analysis. Because some participants had participated in multiple previous surveys, the number of unique participants in this analysis was 192. The three focal dependent variables are: the respondent's usual travel mode to campus, the extent to which they like to ride a bike (on a 5-point Likert-type scale), and the extent to which they feel confident in their bicycling skills (on a 4-point ordinal scale). I addressed the small sample size by breaking down the overall dataset into smaller complete datasets particular to each focal dependent variable, so as to avoid excluding cases for missing-ness of the other variables, which are irrelevant within each particular characteristic's recall analysis. This approach provides a sample size of 249 observations for the skill variables, 259 for attitudes, and 264 for bicycle use.

I first assess recall accuracy through the use of the Cramer's V test, which is a measure of the degree of association between two categorical variables that falls between 0 (no association) and 1 (perfect association) (Cohen, 1988), by comparing retrospective answers with prospective answers for the three dependent variables of interest. A small degree of association would be indicated by Cramer's V values of around 0.1 or less, medium at roughly 0.15 to 0.3, depending on the scale of the dependent variable, and a high degree of association from 0.25 to 0.5 (again, depending on the scale of the dependent variable).

In addition, I employ generalized linear models, as the dependent variables – recalled behavior, attitude, or skill – are on an ordinal scale. Rather than model the change in recollection (or lack thereof), as done in previous work (Peters, 1988; Teitler et al., 2006), I use the recalled answer as the dependent variable, modeled using a Bayesian ordinal logistic model estimated using *R* and the *rstan* package (R Core Team, 2016; Stan Development Team, 2014). I then include the prospective answer as the independent variable of interest in the generalized linear model. I apply this modeling approach to all three traits (bicycling behavior, attitude, skill) to

answer the first research question about whether more concrete traits are recollected more accurately than more abstract traits. Evidence in favor of my hypothesis would be greater correlation between retrospective and prospective answers for behavior and lower correlation for attitude and skill. In the linear equation, I also include an interaction term between the prospective answer and the time elapsed between the prospective answer and the recalled answer (between 1 and 4 years) to help answer the second research question: Does recall accuracy decline with increasing elapsed time? If the interaction terms for the longer elapsed times have substantial, negative associations with the dependent variable, my hypothesis for this research question will be confirmed. The respondent's current bicycling behavior, attitude, and skill is added to each respective model to assess my third hypothesis that respondents will emphasize change in their retrospective answer. I would find support for this hypothesis if these variables have substantial, negative associations with the recalled answer.

RESULTS

In comparing individuals' retrospectively recalled bicycle use with their prospective answers, I find a high degree of association: a Cramer's V of 0.71 . While the comparison between recalled bicycling use (yes/no) and prospective answers (yes/no) entails a 2x2 contingency table, bicycling attitude has a 4x4 table and skill has a 5x5 table, so a statistical handicapping of their Cramer's V values indicates that they both have high or very high associations, as well (Cohen, 1988), of 0.35 and 0.64 , respectively.

Usual Bicycling Use to Campus

In the model of recalled bicycling use to campus, I find that participants who answered prospectively that they usually rode a bicycle to campus were much more likely to recall using a bicycle to campus. For the influence of time between the prospective and retrospective answers, the model estimates a moderate but uncertain positive association, suggesting that if a participant prospectively indicated they usually bicycled to campus, they become somewhat more likely to recall bicycling as years pass. Bicycle use in the present is positively and strongly associated with recalled bicycling use.

Table 1. Parameter Estimates of Model of Recalled Bicycle Use to Campus (n = 264)

Variable	Mean	S.E.
Intercept	-1.54	0.28
Prospective Bicycle Use	3.23	0.60
Years Elapsed * Prospective Bicycle Use	0.41	0.43
Present Bicycle Use	1.31	0.43

Note: The bold coefficient estimates indicate significance at the $p = 0.05$ level.

Bicycling Liking

In the model of bicycling attitude, I find that individuals who prospectively replied “Neutral” or “Strongly Agree” to the statement “I like riding a bike” were much more likely to recall positive attitudes, relative to someone who prospectively said that they “Strongly Disagree”. Individuals who prospectively answered “Somewhat Agree” were also more likely to provide a positive recollection, though the association was somewhat less certain. The evidence of the influence of years elapsed is mixed, though generally indicates that the influence of time has an uncertain association with recalled bicycling attitude. Finally, individuals’ attitudes in the present day are very strongly associated with more positive recollections of their bicycling attitude.

