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An Analysis of Travel Characteristics of Carless Households in California

A Research Report from the University of California Institute of Transportation Studies

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16. Abstract
In spite of their substantial number in the U.S., our understanding of the travel behavior of households who do not own motor vehicles (labeled "carless" herein) is sketchy. The goal of this paper is to start filling this gap for California. We perform parametric and non-parametric tests to analyze trip data from the 2012 California Household Travel Survey (CHTS) after classifying carless households as voluntarily carless, involuntarily carless, or unclassifiable based on a CHTS question that inquires why a carless household does not own any motor vehicle. We find substantial differences between our different categories of carless households. Compared to their voluntarily carless peers, involuntarily carless households travel less frequently, their trips are longer and they take more time, partly because their environment is not as well adapted to their needs. They also walk/bike less, depend more on transit, and when they travel by motor vehicle, occupancy is typically higher. Their median travel time is longer, but remarkably, it is similar for voluntarily carless and motorized households. Overall, involuntarily carless households are less mobile, which may contribute to a more isolated lifestyle with a lower degree of well-being. Compared to motorized households, carless households rely a lot less on motor vehicles and much more on transit, walking, and biking. They also take less than half as many trips and their median trip distance is less than half as short. This study is a first step toward better understanding the transportation patterns of carless households.

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An Analysis of Travel Characteristics of Carless Households in California

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

May 2018

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TABLE OF CONTENTS

List of Tables

List of Figures

Executive Summary

In spite of their substantial number in the U.S., our understanding of the travel behavior of households who do not own motor vehicles (labeled “carless” herein) is sketchy. The goal of this paper is to start filling this gap for California. We perform parametric and non-parametric tests to analyze trip data from the 2012 California Household Travel Survey (CHTS) after classifying carless households as voluntarily carless, involuntarily carless, or unclassifiable based on a CHTS question that inquires why a carless household does not own any motor vehicle. We find substantial differences between our different categories of carless households. Compared to their voluntarily carless peers, involuntarily carless households travel less frequently, their trips are longer and they take more time, partly because their environment is not as well adapted to their needs. They also walk/bike less, depend more on transit, and when they travel by motor vehicle, occupancy is typically higher. Their median travel time is longer, but remarkably, it is similar for voluntarily carless and motorized households. Overall, involuntarily carless households are less mobile, which may contribute to a more isolated lifestyle with a lower degree of well-being. Compared to motorized households, carless households rely a lot less on motor vehicles and much more on transit, walking, and biking. They also take less than half as many trips and their median trip distance is less than half as short. This study is a first step toward better understanding the transportation patterns of carless households.

Introduction

In spite of the critical importance of mobility for quality of life and economic well-being, the travel behavior of households without motor vehicles has so far received relatively little attention even though "carlessness" may be the most vivid expression of mobility disadvantage in a car-centric society such as ours (Social Exclusion Unit, 2003; Clifton and Lucas, 2004). Currently, approximately 10.6 million (9.0 %) of U.S. households do not own a motor vehicle (ACS, 2012-16), including over one million in California. These households can be organized into two groups: involuntarily carless households who are forced to live without cars and voluntarily carless households who simply chose to live without cars. Johnson *et al.* (2010) argued convincingly about the need to distinguish between these two groups when considering transportation disadvantage. Moreover, Mitra and Saphores (2017) showed that significant socio-economic and demographic differences exist between these two groups. Note that in this paper we call "carless" households who do not own any motor vehicle (car, pickup, van, SUV, or motorbike).

Recognizing the travel heterogeneity of carless households is important from a policy perspective. In line with the U.S. DOT strategic goal that seeks to "foster quality of life in communities… to increase transportation choices and access to transportation services for all (U.S. DOT, 2013)," it is essential to understand the travel behavior of households who are unable to own a motor vehicle for crafting policies that foster a more equitable transportation system. Indeed, many involuntarily carless households consist of people who are experiencing economic hardship, disabilities, racial and age discrimination, or cultural barriers.

Understanding the travel pattern of voluntarily carless households is also necessary to formulate policies that aim at decreasing vehicle use in our auto-oriented society. Reducing the daily use of personal vehicles would help relieve congestion and decrease road accidents, improve air quality, cut emissions of greenhouse gases, and enhance the health of people who switch to more active modes of transportation such as walking and biking.

Unfortunately, our understanding of the travel behavior of carless households is still sketchy. In that context, the objective of this study is to compare and contrast the travel patterns of voluntarily and involuntarily carless households with those of motorized households. For that purpose, we analyze diary data from the 2012 California Household Travel Survey (CHTS), which asked its carless respondents the reasons why they do not own a motor vehicle.

In the next section, we review selected papers directly relevant to this study before presenting our data and our methodology. After discussing our findings, we summarize our conclusions, mention some limitations of our work, and propose directions for future research.

Carless Households Travel Patterns: State of the Literature

Although scholars have studied the travel behavior of different disadvantaged groups over the years - e.g., low income persons (Giuliano, 2005; Dodson *et al.*, 2010), or older people (Collia et

al., 2003; Haustein, 2012) - carless households seem to have attracted limited attention. Research on the travel behavior of carless households is even more limited, with only a handful of published studies.

A few early studies have analyzed the travel patterns of carless households. In upstate New York, Paaswell and Recker (1976, 1978) conducted an extensive survey of 400 Buffalo residents. After noting the degree of heterogeneity of carless people, they concluded that public transit is a viable alternative to a car for only a few activities. In California, after analyzing Los Angeles County data from the 1976 urban and rural travel survey, Marquez (1980) reported that members of carless households make fewer daily trips, and thus are less mobile than their motorized counterparts. Both studies agreed that walking is the prevalent mode for carless households, particularly for shopping and for other activities within their neighborhood.

In an analysis of data from the 2009 National Household Travel Survey and from focus groups of recent California immigrants, Lovejoy (2012) examined the nature and extent of private vehicle use among households with no cars or with more drivers than cars. She found that vehicle use for carless households is highest for social/recreational and religious activities and very low for shopping or medical trips. She also reported greater mobility fulfilment in households with at least one vehicle compared to households with none.

Recently car-sharing has become popular among carless households as a way to enhance their mobility. The importance of car-sharing for carless households was confirmed by Clewlow (2016), who discovered that many car-sharing members belong to carless households after analyzing San Francisco Bay Area data from the 2012 California Household Travel Survey.

The other studies we found characterize carless households (Mitra and Saphores, 2017), or the dynamics of carlessness (Sattlegger and Rau, 2016; Klein and Smart, 2017).

Three recently published papers analyzed the 2012 CHTS to better understand carless travelers. Mitra and Saphores (2017) estimated generalized structural equation models to characterize voluntarily and involuntarily carless households but they did not consider their travel behavior. They reported that voluntarily carless households are more likely to have a higher income, a better education, more employed members, and fewer children than their involuntarily carless peers. They also found that on average they live in denser, more land-use diverse, and more walkable areas with better transit service. Moreover, compared to their voluntarily carless counterparts, involuntarily carless households tend to be less affluent and they tend to live in areas that are less land-use diverse, less walkable, and with worse transit coverage.

Brown (2017) also analyzed the 2012 CHTS. She contrasted the characteristics of car-free (voluntarily carless) and car-less (involuntarily carless) CHTS respondents, and explained how much (number of trips) and how far (VMT) they travel. She reported that car-less respondents have lower household incomes, lower educational attainments, and are disproportionately non-white compared to car-free respondents. Moreover, car-free respondents take more trips and travel more. However, her findings are questionable for several reasons. First, even though she discussed her results in terms of households, her analyses were conducted in terms of

individuals. Second, she relied on t-tests to assess differences in non-normal populations. Third, her linear regression models that explain VMT and the number of trips did not account for the non-negativity of these variables and for the large percentage of respondents who did not travel on their CHTS survey day.

