Transportation Research Part A 46 (2012) 1594–1607

Contents lists available at SciVerse ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Attitudes, mode switching behavior, and the built environment: A longitudinal study in the Puget Sound Region

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ARTICLE INFO

Article history:
Received 1 November 2010
Received in revised form 2 July 2012
Accepted 14 August 2012

Keywords:
Mode switching behavior
Attitudes
Perceptions and feelings
The built environment
Density
Carpool

ABSTRACT

Carpooling in the US has a storied history. After experiencing a peak 20% mode share in 1980, the current share of carpooling for work trips is about 10% and the majority of these carpooling trips are made by intra-household members. Casting the choice between SOV and carpool as a social dilemma in which SOV is a noncooperative choice and carpool is a cooperative one, we propose to test two hypotheses. First, the switch from SOV to carpool and the reverse choice are attributed to different factors—structural factors, or those factors altering the objective features of a decision scenario such as travel time and travel cost, play a dominant role in the switch from carpool to SOV while psychosocial factors (attitudes and beliefs) play a critical role in the switch from SOV to carpool. Second, the two choices are underlay by different behavioral mechanisms. In particular, we expect self-justification by carpool-to-SOV switchers—after they switch from carpool to SOV, they adjusted their attitudes toward carpool accordingly to match their behavior. The analysis of the first three waves of the Puget Sound Transportation Panel supports these two hypotheses. Our study results recommend developing programs and policies that aim at influencing people's subjective assessments of carpooling, in addition to the existing ones that mostly focus on incentivizing carpooling, and differentiating between programs seeking to encourage SOV users to switch to carpool and those aiming to maintain existing carpoolers.

1. Introduction

While congestion can occur at any hour and on any day of the week, it is still typically the worst at peak hours when people commute to and from work (Redmond and Mokhtarian, 2001)—commuting remains at the core of the transportation problems (Horner, 2004). Every day, nearly 140 million workers commute to work (Census Bureau, 2009). Except for a few regions, single occupancy vehicle driving (SOV) is still the choice of the vast majority. As of 2009, the shares of commutes made by SOV, carpool,[1] transit, and other modes are 76%, 10%, 5%, and 9%, respectively (Census Bureau, 2009). Among motorized modes, if SOV is at one end of the spectrum for efficiency, comfort, and flexibility and transit is at the other end of the spectrum for pro-environmentalism, carpool falls somewhere in between—it can offer more efficiency, comfort, and flexibility than transit and it is a more socially desirable mode than SOV in reducing congestion and pollution.

Carpool in the US has a storied history. Motivated by fuel shortages throughout the US and the accompanied higher fuel costs (Ferguson, 1997) and widespread public concerns, carpool enjoyed a 19.7% mode share in 1980 (Census Bureau, 2010). In 2009, its share is about 10% (Census Bureau, 2009). The decline in the last 30 years is accompanied by the greater use of HOV and HOT lanes (Brookings Institute, 2004). Today, amid increasing congestion and environmental concerns, carpool is

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[1] Includes vanpool.

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http://dx.doi.org/10.1016/j.tra.2012.08.001

once again on the agenda for many local governments. For example, Washington State Department of Transportation recently started a Flexible Carpool Pilot Project that will potentially allow drivers and riders to arrange shared rides on the fly (Washington State Department of Transportation, 2010). Many others have also started ride-matching programs (Johnson et al., 2010). It is the hope of the many that carpooling, which requires less infrastructure investment than transit, may once again become a significant alternative mode, with the aid of technology.

The existing literature on mode choice points out multiple factors that can explain the choice of choosing or not choosing carpool. These factors can be broadly categorized as the structural factors that describe the objective characteristics of a decision scenario and those person-level psychosocial factors that capture one's cognitive assessment of a mode, for example, attitudes toward carpool and beliefs about the benefits of carpooling. The structural factors can be further divided into those describing the alternatives like travel time and travel cost and those describing the environment under which a commute trip is made, for example, the density surrounding home and workplace (Ben-Akiva and Lerman, 1985). The literature pertaining to carpool suggests that both structural and psychosocial factors are important (Duecker et al., 1977; Li et al., 2007; New York State Department of Transportation, 1977; Teal, 1987).