Table 2. Parameter Estimates of Model of Recalled Bicycling Attitude (n = 259)

Variable	Value	Mean	S.E.
Cutpoints	1	1.67	0.99
	2	3.85	1.05
	3	5.88	1.07
	4	8.29	1.10
Prospective Attitude	Strongly Disagree	-	-
	Somewhat Disagree	-0.13	1.21
	Neutral	2.41	1.18
	Somewhat Agree	1.91	1.08
	Strongly Agree	3.05	1.12
Years Elapsed * Prospective Attitude	Strongly Disagree	-	-
	Somewhat Disagree	1.50	1.09
	Neutral	-1.17	0.52
	Somewhat Agree	0.17	0.24
	Strongly Agree	-0.07	0.25
Present Attitude	Strongly Disagree	-	-
	Somewhat Disagree	2.33	0.73
	Neutral	3.22	0.78
	Somewhat Agree	4.65	0.78
	Strongly Agree	6.63	0.84

Note: The bold coefficient estimates indicate significance at the p = 0.05 level.

Bicycling Skill

The bicycling skill model’s parameter estimates indicate that individuals who provide prospective answers of “Not very confident” or higher were more likely, relative to someone who could not ride a bike, to provide a recalled answer of similarly high skill. However, these estimates were very uncertain. Generally, the influence of the passage of time is to make individuals more likely to rate their bicycling skill negatively, though two of the three parameters were very uncertain. Individuals who currently feel “Somewhat confident” or “Very confident” in their bicycling skill are extremely likely to recall similarly high skill, relative to an individual who currently can not ride a bike.

Table 3. Parameter Estimates of Model of Recalled Bicycle Skill (n = 249)

Variable	Value	Mean	S.E.
Cutpoints	1	3.94	1.95
	2	11.68	2.67
	3	15.88	2.76
Prospective Skill	Cannot ride	-	-
	Not very confident	4.15	3.28
	Somewhat confident	2.28	3.03
	Very confident	3.63	3.03
Years Elapsed * Prospective Skill	Cannot ride	-	-
	Not very confident	-3.19	1.25
	Somewhat confident	-0.74	0.39
	Very confident	-0.16	0.26
Present Skill	Cannot ride	-	-
	Not very confident	4.32	2.90
	Somewhat confident	11.01	3.23
	Very confident	14.26	3.28

Note: The bold coefficient estimates indicate significance at the p = 0.05 level.

DISCUSSION

Difference between Different Types of Questions

The results support my hypothesis, as prospective bicycling behavior has the strongest, most certain association with recalled behavior than prospective attitudes and skills do with their corresponding recollections. Also, bicycling behavior is the only attribute that displayed a stronger association between prospective and recalled answers than between present attributes and recalled answers. There are a number of different reasons this pattern could arise. First, it could be that more concrete characteristics are more readily recalled than more abstract attributes. Another possible explanation is that skills, which displayed counter-intuitively uncertain associations between prospective and recalled skill, are cumulative, while behavior and attitudes are more readily changed. As a consequence, there may be greater multicollinearity between prospective, recalled, and present skill than for the other bicycling characteristics. In a

similar vein, it is possible that the scale size (i.e. number of response options) affects recall accuracy. Participants were only allowed two answers for usually bicycling to campus: they either did, or they did not; they could not provide a “sometimes” or “most of the time” answer. In contrast, participants were given an ordinal, 4- or 5-point scale for bicycling attitude and skill, which may make recalling the precise answer given in previous years more challenging. And of course, it is possible that all of these explanations (and perhaps more) are simultaneously at play.

Influence of Elapsed Time

The three models provide mixed and mostly uncertain associations between elapsed time and the dependent variables. This evidence contrasts with my hypothesized association and with the literature on recollection and memory, which suggests that forgetting of autobiographical events has a linear, consistent decline as time elapses (Belli et al., 2001).

Influence of Current Characteristics

For each recalled characteristic, the respondents’ current state for that characteristic typically had a strong association with their recollection. As mentioned previously in the discussion, this could arise due to multicollinearity between prospective, recalled, and present characteristics. Or it could reflect the impulse of individuals to base recollection of past characteristics upon their current state of that characteristic, which is somewhat in line with my hypothesis. However, the phenomenon observed here seems to match that seen in other contexts, in which individuals’ project their current state backward (Teitler et al., 2006), rather than seek to differentiate between past and present states as might be expected if individuals were “telling a story” about a

personal process of change or growth. The evidence therefore argues against my hypothesis and instead aligns with previous findings.

Assessment of Dissertation Studies' Reliability

The time elapsed in my panel analysis of UC Davis undergraduates ranges between 1 and 4 years, but the durations between the focal time period (age 16) and current day are often longer than four years in my study of driver's licensing (Chapter 5). But this recall analysis suggests that the effect of elapsed time on recall is small. The validity of recalled answers may only become a serious concern as the time elapsed spans decades, given the linear, consistent decline in autobiographical memory as time passes (Belli et al., 2001). The broad implications of the recall analysis results, though, suggest that recalled answers are strongly associated with prospective answers, providing support for the measurement validity of my dissertation studies that rely on participants' recollections. This strong relationship is attenuated by individuals' present characteristics, though that would be expected, given the relatively static nature of many of these traits and the corresponding multicollinearity between recalled, prospective, and present characteristics.