Kühne *et al.*, (2018) analyzed data from the 2008 Mobility in Germany (MiD) Survey and from the 2012 CHTS to examine what socio-economic and built environment factors motivate households to voluntarily forgo their motor vehicles in Germany and in California. They found that in both Germany and California, households with a lower income or fewer children, and who reside in denser neighborhoods, closer to transit stations, are more likely to be voluntarily carless. However, households with more education are more likely to be voluntarily carless in Germany, whereas the reverse is true in California. Moreover, employment density and public transit have a higher impact on voluntary carlessness in Germany than in California.

In Vienna, Austria, Sattlegger and Rau (2016) carried out a mobility biography study to understand voluntarily carlessness. They concluded that treating carlessness as socially normal is a key to carless mobility and to voluntary carlessness.

After examining data from the U.S. Panel Study of Income Dynamics (PSID), Klein and Smart (2017) found that carlessness is temporary for most carless families, who are more likely to have a lower income and to be immigrants or people of color.

In another group of studies, the lack of car ownership has been used as an indicator of disadvantage. The motivation for this approach is that carlessness is generally associated with a lack of participation and with social exclusion. For example, Bromley and Thomas (1993) analyzed data from the Swansea Household Travel Survey in Britain to understand the relationship between car-ownership and shopping behavior. They concluded that carless consumers are forced to rely on local stores. These are more expensive and offer more restricted choices than superstores, which are only reachable by car. Also in the United Kingdom, Bostock (2001) found that carlessness restricts access to health and social care resources such as food shops, health-care services, and social networks, based on her analysis of a survey of low-income mothers with young children in the Midlands. Moreover, she argued that carlessness is an indicator of low socio-economic status and of walking as a mode of transport.

After reviewing papers dealing with the transportation hardships of welfare recipients, Blumenberg and Manville (2004) concluded that carlessness significantly reduces the likelihood of finding a job. Cebollada (2009) reached a similar conclusion after analyzing the relationship between daily mobility and labor market exclusion in the Barcelona Metropolitan Region, through in-depth interviews of 47 people from different organizations.

More recently, after analyzing British National Travel Survey data covering 2002 to 2010, Mattioli (2014) argued that the relationship between social exclusion and carlessness is more local than global because it largely depends on the composition and travel behavior of carless households, which varies substantially across different types of areas. While carless households in peripheral

and rural areas are either virtually immobile or highly dependent on car lifts, they are more mobile and less constrained in larger urban areas.

However, Johnson *et al.* (2010) challenged the use of carlessness as an indicator of disadvantage. They argued that carlessness can be the right choice for low income households who may otherwise bear the significant financial stress of having to pay for a motor vehicle.
In summary, we found only a few papers on the travel behavior of carless households and none that distinguishes between voluntarily and involuntarily carless households, although recognition of intragroup heterogeneity among carless households is critical from a transportation disadvantage perspective (Johnson *et al.*, 2010).

Data and Analysis Method

Survey Data

In this paper, we analyze travel diary data from the 2012 California Household Travel Survey (CHTS), which collected extensive travel information from households in all of California's 58 counties. After some pretesting in late fall of 2011, the survey was fielded in January 2012, and travel data were collected every day for a full year. Participating households were asked to record their travel in a diary for a pre-assigned 24-hour period for all of their members. In addition, a subset of households agreed to wear GPS devices for three days, and others carried a GPS device in their vehicles for seven days.

In total, 42,431 households completed the 2012 CHTS, yielding information about 109,113 persons, who took 460,528 trips to undertake 604,711 activities. Trip data include modes, travel distance, arrival and departure times, as well as types of activities. The CHTS also collected detailed demographic information for each individual and each participating household, as well as the geolocation of their residence and places of work.

Characterization of Voluntarily and Involuntarily Carless Households

Following Mitra and Saphores, (2017), we classified carless households into three groups: 1) voluntarily carless households, who chose to live without a car, 2) involuntarily carless households, who are forced to live without a car, and 3) 'unclassifiable' carless households, who could not unambiguously be assigned to one of the other two groups.

To classify carless households, we relied on answers to the CHTS question that asks why a carless household does not own a motor vehicle (see Table 1). A household was deemed voluntarily carless if the reasons invoked are either "1: Do not need a car," or "2: Concerned about impact on environment," or combinations of answers given by items 3 to 6 in Table 1. In combination with items 1 and 2, we assumed that households who answered "Can't drive", "No driver's license", "Get rides from other people", or "Use public transit" are voluntarily carless. Conversely, households who stated that they cannot afford a vehicle, cannot get insurance, have health/age constraints, or combined reasons given by items 11 to 14 in Table 1, were classified as involuntarily carless. All other carless households were deemed "unclassifiable."

After excluding observations with missing information about the survey respondents, their households, or the characteristics of their trips, we obtained a final sample of 2,156 carless households (including 325 voluntarily, 924 involuntarily, and 907 "unclassifiable" carless households) and 35,282 motorized households. The large fraction of unclassifiable households (907 out of 2,156) reflects that constraint and choice can co-exist for a number of carless households but from the authors' perspective it is to a large extent the product of the wording of the CHTS question used to capture the reasons why some households are carless (see notes below Table 1). This question asked respondents to select reasons why their household is carless but there was no direct question asking them if carlessness was voluntary or not.

Linked Trips and their Characteristics

Our main goal here is to contrast the travel patterns of voluntarily and involuntarily carless households, and to compare them with those of motorized households.

To characterize travel patterns, we first constructed linked trips. In the 2012 CHTS, a trip (which describes a person's movement from one place to another and is characterized by a change of location) was treated as unlinked and entered as a single record with specific departure and arrival times. For example, if a person changes travel mode once to reach her ultimate destination, her journey was recorded as two separate trips in the 2012 CHTS. As a result, a calculation of the total number of trips taken by her household would overestimate the number of trips by counting the legs of a linked trip as separate trips, and it would underestimate both travel time and travel distance per trip by considering these characteristics for each trip leg.

To address this potential problem, we "reassembled" linked trips by using the methodology that Caltrans relied on for the 2001 CHTS. We considered that a trip is "linked" when a person changes travel mode to reach a target destination, or when a driver makes a stop to serve a passenger (drop off or pick up) on the way to a target destination. Trips that do not meet the above characteristics are unlinked. To put together a linked trip, the trip to the location where the travel mode changed or where a passenger was served were combined with the trip continuing from that location to an ultimate destination. A linked trip may therefore include more than one stop to change modes or to serve passengers. The distance traveled during a linked trip is the sum of the distances of all its legs. Likewise, the duration of a linked trip is the sum of the travel times on all of its legs excluding activity durations. To associate a mode to a linked trip, we assumed that the trip with the longest distance among the different components of a linked trip characterizes that linked trip. Although we considered both the main mode of a linked trip and the modes on all of its legs, we relied on the former for analyzing modal share.

After creating linked trips, we analyzed both linked and unlinked trips. To characterize trip type, we initially considered conventional transportation planning definitions that distinguish between home-based work trips, work-based other trips, and so on. However, this classification was not insightful here so we created instead indicators to track whether a trip involved: a) work; b) school or after school activities; c) civic, recreational, religious, or social activities; d) personal business (e.g., going to a bank, servicing a motor vehicle, running household errands, visiting a government office, or going to a health care or pet care

appointment); and e) shopping. Results presented herein are based on both linked and unlinked trips, unless otherwise noted.

Statistical Methods

To contrast the travel patterns of carless and motorized households (our main goal in this paper), we analyzed the number of trips taken on the survey day, their length and duration, the modes used, and some of their purposes (e.g., shopping). We also considered the impact of population density on trip characteristics since a high enough density is necessary to have a viable transit system. Variables of interest are therefore non-negative and involve categories (e.g., travel mode), frequencies (such as the percentage of trips under 1 mile), counts (e.g., number of trips), and continuous values (e.g., trip distance).

To detect the presence of a relationship between two categorical variables, we relied on chi-square tests.