Many of the existing studies on mode choice rely on cross-sectional datasets, which assume static choices (Kitamura, 1990)—individuals are assumed to choose one from a set of multiple alternatives, whereas in reality, people contemplate whether to switch from a default, usually habitual one to a new choice. Symmetry is another assumed property of these studies (Kitamura, 1990)—in the context of a mode switch between SOV and carpool, this means that the decision process underlying the switch from SOV to carpool is the same as the reverse one from carpool to SOV. We argue, in this paper, that these two choices are likely attributed to different factors. To substantiate this argument, we discuss two relevant concepts: social dilemma and cognitive dissonance. The decision to drive alone or carpool can be framed as a social dilemma (Vugt et al., 1996). Social dilemma describes a situation in which individuals receive greater outcomes by making noncooperative choices (e.g., driving alone), but each individual is better off if all or most make cooperative choices (e.g., carpool). In a scenario where the noncooperative choice is made by most people, it is likely the utility of the noncooperative option derived from the structural factors outweighs that of the cooperative option. Yet, a small share of the population still chooses the cooperative option. Though it is possible that for these people, the utility of choosing the cooperative choice based on the structural factors is greater than that of the noncooperative choice, it is also likely that this small segment of the population is different from the majority—the determining factors of their choices are not structural factors, but person-level cognitive ones. This notion is supported by both empirical studies in carpool (Duecker et al., 1977; Horowitz and Sheth, 1978; Li et al., 2007; New York State Department of Transportation, 1977) and anecdotal evidence—some respondents have indicated that "saving money on fuel and parking is important, but the environmental benefits provide the real motivation" (Johnson et al., 2010).

Not only that the factors contributing to the choice from SOV to carpool may be different from those to the mode switch from carpool to SOV, but also, we argue that the underlying behavioral mechanisms may differ between the two choices. Structural factors, psychosocial factors, and behavioral outcome form three interdependent axes in a decision scenario (Bandura, 1986), i.e., while structural factors and psychosocial factors clearly have an influence on behavior, it is also possible that behavior extends to psychosocial factors such as attitudes and beliefs. This phenomenon is supported by the theory of cognitive dissonance (Festinger, 1957) and is particularly associated with the choice of the noncooperative option in a social dilemma—people were found to adjust their attitudes after choosing the noncooperative option (Vugt et al., 1996, 1995).

In this paper, we apply the Puget Sound Transportation Panel to distinguish between the mode switch from SOV to carpool and the reverse one from carpool to SOV. In doing so, we seek to uncover the differential factors that contribute to these two different mode-switching decisions and the behavioral mechanisms that underlie the two. We postulate two hypotheses. First, structural factors play a more important role than psychosocial factors in the mode switch from carpool to SOV, whereas the reverse is true for the mode switch from carpool to SOV. Second, in the mode switch from carpool to SOV, people adjust their attitudes to match their choice of SOV. We employ two structural equations models to test these two hypotheses.

Distinguishing the factors as well as the behavioral processes underlying these two different mode-switching choices has important policy implications. Most of the existing programs promoting carpool focus on structural factors. If our first hypothesis were true—structural factors and psychosocial factors dominate in the choices from carpool to SOV and from SOV to carpool, respectively, it would suggest developing different, targeted policies for SOV and carpool users, respectively. To encourage more people to switch from SOV to carpool, not only incentives of carpool are needed, but also policies promoting affection toward carpool are necessary and important. To discourage people from switching from carpool to SOV, we should break those structural links that promote the choice of SOV over carpool. In addition, effective policies may need to distinguish those that promote the incentives of carpool (e.g., creation of HOV/HOT lanes) from those that discourage SOV (e.g., tolls and gasoline tax).

In addition to the potential implications in policy making, the study is innovative in three aspects. First, different from most of the studies that assume a symmetric choice process, it explicitly tests the hypothesis that the switch from SOV to carpool may be fundamentally different from the one from carpool to SOV. Second, it is one of the first studies that examine the possible bi-directional process between mode switching and changes in attitudes, through which we test the presence of cognitive dissonance and identify post-adjustment in attitudes after the choice is made. The behavioral insights obtained in this study contribute directly to the literature of travel behavior dynamics that, despite its importance (Kitamura, 1990), has not been given sufficient attention. Lastly, though there are numerous studies investigating the impact of the built environment and that of attitudes on travel behavior separately, only a limited number of them examined both at the same time. This study is one of them. Our results demonstrate the importance of both.