Implications for Past and Future Research

This analysis represents a rare example of comparing prospectively-collected responses with recalled answers to assess the measurement validity of retrospective surveys. Further validity assessments should be conducted, ideally with larger samples and extending beyond 4 years elapsed between focal event and the present date, to bolster the literature on recall validity. If prospective data is not available for the main variables of interest, it may be worthwhile to ask

retrospective questions on related topics (e.g. residential location, workplace) that could be verified and assessed for accuracy as a proxy for measurement validity on the focal variables. And as Schoenduwe et al. (2015) suggest, designing retrospective surveys to take advantage of known idiosyncrasies of cognitive psychology and memory would likely improve measurement validity further still.

CONCLUSION

In this analysis, I assess the measurement validity of recalled characteristics related to bicycling: usual use of a bicycle to commute, bicycling attitude, and bicycling skill. I use data collected prospectively in the 2012-13, 2013-14, 2014-15, and 2015-16 UC Davis Campus Travel Surveys and retrospectively in the 2016-17 UC Davis Campus Travel Survey on these attributes in my statistical analysis. I find that prospective and recalled answers are strongly associated, that the passage of time has a weak, uncertain influence on recollection, and that present characteristics moderate the relationship between prospective and retrospective answers. I conclude that the recalled answers display a sufficient degree of correspondence to prospectively-collected response to have faith in analyses using retrospective survey data (at least those that do not query characteristics beyond 4-5 years). Finally, I suggest that travel behavior researchers interested in retrospective survey methods consider performing additional assessments of measurement validity in their own studies to increase the evidence base on this important methodological topic.

APPENDIX F – KEY TERMS

In this dissertation, I use several words or phrases that are not in common usage or may have ambiguous meanings, sometimes varying in meaning by field of study. This section provides definitions and citations for these key terms as I use them in this dissertation.

Attitude: “The degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question” (Ajzen, 1991).

Bicycle Infrastructure: Public right of way allocated to bicyclists. Common examples in the US context include bicycle lanes (on-street dedication of ~5’ of lane width to bicyclists, separated by a painted line); off-street bicycle paths (which may be shared-use paths for use by pedestrians and other active modes of travel); and sharrows (shared-use arrows, painted indications that bicyclists can take the full car travel lane) (Fitch et al., 2016a).

Binomial Logistic Regression: A statistical model of a process with only two outcomes (yes/no, success/fail, etc.). Can also extend to aggregate settings, by summing up the “successes” and considering the number of “trials”, or efforts/counts. In the case of a binary logistic regression, a logit link is used to translate between the probability scale of the binomial distribution and the unconstrained scale of the linear model (McElreath, 2015).

Censored Regression: A type of (generalized) linear regression model in which the dependent variable has an upper or lower limit, constraining the value observed for respondents who exceed the limit (Tobin, 1958). For example, a bathroom scale may not display weights beyond 300 lbs,

and anyone weighing greater than 300 lbs would be consequently recorded as 300 lbs; the weight variable would therefore be censored to fall below 300 (and above 0).

Content Analysis: A research approach used to extract meaning from text data, such as interview transcripts (Hsieh and Shannon, 2005).

Event History Analysis: see **Survival Analysis**.

Generalized Linear Model (GLM): An extension of linear regression models to variable scales beyond continuous, ratio variables used in linear regression. GLMs link a linear model with a parameter of a likelihood function through a link function (used to convert between the unbounded scale of the linear model and the bounded scale of the parameter). Examples of GLMs include the **Binomial Logistic Regression**, **Ordinal Logistic Regression**, and many others (McElreath, 2015).

Graduated Driver's Licensing laws (GDL): Restrictions and requirements of novice drivers before they can acquire a full, unrestricted driver's license, such as passenger and time of day restrictions at certain ages (Preusser and Tison, 2007), usually implemented as a series of three stages. The first GDL was implemented in Florida, and they have since spread to all 50 states (National Highway Traffic Safety Administration, 2008). Individuals can circumvent the GDL requirements by waiting past age 16, usually until 17 or 18, to take their driver's licensing exam (Insurance Institute for Highway Safety, 2015).

Hierarchical Model: see **Multilevel Model.**

Infill Development: Building on parcels within existing city boundaries rather than beyond them (i.e. “greenfield” development) (Fulton and Shigley, 2012).