Plots show that the distributions of counts and of continuous travel characteristics (omitted for brevity) are far from normal, either because they have long right tails (e.g., travel times), mass concentrations at 0 (e.g., number of trips during the survey day), or both. Since parametric tests typically have more power than equivalent non-parametric tests, we used ANOVA if a simple monotonic transformation (e.g., a logarithmic transformation) could make the distribution of the transformed variable approximately symmetric and bell-shaped. ANOVA tests that the means of different categories are equal under the assumption that data are normally distributed. Since the normal distribution is symmetric, a test of the means is also a test of the medians of the transformed data, and therefore a test of the medians of the untransformed data because a monotonic transformation conserves medians.

If we could not find a simple way to transform the distribution of a variable of interest to make it almost “normal”, we conducted a Kruskal Wallis (KW) test, which is a non-parametric version of ANOVA (Conover, 1999). A KW test assesses whether different samples originate from the same distribution, so statistical significance indicates that at least one sample originates from a distribution that differs from the distribution of at least another sample, but it does not identify which ones. If the samples considered have identically shaped and scaled distributions that possibly differ only in their medians, the KW null hypothesis is that all samples have equal medians, and the alternative is that not all population medians are equal. For both ANOVA and KW tests, we therefore reported median values of the travel characteristics considered.

Prior to conducting statistical tests, we formulated a number of hypotheses. We expected that carless household would travel less frequently, over shorter distances, and that they would rely more on active modes (walking, biking, and transit). We also hypothesized that it would take involuntarily carless households longer to travel for the same purpose than for their voluntarily carless counterparts. However, since it would be difficult (and cumbersome) to consider in advance all the interesting hypotheses for such a multi-faceted question as travel behavior, we conducted post-hoc tests to detect which groups of households differ for different travel characteristic.

For our chi-square tests, we used the post hoc procedure developed by Goodman (1963) with a Dunn-Bonferroni correction for selecting the appropriate critical value. The test statistic here is the difference of proportions (or frequencies) divided by the square root of the sum of the squared standard errors of estimated proportion. Under the null hypothesis that the frequencies are equal, it has a normal distribution.

For ANOVA, we used Tukey-Kramer post-hoc tests (Ramsey, 2010), and for KW, we relied on Conover-Iman post-hoc tests (Conover & Iman, 1979) with a Benjamin and Yekutieli (2001) adjustment to control the false discovery rate. The Conover-Iman test is based on a *t*-distribution approximation of the distribution of a rank sum-like test statistic. It is more powerful that the better-known Dunn's (1964) post hoc test, and it is available in Stata. For all our tests, we used a probability of Type I error of α=0.05 before post-hoc test adjustments.

Findings

We performed our statistical work using Stata 14. Tables 2 to 5 and Figures 1 to 4 display and illustrate our results. After summarizing some key characteristics of households in our sample, we discuss the number of household trips, before covering trip structure, and travel modes. We focus on the differences between voluntarily and involuntarily carless households, and contrast their travel characteristics with those of motorized households. Characteristics of unclassifiable carless households are just provided for completeness.

Key Characteristics of Sample Households by Vehicle Ownership Group

Table 2 shows descriptive statistics for some key variables characterizing our four groups of households. Kruskal-Wallis tests show that the distributions of household size, number of employed members, income, educational achievement, ethnicity, and population density differ between the four groups of households considered.

First, we see that carless households are predominantly nuclear, whereas couples are most common among motorized households. Second, carless households are much more likely to have no employed members (61.3% and 47.1% for involuntarily and voluntarily carless households respectively) than motorized households (19.0%). As a result, over half of carless households (almost 80% of involuntarily carless households) are in the lowest income group (<$25,000), and very few belong to the highest income group.

Education is likely an underlying reason for lower income, as the mode of the distribution of educational achievements among carless households is a high school degree. Indeed, only 20.3% of involuntarily carless households have a bachelor degree or better, versus 32.9% of voluntarily carless households. By contrast, almost 60% of motorized households have a BS/BA (28.9%) or better (30.6%). Ethnicity may also play a role here because the proportion of African Americans among carless households is three times as large as among motorized households.

Another basic difference is that motorized households predominantly (77.6%) reside in single-family dwellings, versus only 23.7% to 31.4% for carless households. Table 2 also shows that

27.9% of motorized households live in lower density areas (where single-family housing is more common), although they are pretty evenly distributed across all four density ranges. By contrast, roughly half of carless household reside in high density areas (>10,000 people/mi^2). A more in-depth analysis of the characteristics of carless households can be found in Mitra and Saphores, 2017.

Number of Trips

In Table 3, we consider the number and the percentage of households who did not travel on their survey day, the number of those who traveled, the median number of household trips, and the number of trips per adult in a household.

We first note that a larger percentage of involuntarily carless households did not travel on their survey day compared to voluntarily carless households (27.7% vs. 21.9%), although this difference is not statistically significant. Moreover, carless households were more than twice as likely to stay at home compared to motorized households (from 21.9% to 27.7% for the former vs. only 12.3% for the latter), which points to a basic difference in mobility.

Overall, voluntarily carless households (with a median number of three trips per household) are more mobile than their involuntarily carless counterparts (their median number of trips is two per household). However, carless households take at most half as many trips as motorized households (2 to 3 for the former vs. 6 for the latter).

We did not find significant differences in the impact of population density (results not shown for conciseness) on the number of trips beyond the higher number of trips for motorized households, and the fact that households tend to take more trips at higher population densities. Tests of the median number of trips per adult only showed a difference between carless households and motorized households (2 for carless adults vs. 3 for motorized adults).

Structure of Trips

In Table 4, we examine the number of segments in a trip, trip distance, trip duration, and out-of-home activities during a trip. For both distance and duration, we also consider the impact of population density.

From the top of Table 4, we see that more than half of the trips in our sample have only one segment. Moreover, carless households (36.9% and 40.7% for voluntarily and involuntarily carless households respectively) have a significantly larger number of linked trips than motorized households (14.8%), likely because they depend more on transit (see Table 5).

Let us now consider trip distance. As expected, motorized households drive the farthest (their median trip distance is 3.48 mi). Moreover, involuntarily (1.63 mi) carless households have a significantly larger median trip distance than voluntarily carless households (1.29 mi). A decomposition by trip activity (Panel A of Figure 1) suggests that this difference is driven by travel that involves work (3.64 mi vs. 2.58 mi); civic, recreational, religious, and social activities (1.49 mi vs. 0.85 mi); and personal business (2.50 mi vs. 1.54 mi).

Panel B of Figure 1 shows that carless households have a much higher percentage of short trips (<1 mile) than motorized households: 43.0% and 38.5% respectively for voluntarily and involuntarily carless households versus only 18.8% for motorized households. Conversely, motorized households have a higher percentage of longer trips than carless households: fewer than 8% of the trips of voluntarily and involuntarily carless households are over 15 miles versus 16.2% for motorized households.

As expected, as population density increases, the median trip distance decreases monotonically. This change is much larger for voluntarily carless households (it drops from 5.25 mi down to 1.03 mi as density goes from 1,500 to over 10,000 people/mi^2) than for involuntarily (from 2.54 mi to 1.41 mi for) or motorized (from 4.69 to 2.85 mi) households. One possible explanation is that voluntarily carless households can take advantage of the benefits of higher population densities to fulfill their needs without traveling as far because they are well adapted to their environment, as argued by the proponents of residential self-selection (e.g., see Mokhtarian and Cao, 2008), although the relationship between preferences, travel, and urban form is likely more complex (see some of the references in Jarass and Scheiner, 2018).

An analysis of trip durations reveals additional and more marked differences between voluntarily and involuntarily carless households. First, we see that the median trip duration for voluntarily carless households (15 min) is similar to that of motorized households (also 15 min) and significantly less than for involuntarily carless households (20 min).