The rest of the paper is organized as follows. In Section 2, we offer a review of the pertinent literature, with a focus on attitudes and travel behavior. Given the recent interest in the built environment, we also reviewed relevant studies relating to the built environment, attitudes, and travel behavior. In Section 3, we describe our empirical datasets. The two structural equations systems employed to test the two hypotheses stated above are specified in Section 4. The results and the discussion follow in Sections 5 and 6.

2. Attitudes and travel behavior

Attitudes constitute a key component of psychosocial factors (Bandura, 1986). Introducing attitudes as explanatory variable based on the attitude–behavior relations in social psychology has been demonstrated to increase the power of models in explaining travel behavior (Anable, 2005; Johansson et al., 2006; Nilsson and Küller, 2000). Social psychologists generally agree on three types of attitudes: perceptions (cognitions), which refer to the evaluation about some attributes of an object; feelings, which reflect the affect or liking; and conation, which encompasses one's motivation, the intention, and the drive of performing a behavior (Golob, 2001). Attitude plays an important role in triggering a behavioral change. The theory of planned behavior (Ajzen, 1991) hypothesizes three principal axes in affecting behavioral change: attitude referring to one's evaluation of a specific behavior, subjective norm reflecting the social pressure associated with the conduct of the behavior, and perceived behavioral control as a measure of ease in successfully performing a behavior. This conceptual framework, which is supported by many empirical works of travel behavior (Bamberg et al., 2003; Bamberg and Schmidt, 2001; Fujii and Kitamura, 2003), suggests that interventions in attitudes can result in a change in travel behavior. In the great number of studies seeking to understand the formation and the use of carpooling, attitudinal variables have also been found mostly important (Duecker et al., 1977; Horowitz and Sheth, 1978; Li et al., 2007; New York State Department of Transportation, 1977) in addition to the structural factors such as travel time and cost savings (Ferguson, 1997; Hunt and McMillan, 1997; Teal, 1987), reliability, and vehicle shortage (Ferguson, 1997; Teal, 1987).

The attitude–travel behavior researchers primarily focus on the first two categories of attitudes: perceptions and feelings (Choo and Mokhtarian, 2004; Dobson et al., 1978; Golob, 2001; Golob et al., 1979; Hensher et al., 1975; Koppelman and Lyon, 1981; Levin, 1979; Mokhtarian and Salomon, 2001, 1997; Ory and Mokhtarian, 2005). In one of the early studies on attitudes and travel behavior (Koppelman and Lyon, 1981), perceptions are an overall evaluation of travel modes based on their characteristics; feelings refer to the liking and personal norms of travel modes. These two items are associated to mode choice by a mediator—"preference". Jointly modeled are "situational constraints", which are related to automobile accessibility. This model explained a considerable amount of variation in mode choice behavior. The attitudinal factors that are found important in carpool related literature can also be associated with these two terms. In particular, perceptions of carpool relate to the ease in finding a ride partner, the ability to use HOV lanes to save travel time and cost (Li et al., 2007; Washington State Department of Transportation, 2007), reliability (Burris et al., 2007), and reduced level of stress (Washington State Department of Transportation, 2007). Feelings of carpool include enjoyment of the journey (Li et al., 2007) and one's belief about the societal and environmental benefits of carpooling (Li et al., 2007).

While the link from attitudes to travel behavior is both theoretically established and empirically supported, the reverse direction—people modify their attitudes to match travel behavior, is also possible. Theory of cognitive dissonance (Festinger, 1957) hypothesizes that when there is a mismatch between attitudes and behavior (for example, one who thinks that transit is good for the society may drive a gas guzzler), people experience psychological tension and thus modify their attitudes to justify the behavior or alter behavior to match attitudes.

Empirical evidence supports this reverse link from behavior to attitudes. Golob et al. (1979) asked the respondents to rate the degree of importance on a set of alternative attributes. It was found that the ratings favor the chosen alternatives. Levin (1979), with another sample, confirmed Golob et al.'s findings by observing that people placed more weight on those attributes supporting their chosen alternative. Tertoolen et al. (1998) studied the impact of providing feedback on people's private car use. After the environmentally-conscious people were told that they drove more than they anticipated, they reduced their environmental awareness to match their behavior. Vugt et al. (1996) examined solo drivers' levels of support towards carpooling before and after the first construction of a carpool lane in Europe and found a decrease in support. The reduction was likely made to justify their continued use of SOV, after the construction of the carpool lane.