Latent Markov Model: An extension of latent variable models, which were developed to address measurement error by using the joint information provided by multiple observed variables to estimate unobserved constructs (e.g. factor analysis) (Collins and Lanza, 2010). Latent class models are a version of latent variable modeling in which the latent variable is categorical and therefore comprised of multiple “classes” (rather than a continuous dimension, as in factor analysis). Latent Markov models are longitudinal extensions of a latent class model, using panel data to estimate how entities or individuals may shift, or “transition”, between different classes over time (Bartolucci et al., 2013). The transition between classes is a Markov process, in which an entity’s probability of occupying a certain state depends on their state in the previous time period (Bartolucci et al., 2013).

Latent Transition Analysis: see **Latent Markov Model.**

Longitudinal Coding: A second-cycle coding process that entails the re-examination of first-cycle codes to determine common process of change (Saldana, 2009).

Longitudinal Panel: A research design that consists of a series of observations of the same individuals (or entities) over multiple time periods, as opposed to cross-sectional (one time

period) or repeat cross-sectional (multiple time periods, different individuals) research designs (Kitamura, 1990).

Millennial (Generation): Individuals born between 1981 and 1996 (Pew Research Center, 2014).

Minimum (Driver's) Licensing Age: The earliest age at which an individual can obtain a driver's license (rather than a learner's permit, which requires adult supervision) (see

Generalized Linear Model (GLM): An extension of linear regression models to variable scales beyond continuous, ratio variables used in linear regression. GLMs link a linear model with a parameter of a likelihood function through a link function (used to convert between the unbounded scale of the linear model and the bounded scale of the parameter). Examples of GLMs include the **Binomial Logistic Regression**, **Ordinal Logistic Regression**, and many others (McElreath, 2015).

Graduated Driver's Licensing laws (GDL) (Preusser and Tison, 2007).

Mobility Biography (or Biographies): A research approach or theoretical framework that seeks to better understand how key life events, such as marriage, job change, or the birth of a child, influence everyday travel behavior (Müggenburg et al., 2015).

Motility: The capability of travel, which is formally composed of the dimensions of *aptitudes* (which I reference as skills and knowledge), *representations* (which I reference as attitudes and

norms) as well as *access* (Kaufmann, 2002). Motility's underlying characteristics resemble the independent variables in the **Theory of Planned Behavior (TPB)**.

Multilevel Model: A type of **Generalized Linear Model (GLM)** that accounts for clustering in the data (e.g. repeat observations for individuals, children sharing the same classroom or school). It accounts for this clustering by pooling the information shared by observations within the same cluster via estimation as part of a parent distribution (often a normal distribution) for that cluster (McElreath, 2015).

Natural Experiment: A research design resembling a “true” experiment, but the researcher(s) do not control when or to whom the experimental treatment is applied.

Norm: Rules of behavior based on concerns about maintaining a consistent and favorable self-concept as well as building and maintaining interpersonal relationships (Wood, 2000).

Descriptive Norm: A rule of behavior based on what is considered to be commonly or typically done (Cialdini and Goldstein, 2004).

Injunctive Norm: A rule of behavior based on what is considered socially-accepted or approved (Cialdini and Goldstein, 2004).

Personal Norm: A self-imposed rule of expected or obligated personal behavior (Onwezen et al., 2013).

Ordinal Logistic Regression: A *Generalized Linear Model (GLM)* that accounts for the ordered nature of the outcome/dependent variable (e.g. rating bicycling skill from 1 – unable to ride a bike – to 4 – confident in bicycling ability) through the use of a cumulative logit link function (McElreath, 2015).

Perceived Behavioral Control: The degree to which an individual feels they can easily perform a behavior (Ajzen, 1991).

Quasi-Experiment: A research design that resembles a “true” experiment but does not feature random assignment to treatment groups (Campbell and Stanley, 1963).

Random Effects Model: see **Multilevel Model**.

Retrospective Survey: A questionnaire that asks about respondent’s past characteristics, typically but not always to assemble a sense of the respondent’s life history with respect to the characteristic of interest (Schoenduwe et al., 2015). This creates a retrospective **Longitudinal Panel**, as opposed to a prospective longitudinal panel, which features respondents’ characteristics reported contemporaneously.

Semi-Structured Interview: A style of interviewing that uses a formal, “structured” interview transcript from which the interviewer can deviate or adapt as appropriate in an effort to answer “why?” questions about the behavior or characteristics of interest (Fylan, 2005).

Structural Coding: A first-cycle coding approach that assigns conceptual phrases to a relevant portion of an interview (Saldana, 2009). These codes are often then used in subsequent second-cycle coding and/or summarized for analysis.

Survival Analysis: A family of statistical models that analyze the duration of events (also called “time-to-failure”), derived from early efforts in sociology and demography to understand common patterns of mortality and its causes (Singer and Willett, 2003).

Theory of Planned Behavior (TPB): Posits that behavior is the direct result of intention (as well as perceived behavioral control), which is itself influenced by **Attitude**, **Norm**, and **Perceived Behavioral Control** (Ajzen, 1991).

Tobit Regression: see **Censored Regression**.