A breakdown of trip durations by activity (Panel A of Figure 2) confirms that the median trip duration of involuntarily carless households is larger across the board compared to all other household groups considered. The difference with voluntarily carless households is statistically significant for civic, recreational, religious, and social activities (15 min vs. 20 min) and for personal business (15 min vs. 25 min). Although median trip durations are shortest across the board for motorized households, they are statistically different from those of voluntarily carless households only for shopping trips (10 min vs. 15 min).

An analysis of the frequency of trip durations also reveals significant differences. First, the frequency of short trips (up to 10 min) is higher for voluntarily (34.1%) than for involuntarily (28.2%) carless households, but not as high as for motorized households (39.1%). Conversely, the frequency of longer trips is lower for voluntarily carless than for involuntarily carless households: 15.8% vs. 19.9% for trips lasting between 31 and 60 min, and 7.0% vs. 10.9% for trips over one hour. Interestingly, the frequency of trips over 30 minutes is lowest for motorized households, which illustrates the mobility advantage conferred by motor vehicles. These differences are depicted on Panel B of Figure 2. These results do not mean, however, that involuntarily carless households take longer trips than motorized households. They just indicate that involuntarily carless households have a higher proportion of longer trips.

The link between population density and median trip duration further differentiates voluntarily and involuntarily carless households. As population density increases, the median trip duration of voluntarily carless households first increases from 15 to 18 min before dropping back to 15 min. For involuntarily carless households, however, it simply increases from 20 to 21 min, which

suggest that they cannot take advantage of the higher concentration of businesses and entertainment opportunities expected at higher densities. The relationship between population density and median trip duration is flat (it remains at 15 min) for motorized households.

The bottom of Table 4 reports tests of the percentage of trips involving different out-of-home activities. Involuntarily carless households have a lower percentage of work trips (11.7%) than voluntarily carless (20.0%) and motorized (20.9%) households, likely because more of them are unemployed (see Table 2). They also have a lower percentage of civic, recreational, religious, or social trips than motorized households (31.6% vs. 37.1%), but a higher percentage of shopping trips (28.7% vs. 20.6%). There is no statistically significant difference between voluntary and motorized households here.

Travel Mode

Let us now focus on travel modes (Table 5). Our analysis has three components: we consider modes by trip distance, by trip purpose, and as a function of population density.

As expected, compared to carless households, motorized households rely mostly on motor vehicles (for 87.8% of their trips), much less on walking and biking (9.5%), and very little on public transit (2.2%) (see Figure 3). Compared to their voluntarily carless counterparts, involuntarily carless households rely more on transit (33.8% vs. 28.1%), but they walk or bike less (41.0% vs. 49.1%).

As expected, trip distance clearly matters for mode selection. For short trips (under 1 mile), carless households overwhelmingly walk or bike, whereas motorized households prefer to drive. As trip distance increases, motor vehicles and transit play an increasingly large role for carless households although walking/biking retains a non-trivial percentage of trip modes up to 15 miles. For trips over 15 miles, voluntarily and involuntarily carless households use transit at least half the time, whereas motorized households drive 94.6% of the time.

A breakdown by trip activity confirms that voluntarily carless households walk more than others, while motorized households walk much less than carless households. The difference in walking/biking between voluntarily and involuntarily carless households is statistically significant for civic, recreational, religious, and social trips (30.3% vs. 17.1%); for personal business (55.7% vs. 42.8%); and especially for shopping (76.7% vs. 48.1%).

As expected, population density plays an important role in mode choice, although its impact is not monotonic. At intermediate population densities (1,501 to 10,000 people/mi^2), voluntarily carless households rely at least as much on motor vehicles as their involuntarily carless counterparts. At higher densities (over 10,000 people/mi^2), however, voluntarily carless households depend less on motor vehicles (10.1% vs. 17.3%) and on transit (30.1% vs. 36.9%), but they walk more (56.8% of their trips vs. 44.0%). As population density increases, motorized households tend to rely a little more on transit and on walking/biking and a little less on their motor vehicles although motor vehicles still dominate their mode choice.

Finally, we found that vehicle occupancy for car/taxi/van trips is typically higher for carless than for motorized households (Figure 4; results omitted from Table 5 for conciseness). For example, while members of motorized households travel alone for 46.7% of their car/taxi/van trips, that percentage is only 17.5% and 8.2% for voluntarily and involuntarily carless households respectively. Moreover, members of involuntarily carless households travel more often in more crowded vehicles: 21.7% of their car/taxi/van trips involve four or more occupants, compared to only 15.0% for voluntarily carless and 12.3% for motorized households.

Conclusions

In spite of the substantial number of U.S. households who do not own a motor vehicle (10.6 million, including over 1 million in California), our understanding of the travel behavior of this group is still sketchy. To start filling this gap for California, we analyzed travel diary data from the 2012 CHTS using parametric and non-parametric methods with post-hoc tests.

Compared to motorized households, we find that carless households take less than half as many trips, and their median trip distance is less than half as short, with a higher proportion of short trips (under 1 mile). Conversely, median travel times tend to be longer for involuntarily carless households (but not voluntarily carless households) than for motorized households. Unsurprisingly, carless households rely a lot less than motorized households on motor vehicles. Instead, they use transit more and walk/bike a lot more.

Our main focus in this study, however, was on differences in travel behavior between voluntarily and involuntarily carless households. Compared to the former, involuntarily carless households travel less frequently and the length of their trips is significantly longer even though they are slightly less affluent. This is especially the case for trips that involve work; civic, recreational, religious, or social activities, and personal business.

Moreover, the trips of involuntarily carless households take significantly more time than those of voluntarily carless households. One possible reason is that involuntarily carless households rely more on transit, and total travel time by transit includes out-of-vehicle time (walking and waiting). A second reason may be that voluntarily carless households can satisfy more of their needs without travelling too long or too far as they are more likely to live in neighborhoods with mixed land use and higher population densities (Mitra & Saphores, 2017), in environments that better fit their needs.

Voluntarily carless households also walk/bike more and depend less on motor vehicles and on transit than involuntarily carless households, possibly because they live in more pedestrian-friendly areas (Mitra and Saphores, 2017). The higher use of public transit by involuntarily carless households suggests that public transit is still predominantly used by captive riders even though recent transit investments have targeted choice riders. This strategy may be counter-productive, however, as Giuliano (2005) cautioned that substantially increasing the ridership of discretionary users could only be achieved by sacrificing service for those who rely the most on transit (i.e., involuntarily carless households).

Finally, when voluntarily carless households use motor vehicles, the occupancy of these vehicles is typically lower than when involuntarily carless households use cars. One possible reason may be that involuntarily carless households have less flexibility for using motor vehicles because they are less affluent (Table 2), which gives them an incentive to share vehicles. A second reason may be that, since involuntarily carless households rely more on motor vehicles for civic, recreational, religious and social trips and for shopping, they may be traveling together with other household members, friends, or relatives.

Overall, involuntarily carless households appear to be less mobile than voluntarily carless households, and their trips tend to take more time as they travel further, even though they tend to be less affluent. These travel patterns, which we interpret as symptoms of transportation disadvantage, may contribute to a more isolated lifestyle with a lower degree of well-being.

In the short term, there is no magic bullet for improving the mobility of involuntarily carless households, as access to a motor vehicle is the key to a high level of quality mobility in most of the U.S. (Klein and Smart, 2017). Helping involuntarily carless households acquire a motor vehicle may seem like an obvious remedy, but since most involuntarily carless households are less affluent (Table 2), they may not be able to keep their motor vehicles without additional support (Klein and Smart, 2017).

Improving transit services (especially outside of peak-hours) with a focus on involuntarily carless households would likely bolster their mobility. Our results also suggest investing more in biking and walking, which are the main modes for carless households.

Changes in land use policy and increasing the supply of affordable housing could help address the plight of carless households, although these approaches would take time and are politically challenging. Land use policies that favor higher population and job densities in a mixed-use environment with a pleasant architecture are likely to make public transit and walking / biking both more attractive and more enjoyable. If such developments also provided affordable housing (a major problem in California), they would improve the mobility of involuntarily carless households and likely motivate new households to voluntarily forgo their motor vehicles.