Some researchers set out to understand the relative causality between attitudes and travel behavior. Tardiff (1977) defined an attitudinal variable capturing the difference in the overall satisfaction of bus and car based on eight modal attributes, such as cost and convenience, and found that the link from mode choice to attitudes overshadowed the reverse direction. Dobson et al. (1978) developed two attitudinal variables: "belief"[2] and "affect" to represent perceptions and satisfactions of bus separately. When "affect" was used as a mediator between "belief" and the frequency of bus use, the interdependence between the two was found. However, when "affect" was removed, they found that a change in the frequency of bus use led to a change in "belief", but not vice versa. Another example is Golob's study (2001), in which people's attitudes on acceptability, fairness, and effectiveness of a pricing project were separately modeled with travel demand by mode. Significant influences of travel demand on attitudes were found in all models, while no significant links from attitudes to travel demand were found.

[2] Similar to perceptions by Koppelman and Lyon (1981).

The recent interest in the role of the built environment in travel behavior has resulted in only a few studies that jointly examined attitudes, the built environment, and travel behavior. The results of these studies have generally supported the role of attitudes, regardless the significance of the built environment. In an analysis of five neighborhoods in the San Francisco Bay Area, Kitamura et al. (1997) found that once attitudinal variables about urban life were brought in, the ability of neighborhood descriptors in explaining the variation of trip generation by mode and modal split decreased. In another study, Bagley and Mokhtarian (2002) concluded that neighborhood type had the least impact on travel demand compared with those of attitudinal and lifecycle variables. Supporting these results, Lund (2003) found that attitudes towards walking were of greatest significance in predicting the frequency of walking trips, while no significant relationship between neighborhood variables and the frequency of strolling trips was identified. In a quasi-longitudinal experiment, Handy et al. (2005) demonstrated the impact of neighborhood type on travel behavior after accounting for the attitudes toward travel preferences—both attitudes and neighborhood type variables were significant. In a study analyzing children's travel mode choices, McMillan (2007) concluded that though the urban form of a neighborhood was important, its impact was modest compared with that of attitudes. In a study comparing the roles of the built environment and attitudes, Schwanen and Mokhtarian (2005) found a differential role intersected by the type of neighborhood—in an urban environment, the power of neighborhood and attitudinal variables seemed to be balanced, whereas neighborhood variables prevailed in a suburban environment.

Attitudes are conventionally elicited in surveys by asking respondents their degrees of agreement to a set of statements. Attitudes can also be thought as reflections of beliefs and values, which reside at a deeper level in individuals (Oppenheim, 1992). These underlying beliefs and values can be viewed as latent factors of the observed responses to attitudinal statements. In theory, these latent factors are thought to more accurately reflect people's psychosocial dispositions. One of the earlier studies using these latent constructs is by Train et al. (1987), who used two latent factors: belief in personal effectiveness in saving energy and belief in something should be done to save energy. They found that the former was an important drive of switching to a new rate schedule of electricity. Later studies found similar results. In one study of integrating attitudes into a choice model, Ashok et al. (2002) constructed two latent variables—the satisfaction with the current service and the cost of switching to a new one to explain the switching behavior of the customers of a cable television provider. In another study, they modeled the switching behavior of the customers of a health care provider as a function of latent satisfaction with the cost and coverage of the current service. In both studies, the authors stated that integrating latent variables improved the overall model performance. A recent example in travel choices can be found in Choo and Mokhtarian (2004), where latent attitudes were found a significant influence in explaining the choice of vehicle type.

It has also been argued that the derivation of the latent factors of the attitudinal statements is best obtained simultaneously with the estimation of the choice model (Train et al., 1987). Furthermore, those latent constructs may also be influenced by some explanatory variables, which also enter the utility function for the choice model. First introduced into marketing research by McFadden (1986), such model is one of the extensions of the conventional random utility model (Walker and Ben-Akiva, 2002). Ben-Akiva et al. (2002) elaborated this model and demonstrated its applications in three case studies. In the first study, two latent factors—ride comfort and convenience—affected the mode choice and, in the meantime, were determined by traveler characteristics and other observed mode attributes. In the second study, the impacts of the latent cost and benefits of a telecommuting program on its adoption were investigated. The latent variables were explained by the characteristics of the subjects and other observed attributes of the program. In the third study, the latent satisfaction with a traveler information system was modeled as a determinant of the willingness-to-pay and influenced by characteristics of travelers and observed attributes of the system. In all three studies, the authors concluded that the latent variables enriched the understanding of the decision process of choice behavior. This statement is also corroborated by more recent studies using latent factors to understand travel choices (Atasoy et al., 2010; Johansson et al., 2006). In contrast, the impacts of the explanatory variables on the latent variables turned out to be marginal.

3. Data

We apply the Puget Sound Transportation Panel (PSTP) in this study. Between 1989 and 2002, the Puget Sound Regional Council conducted 10 waves of general-purpose travel surveys and eight waves of follow-up Attitudes and Values survey. In each general-purpose travel survey, people who were 15 years old or above were asked to fill out a 2-day travel diary. The panel dataset is composed of approximately 2000 households in four counties in the state of Washington: King, Kitsap, Pierce, and Snohomish counties. In addition to collecting information on travel behavior and attitudes, the panel survey also collected information on respondents' socio-demographics. Because the entire panel spanned over 10 years, it is inevitable that there have been some changes in the questionnaire to reflect changes in the population and new policy interests. Consequently attitudinal and value related questions also experienced changes. Since we are interested in understanding changes in people's attitudes over time, it is important that the instrument used to measure attitudes remains the same over time. Thus, we pooled three waves of the Attitudes and Value surveys: 1990, 1993, and 1996; these three waves have the same set of questions on attitudes. They correspond to travel surveys conducted in 1989, 1993, and 1996.

3.1. Sample selection and mode choice

The focus of this study is on the mode choice of the home-work trip. For each respondent participating in at least two waves of the 1989, 1993, and 1996 surveys, the primary commute mode was identified in each wave. The primary mode

Table 1
Characteristics of the study sample and the regional sample.

	Regional sample		Study sample	
Gender	Male 48%	Female 52%	Male 48%	Female 52%
Income	<$35,000 35%	⩾$35,000 65%	<$35,000 26%	⩾$35,000 74%
	Mean	Std.	Mean	Std.
Household size	2.53	1.29	2.83	1.16
# Of vehicles	2.14	1.17	2.42	0.99
# Of employed	1.18	0.91	1.75	0.59

is defined as the mode that was most frequently used for commute trips. A total of 2221 respondents were identified as those who participated in at least two of the 1989, 1993, and 1996 waves. Among them, 212 respondents switched modes from one wave to another and only about 5% (about 10 people) of these mode switchers selected transit or non-motorized modes. These users of transit or non-motorized modes were then dropped from the sample due to their small sample size. In this study, we focus on mode switching between SOV and carpool. The final sample consists of 1804 respondents, who used either SOV or carpool as their primary commute mode in any two of the three waves identified. In other words, each respondent appeared in two waves in our sample. The initial wave is called the baseline wave; the latter wave is called the subsequent wave. Because there are three waves available, it is possible that the baseline wave or the subsequent wave may differ for different subjects.

The final sample for the study comprises four groups of participants: SOV stayers (people who used SOV in two waves), SOV to carpool switchers (people who used SOV in the baseline wave, but switched to carpool in the subsequent wave), carpool stayers (people who carpooled in two waves), and carpool to SOV switchers (people who carpooled in the baseline wave, but switched to SOV in the subsequent wave).[3] The vast majority (1510) of the sample are SOV stayers compared to 92 carpool stayers. Only 65 people switched from SOV to carpool; and 137 people switched from carpool to SOV. These numbers indicate a strong reliance on automobile driving in the Puget Sound Region during the early 1990s.

3.2. Socio-demographic variables

Table 1 compares the characteristics of the study sample and the regional sample. Seventy four percent of the households in the study sample have a household income of $35,000 or more as opposed to 65% in the regional sample. The gender split is identical between the two samples. Households in the study sample on average are larger, have more vehicles, and have more people employed.

Table 2 shows the distribution of the study sample in the baseline wave and the changes between the baseline and the subsequent wave for each of the four groups on three variables: number of the employed (Golob, 2001), number of vehicles (Teal, 1987), and household income.[4] We observe (Table 2) that the SOV to carpool switchers experience an increase in the number of vehicles in the household compared with other groups. The number of vehicles measures one's access to vehicles: A higher level of vehicle access is expected to induce a higher level of demand for driving alone. Yet, the group that has the largest share of respondents with an increase in vehicle ownership is the SOV to carpool switchers, closely followed by the carpool to SOV switchers. About 60% of the SOV stayers and carpool stayers experience no change in vehicle ownership. About one third of the SOV to carpool and carpool to SOV switchers experience an increase in the number of vehicles in their households, compared to the 15–20% range in the other two groups. In terms of household income, the carpool to SOV group has a higher share of households associated with an increase in incomes.