To encourage more people to become voluntarily carless, transportation planners in California may review experiences in Europe and Australia, where voluntary travel behavior change (VTBC) programs provide information, assistance, motivation or incentives (Stopher *et al.*, 2009) to entice people to switch to greener, more active modes. Additional information and incentives may also help involuntarily carless households fulfill their transportation needs.

The development of a sharing economy coupled with the emergence of self-driving vehicles hold great promises for enhancing the mobility of carless individuals, especially those who are involuntarily carless. In particular, bike-sharing (Martens, 2013) and affordable car-sharing (Kim, 2015) programs could start addressing transportation disadvantage in urban environments, although in a number of cases, users of a number of public bicycle and car

sharing schemes have so far been more likely to be white, middle-class males (e.g., see Clark and Curl, 2016; or Tyndall, 2017). Car sharing would become even more attractive if self-driving would substantially cut its cost as it would disconnect vehicle ownership from mobility. However, the timing of this potential revolution is still uncertain.

One limitation of this study is that we classified carless households based on an indirect CHTS question. This required some judgement calls (our classification scheme is detailed in Table 2) and likely contributed to the large number of unclassifiable households. A second limitation is the fairly high percentage of carless households (586 out of 2,156, or 27.2%) who did not provide any reason why their household does not own a motor vehicle. These limitations reduced our ability to contrast voluntarily and involuntarily carless households and led us to create a category of "unclassifiable" carless households, which added some complexity to our analysis. To better distinguish between voluntarily and involuntarily carless households, it would have been preferable if the CHTS had asked respondents explicitly if they chose to live voluntarily without motor vehicles or not. Future work could include conducting a travel survey of carless households, performing more detailed activity analyses, and exploring to what extent ridesharing services, car sharing, and internet shopping may impact the ownership and use of motor vehicles.

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Table 1. Classification of Carless Households

Item number	Reasons and combinations of reasons given by respondents for not having a motor vehicle	Authors' Classification
1	"Do not need a car - can do what I need and want to without a motor vehicle"	Voluntary
2	"Concerned about impact on environment"	Voluntary
3	"Can't drive" and (1 or 2)	Voluntary
4	"No driver's license" and (1 or 2)	Voluntary
5	"Get rides from other people" and (1 or 2)	Voluntary
6	"Use public transit" and (1 or 2)	Voluntary
7	"Too expensive to buy"	Involuntary
8	"Too expensive to maintain (gas/insurance/repairs)"	Involuntary
9	"Health/age related reasons"	Involuntary
10	"Cannot get insurance"	Involuntary
11	"Can't drive" and (7 or 8 or 9)	Involuntary
12	"No driver's license" and (7 or 8 or 9)	Involuntary
13	"Get rides from other people" and (7 or 8 or 9)	Involuntary
14	"Use public transit" and (7 or 8 or 9)	Involuntary
15	Other	Unclassifiable
16	Mentioned at least one reason between 1 and 6 and one reason between 7 and 14 in the list above	Unclassifiable
17	No answer	Unclassifiable

Notes:

1) This table partitions CHTS participants based on their responses to the question: "Please let us know the reasons why you/your household does not own a motor vehicle." Answers were recorded in the CHTS variable HHNOV.

2) The middle column ("Reasons for not owning a motor vehicle") lists the combinations of responses given by the respondents and the rightmost column gives the corresponding authors' classification.

3) A household was assumed to be voluntarily carless if the household respondent answered either "do not need a car" or "concerned about impact on environment" or any combination of reasons given by items 3 to 6 above. These answers do not imply that their choice to be carless was constrained. We acknowledge that we made a judgement call when we interpreted "Can't drive" and "No driver's license" in combination with (1 or 2) as a sign of voluntarily carlessness.

4) Conversely, households who stated that they cannot afford a vehicle, cannot get insurance, have health/age constraints, or gave combinations of reasons as shown by items 11 to 14 above (which exclude the reasons that characterize voluntarily carless households) were assumed to be involuntarily carless. All other carless households were deemed "unclassifiable."

5) A total of 586 (out of 2,156) households did not answer the question above. Our final sample has 325 voluntarily carless, 924 involuntarily carless, and 907 unclassifiable carless households, in addition to 35,282 motorized households.

Table 2. Household Characteristics by Vehicle Ownership Group

Variable	Carless households			Motorized Households (N=35,282)
	Voluntary (N=325)	Involuntary (N=924)	Unclassifiable (N=907)	
Household size				
1	60.9%	59.0%	59.5%	18.9%
2	24.6%	20.1%	23.2%	39.0%
3	7.4%	7.9%	6.8%	16.7%
4	4.9%	6.2%	5.6%	15.1%
5 or more	2.2%	6.8%	4.9%	10.3%
Number of employed household members				
0	47.1%	61.3%	54.4%	19.0%
1	44.6%	32.8%	36.6%	42.4%
2	8.0%	5.2%	7.9%	32.2%
3 or more	0.3%	0.8%	1.1%	6.5%
Annual household income				
<$25,000	56.6%	79.9%	63.1%	13.4%
$25,000 to $49,999	22.5%	15.0%	16.8%	20.7%
$50,000 to $99,999	13.2%	3.8%	11.9%	34.4%
$100,000 to $199,999	6.5%	1.1%	7.4%	24.8%
$200,000 or more	1.2%	0.2%	0.9%	6.7%
Highest household educational achievement				
No high school degree	15.1%	22.4%	15.2%	3.2%
High school graduate	21.5%	27.5%	22.3%	10.0%
Some college	19.4%	19.8%	20.4%	15.2%
Associate degree	11.1%	10.0%	10.9%	12.2%
Bachelor degree	16.9%	12.2%	17.3%	28.9%
Graduate/professional	16.0%	8.1%	13.9%	30.6%
Ethnicity of the household head				
African American	9.5%	13.1%	10.0%	3.1%
Asian	4.9%	2.6%	4.0%	5.9%
Multiple	4.9%	6.0%	5.7%	6.8%
White	62.2%	53.5%	58.1%	68.8%
Other	18.5%	24.9%	22.2%	15.5%
Single family dwelling	25.8%	23.7%	31.4%	77.6%
Population density of block group of residence				
≤1500 people/mi^2	8.3%	10.6%	11.5%	27.9%
1501 to 5000 people/mi^2	15.1%	18.2%	18.7%	25.1%
5001 to 10000 people/mi^2	19.4%	21.9%	20.3%	28.1%
>10000 people/mi^2	57.2%	49.4%	49.5%	18.9%

Table 3. Number of Household (HH) Trips

Category	Carless households			Motorized households (d)
	Voluntarily (a)	Involuntarily (b)	Unclassifiable (c)	
Number of HH with no trips on survey day	71	256	214	4,330
Number of HH who traveled on survey day	254	668	693	30,952
Percentage of HH with no trip on survey day	21.9%^{d}	27.7%^{d}	23.6%^{d}	12.3%^{abc}
Median number of household trips	3^{d}	2^{d}	3^{d}	6^{abc}
Number of trips per adult in the household	2^{d}	2^{cd}	2^{bd}	3^{abc}

Notes: Superscripts ^{abcd} indicate values that are statistically significantly different for post-hoc tests: ^{a} = differs significantly from the value for voluntarily carless households; ^{b} = differs significantly from the value for involuntarily carless households; ^{c} = differs significantly from the value for unclassified carless households; ^{d} = differs significantly from the value for motorized households. Here, before correction or adjustment, α=0.05.