3.3. Attitudinal variables

In the PSTP Attitudes and Values survey, a total of 23 questions were used to measure respondents' attitudes towards different modes of transportation (driving alone, bus, carpool, etc.), each being presented as a mode-specific statement and the respondent was asked to select the most appropriate point on a 7-point agree–disagree scale with 1 being "very strongly disagree", 4 being neutral, and 7 being "very strongly agree". Most of the attitude–travel behavior studies treated these Likert-scale scores as interval variables (Dobson et al., 1978; Reibstein et al., 1980) based on the implicit assumption that the differences between adjacent intervals are equal. This means that the difference between "strongly disagree" and "disagree" is treated the same as that between "agree" and "strongly agree". This assumption has been demonstrated to lead

[3] If a person's mode choices in the three waves were SOV, SOV and carpool, respectively, we selected the 2nd and the 3rd wave for this subject and he/she is identified as SOV to carpool switcher.

[4] These three characteristics are selected based on two criteria: (1) they have been found important in the choice of carpool in the literature; and (2) there is a significant change (at 5% level) on the attribute from the baseline to the subsequent wave.

Table 2
Distributions of the four groups in the study sample on number of vehicles, number of employed, and household income.

Mode transitions (sample size)	Number of respondents in each category						
	Number of vehicles						
	Baseline				Change (%)		
	⩽1	2	3	⩾4	Increase	No change	Decrease
SOV–carpool (65)	7	36	13	9	23 (35%)	33 (51%)	9 (14%)
SOV–SOV(1510)	202	717	418	173	302 (20%)	930 (62%)	278 (18%)
Carpool–SOV (137)	20	74	28	15	44 (32%)	71 (52%)	22 (16%)
Carpool–carpool (92)	11	41	28	12	14 (15%)	54 (59%)	24 (26%)
	Number of employed						
	Baseline				Change (%)		
	⩽1	2	3	⩾4	Increase	No change	Decrease
SOV–carpool (65)	16	43	6	0	9 (14%)	49 (75%)	7 (11%)
SOV–SOV (1510)	504	922	75	9	153 (10%)	1143 (76%)	214 (14%)
Carpool–SOV (137)	32	93	8	4	15 (11%)	96 (70%)	26 (19%)
Carpool–carpool (92)	25	61	6	0	9 (10%)	68 (74%)	15 (16%)
	Income group (0, if household income < $35,000[a]; otherwise, 1)						
	Baseline wave				Change (%)[b]		
	0		1		0 → 1		1 → 0
SOV–carpool (65)	20		45		11 (17%)		3 (5%)
SOV–SOV (1510)	404		1106		211 (14%)		45 (3%)
Carpool–SOV (137)	37		100		26 (19%)		1 (0.7%)
Carpool–carpool (92)	18		74		8 (9%)		2 (2%)

[a] The only consistent cutting point defining income categories in three waves is $35,000.
[b] Percent of those (one of the four groups: SOV-carpool, SOV-SOV, Carpool-SOV, and Carpool-carpool) who experienced a change in household income.

to misleading results (Long, 1997). Factor or principal component analysis, whose aim is to reduce the number of variables by identifying the underlying linearly-combined factors that cause the covariance of the measured variables, is deemed more appropriate in handling a large number of attitudinal questions (Gorsuch, 1990; Velicer and Jackson, 1990). In Kitamura et al. (1997) study, eight factors were generated from 39 attitudinal questions in predicting mobility. In another study, the 39 attitudinal statements were reduced into 10 components, which were then used in the behavioral model (Bagley and Mokhtarian, 2002).

Though both deriving factors, factor analysis is fundamentally different from principal component analysis in that the factors from the former underlie the observed attitudinal variables and the factors from the latter can be viewed as the aggregates of the observed ones. In theory, individuals' feelings and perceptions are better reflected by the latent factors from the factor analysis than from the principal component analysis. In practice, this is not always feasible for two reasons. First, the factors derived from attitudinal statements often only capture a small percentage of the variation in the observed attitudinal statements, resulting in difficulty in estimation. In this study, an exploratory factor analysis showed that the first 12 factors explained less than 50% of the total variation in the 23 attitudinal statements. In other words, the responses seem too dispersed to be legitimate indicators of a few latent constructs. Secondly, different from the previous studies that examined attitudes' role in determining choice behavior, this study hypothesizes a possible bi-directional link between attitudes and behavior and seek to separate the two. This could pose significant computational difficulty if we attempt a simultaneous estimation of multiple endogenous variables and latent factors underlying the attitudinal statements. With these concerns, we applied the Principal Component Analysis (PCA) to reduce the dimensionality of these 23 attitudinal questions. In the last section, we discuss the implications of using PCA in the study.