Table 4. Trip Structure

	Category	Carless households			Motorized HH (d)
		Voluntarily (a)	Involuntarily (b)	Unclassifiable (c)	
	Median number of trip segments	1^{d}	1^{cd}	1^{bd}	1^{abc}
	% of linked trips	36.9^{cd}	40.7^{cd}	32.1^{abd}	14.8^{abc}
	Trip distance (mi). Median:	1.29^{bcd}	1.63^{ad}	1.54^{ad}	3.48^{abc}
Median distance (mi) for trips	Work	2.58^{bd}	3.64^{ad}	3.10^{d}	6.44^{abc}
	School / after school	1.98^{d}	1.50^{d}	1.44^{d}	2.36^{abc}
	Civic, recreational, religious, or social	0.85^{bcd}	1.49^{ad}	1.60^{ad}	3.39^{abc}
	Personal business	1.54^{bd}	2.50^{acd}	1.54^{bd}	3.04^{abc}
	Shopping	1.13^{d}	0.85^{d}	0.98^{d}	2.42^{abc}
Distance interval	Up to 1 mile	43.0%^{d}	38.5%^{d}	39.3%^{d}	18.8%^{abc}
	1-2 miles	15.9%	16.9%	17.6%^{d}	15.6%^{c}
	2-5 miles	21.6%^{d}	19.8%^{d}	18.4%^{d}	25.5%^{abc}
	5-15 miles	12.2%^{bcd}	16.9%^{ad}	15.9%^{ad}	23.9%^{abc}
	Over 15 miles	7.3%^{d}	7.8%^{d}	8.8%^{d}	16.2%^{abc}
Med. dist. vs. pop.	<1,500/mi^2	5.25^{bc}	2.54^{ad}	1.91^{ad}	4.69^{bc}
	1,501-5,000/mi^2	2.29^{d}	1.84^{d}	1.76^{d}	3.51^{abc}
	5,001-10,000/mi^2	1.22^{d}	1.66^{d}	1.58^{d}	3.08^{abc}
	>10,000/mi^2	1.03^{bcd}	1.41^{ad}	1.38^{ad}	2.85^{abc}
	Trip duration (min). Median:	15^{bc}	20^{acd}	18^{abd}	15^{bc}
Median duration	Work	23	28^{d}	25^{d}	20^{bc}
	School / after school	16	20^{d}	20^{d}	15^{bc}
	Civic, recreational, religious, or social	15^{b}	20^{ad}	17^{d}	15^{bc}

	Category	Carless households: Voluntarily (a)	Carless households: Involuntarily (b)	Carless households: Unclassifiable (c)	Motorized HH (d)
	Personal business	15[b]	25[acd]	15[bd]	13[bc]
	Shopping	15[d]	15[cd]	15[bd]	10[abc]
Duration interval	< 10 min	34.1%[bd]	28.2%[acd]	32.1%[bd]	39.1%[abc]
	11 to 30 min	43.1%	40.9%[d]	42.0%	43.5%[b]
	31 to 60 min	15.8%[bd]	19.9%[ad]	17.4%[d]	11.8%[abc]
	over 60 min	7.0%[b]	10.9%[acd]	8.5%[bd]	5.6%[bc]
Med. dur. vs. pop. Density	<1,500/mi^2	15	20[d]	20[d]	15[bc]
	1,501-5,000/mi^2	17[d]	20[d]	19[d]	15[abc]
	5,001-10,000/mi^2	18[d]	20[cd]	15[bd]	15[abc]
	>10,000/mi^2	15[bc]	21[acd]	20[abd]	15[bc]
Out-of-home activities. Median number per trip:		1[cd]	1[cd]	1[abd]	1[abc]
Percentage of trips involving…	Work	20.0[b]	11.7[acd]	16.0[bd]	20.9[bc]
	School / after school	5.1[b]	8.7[acd]	5.8[b]	6.4[b]
	Civic, recreational, religious, or social	32.7	31.6[d]	34.2	37.1[b]
	Personal business	18.5	19.3[d]	17.2	15.0[b]
	Shopping	23.7	28.7[d]	26.8[d]	20.6[bc]

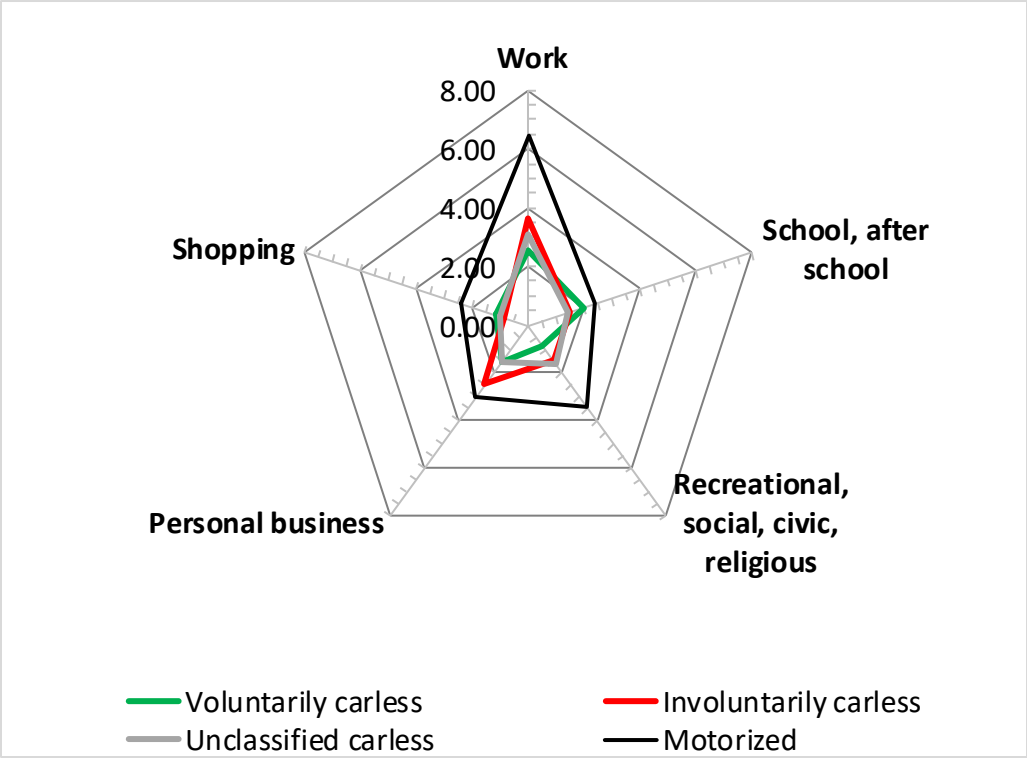
Notes: Superscripts [abcd] indicate statistically significant differences for post-hoc tests: a = Differs from voluntarily carless households; b = Differs from involuntarily carless households; c = Differs from unclassified carless households; d = Differs from motorized households. Before adjustment for multiple post-hoc tests, α=0.05. All joint tests in this table were found to be statistically significant.

Table 5. Travel Modes

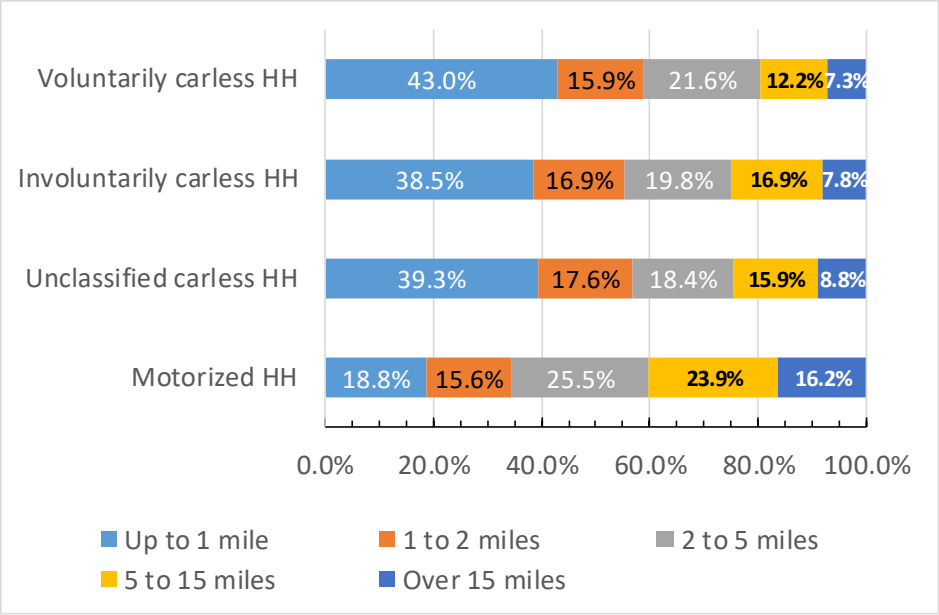
Category			Carless households			Motorized HH (d)
			Voluntary (a)	Involuntary (b)	Unclassifiable (c)	
Mode (% of trips)		Car, taxi, van	20.4%^{cd}	23.3%^{cd}	32.2%^{abd}	87.8%^{abc}
		Transit	28.1%^{bd}	33.8%^{acd}	25.4%^{bd}	2.2%^{abc}
		Walk/bike	49.1%^{bcd}	41.0%^{ad}	40.5%^{ad}	9.5%^{abc}
% of trips with a distance within…	***< 1 mile***	Car, taxi, van	6.3%^{cd}	9.6%^{d}	13.1%^{ad}	60.3%^{abc}
		Transit	4.7%^{d}	5.3%^{d}	3.7%^{d}	0.4%^{abc}
		Walk/Bike	87.2%^{cd}	83.0%^{d}	80.7%^{ad}	38.7%^{abc}
	1 to 2 miles	Car, taxi, van	30.7%^{d}	29.4%^{cd}	38.9%^{bd}	89.6%^{abc}
		Transit	31.7%^{d}	29.2%^{d}	26.4%^{d}	1.5%^{abc}
		Walk/Bike	32.7%^{d}	39.3%^{d}	33.6%^{d}	8.5%^{abc}
	2 to 5 miles	Car, taxi, van	24.4%^{cd}	32.8%^{cd}	47.0%^{abd}	94.9%^{abc}
		Transit	50.4%^{d}	57.5%^{cd}	40.1%^{bd}	2.4%^{abc}
		Walk/Bike	23.7%^{bcd}	8.4%^{ad}	11.5%^{ad}	2.5%^{abc}
	5 to 15 miles	Car, taxi, van	34.6%^{d}	28.0%^{cd}	43.3%^{bd}	95.9%^{abc}
		Transit	53.6%^{bd}	67.8%^{acd}	51.1%^{bd}	3.0%^{abc}
		Walk/Bike	8.5%^{d}	3.3%^{d}	4.2%^{d}	0.9%^{abc}
	> 15 miles	Car, taxi, van	45.1%^{d}	43.0%^{d}	53.4%^{d}	94.6%^{abc}
		Transit	50.6%d	50.2%^{d}	43.3%^{d}	3.8%^{abc}
		Walk/Bike	Too few observations (<5 observations for each carless group)			
Trip purpose	***Work***	Car, taxi, van	24.5%^{cd}	23.8%^{cd}	35.9%^{abd}	84.5%^{abc}
		Transit	29.6%^{d}	34.6%^{cd}	24.6%^{bd}	2.7%^{abc}
		Walk/Bike	44.1%^{d}	39.7%^{d}	37.6%^{d}	12.2%^{abc}
	School/after school	Car, taxi, van	15.1%^{cd}	16.9%^{cd}	29.6%^{abd}	91.9%^{abc}
		Transit	25.5%^{d}	31.8%^{cd}	21.2%^{bd}	1.0%^{abc}
		Walk/Bike	56.8%^{d}	49.4%^{d}	47.0%^{d}	6.9%^{abc}
	Civic, rec., religious, & social	Car, taxi, van	19.1%^{d}	26.6%^{d}	24.4%^{d}	91.2%^{abc}
		Transit	46.9%^{d}	54.9%^{d}	45.2%^{d}	4.1%^{abc}
		Walk/Bike	30.3%^{bd}	17.1%^{acd}	28.5%^{bd}	4.4%^{abc}
	Personal business	Car, taxi, van	22.0%^{cd}	28.1%^{d}	33.4%^{ad}	90.5%^{abc}
		Transit	19.2%^{d}	26.4%^{d}	22.2%^{d}	1.3%^{abc}
		Walk/Bike	55.7%^{bcd}	42.8%^{ad}	42.7%^{ad}	7.7%^{abc}
	Shopping	Car, taxi, van	1.7%^{cd}	9.6%^{d}	17.2%^{ad}	84.9%^{abc}
		Transit	21.7%^{d}	42.3%^{d}	21.0%^{d}	1.6%^{abc}
		Walk/Bike	76.7%^{bd}	48.1%^{ad}	60.8%^{d}	12.9%^{abc}
Population density	***≤ 1,500 people/mi²***	Car, taxi, van	39.3%^{d}	47.3%^{d}	44.5%^{d}	91.4%^{abc}
		Transit	19.7%^{d}	28.5%^{d}	21.2%^{d}	1.6%^{abc}
		Walk/Bike	36.1%^{d}	22.7%^{d}	33.7%^{d}	6.6%^{abc}
	1,501 to 5,000 people/mi²	Car, taxi, van	45.2%^{bd}	31.7%^{ad}	39.9%^{d}	90.3%^{abc}
		Transit	30.1%^{d}	29.0%^{cd}	19.7%^{bd}	1.6%^{abc}
		Walk/Bike	23.1%^{bcd}	37.2%^{ad}	38.9%^{ad}	7.7%^{abc}

5,001 to 10,000 people/mi²	Car, taxi, van	30.8%[cd]	25.0%[cd]	45.8%[abd]	87.9%[abc]
	Transit	21.7%[d]	30.6%[cd]	14.3%[bd]	1.7%[abc]
	Walk/Bike	47.1%[d]	42.0%[d]	36.8%[d]	9.9%[abc]
>10,000 people/mi²	Car, taxi, van	10.1%[bcd]	17.3%[acd]	22.5%[abd]	79.4%[abc]
	Transit	30.1%[bd]	36.9%[acd]	32.2%[bd]	4.8%[abc]
	Walk/Bike	56.8%[bcd]	44.0%[ad]	43.6%[ad]	15.2%[abc]

Notes: Superscripts [abcd] indicate values that are statistically significantly different for post-hoc tests: [a] = differs from the value for voluntarily carless households; [b] = differs from the value for involuntarily carless households; [c] = differs from the value for unclassified carless households; [d] = differs from the value for motorized households. Here, before correction or adjustment, α=0.05. Modes other than car/taxi/van, transit, and walk/bike are omitted because they represent a very small percentage of trips. All joint tests are $\chi^2(3)$ tests and they are statistically significant.

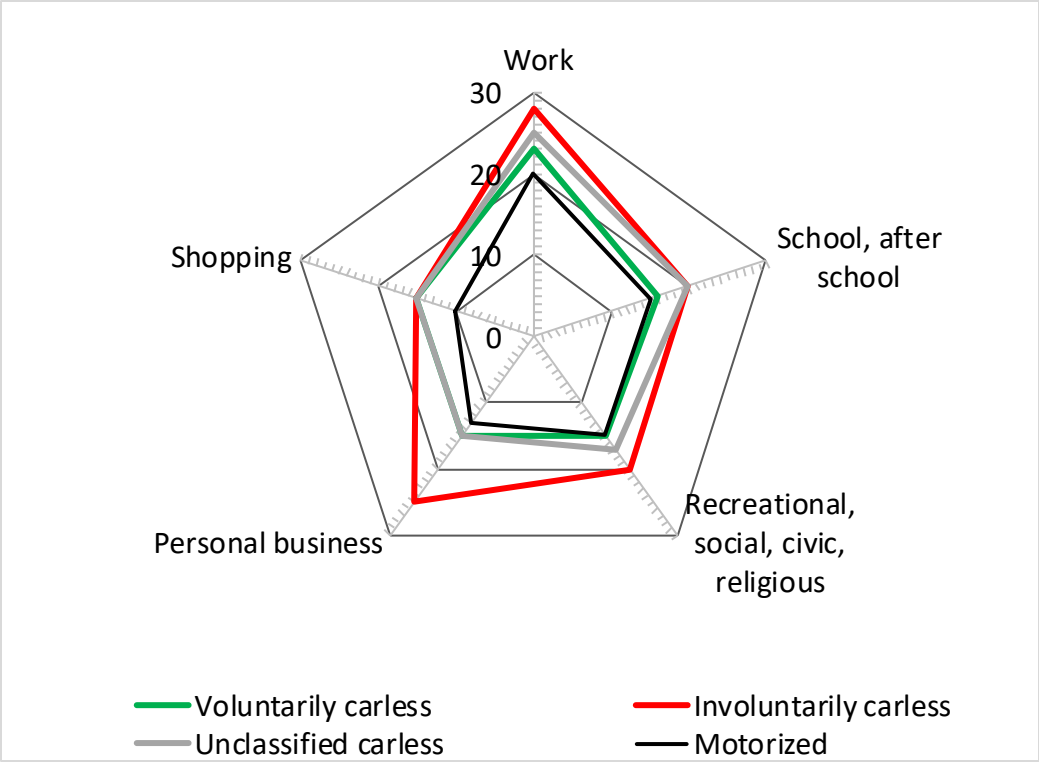


Panel A of Figure 1: Median trip distance (mi) vs. activity

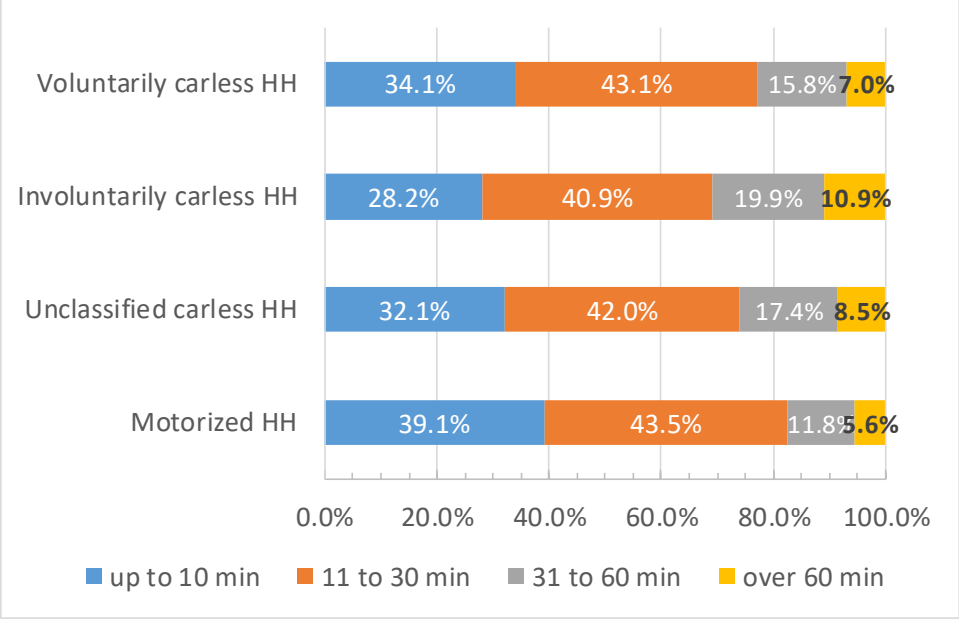


Panel B of Figure 1: Percentage of trips by distance interval

Figure 1. Carlessness and trip distance



Panel A of Figure 2: Median trip duration (min) vs. activity



Panel B of Figure 2: Percentage of trips by duration interval

Figure 2. Carlessness and trip duration

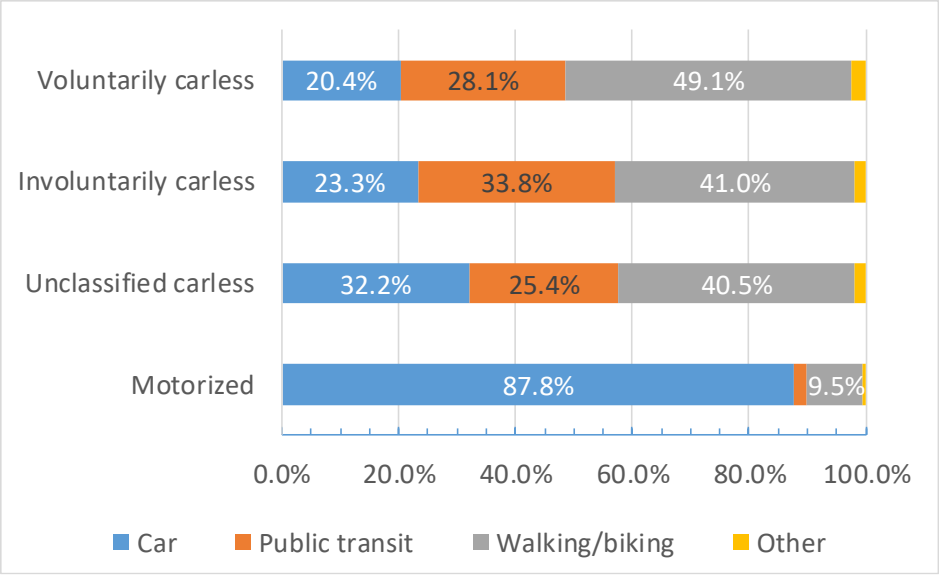


Figure 3. Carlessness and modal shares

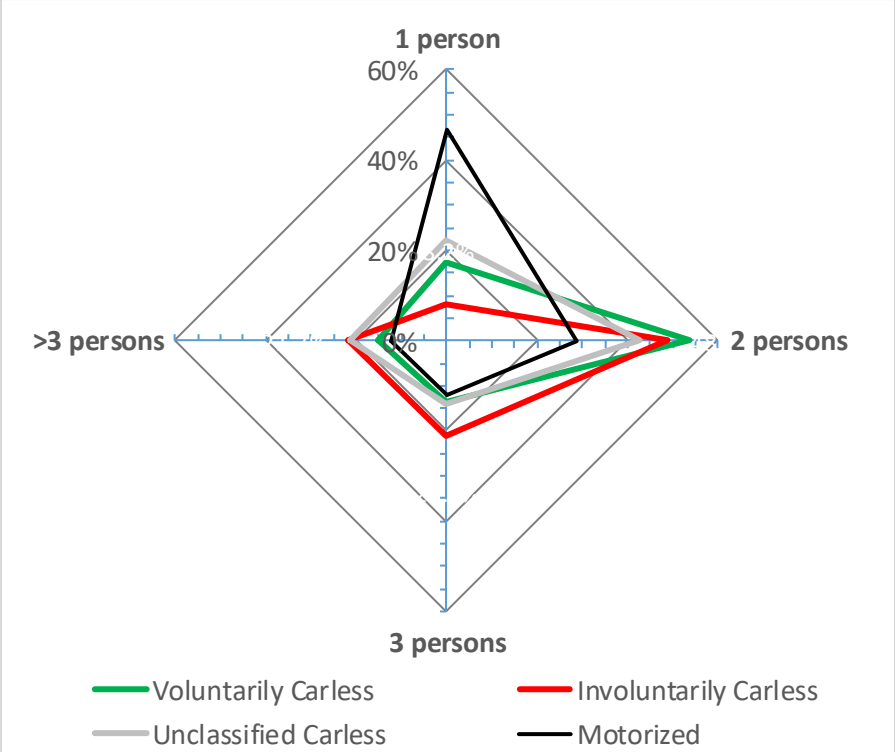


Figure 4. Vehicle occupancy for unlinked car trips