PCA identified six components, which explained 65% of the total variation in the responses to the 23 attitudinal statements. Among these six components, two are relevant to SOV and carpool: Component 1—perceived difficulty of carpool and Component 2—feelings of carpool (Table 3).[5]

Component 1 measures the perceived level of difficulty in using carpool as a commute mode. It is constructed based on four types of statements relating to being able to identify a carpool companion ("I don't know anyone to carpool with" and "It's easy to find someone I can carpool with"), coordinating a jointly acceptable carpool schedule ("My schedule is too erratic to be in a carpool"), and having to rely on someone ("I don't want to rely on someone else to pick me up on time"). Component 2 measures "feelings of carpool", capturing people's affective bias towards carpooling, not only as a personal liking—"Carpooling is an enjoyable way to travel" but also as a normative support—"More freeway carpool lanes should be built" and "It's not fair to have special lanes set aside for buses and carpools".

[5] We also estimated models with all six components, but only two came out significant.

Table 3
Questions that define two principal components.

Statement loaded heavily on the following components	
Component 1: perceived difficulty of carpool	
I do not know anyone to carpool with	+
It is easy to find someone I can carpool with	–
My schedule is too erratic to be in a carpool	+
I do not want to rely on someone else to pick me up to get to work on time	+
Component 2: feelings of carpool	
More freeway carpool lanes should be built	+
It is not fair to have special lanes set aside for buses and carpools	–
Carpooling is an enjoyable way to travel	+

Table 4
Attitudinal components scores summary.

Mode transition	Baseline		Change in	
	Perceptions of carpool	Feelings of carpool	Perceptions of carpool	Feelings of carpool
Carpool–SOV N = 137				
Mean	2.95	2.45	1.05	–0.19
S.D.	2.22	1.07	2.43	1.1
Carpool–carpool N = 92				
Mean	2.18	2.27	0.16	–0.07
S.D.	2.4	1.39	2.7	1.4
SOV–carpool N = 65				
Mean	4.35	1.93	–0.37	0.29
S.D.	1.7	0.95	2.67	1.15
SOV–SOV N = 1510				
Mean	4.55	2.05	0.05	–0.12
S.D.	1.7	1.02	1.86	1.02

A higher score in Component 1 (perceived difficulty of carpool) suggests a lower level of feasibility of using carpool for commute. A higher score in Component 2 (feelings of carpool) reflects a more positive affective bias towards carpool. The means and standard deviations (S.D.) of the two components scores are summarized in Table 4. The baseline value was observed in baseline wave and the change is calculated as difference between baseline wave and the subsequent wave.

Table 4 shows that those who carpooled in the baseline wave have lower scores on "perceived difficulty of carpool" and higher scores on "feelings of carpool", suggesting that they are more likely to view carpool as a feasible mode of transportation and they have a higher level of affection toward it than those SOV users in the baseline wave. There is a contrast in the change of "perceived difficulty of carpool" between the SOV to carpool switchers and the carpool to SOV switchers. The scores of Component 1 for the former group decreased while those of the latter group increased. In other words, those SOV to carpool switchers are more likely to perceive carpool as a feasible mode of transportation than those carpool to SOV switchers. The same applies to Component 2, measuring affections toward carpool—the carpool to SOV switchers adjusted their affections downward and the SOV to carpool switchers adjusted their feelings upward.

3.4. The built environment variables

The significance of the built environment variables was identified in a number of studies (Cao et al., 2006; Chen et al., 2008; Ewing and Cervero, 2001; Limanond and Niemeier, 2003). In this study, we only used population density at home Traffic Analysis Zone (TAZ) and employment density at the workplace TAZ to represent the built environment effect. The use of density to represent the built environment is a result of the data limitation. Though density is only one dimension of the built environment effect, it is often highly correlated with other dimensions such as diversity and design (Cervero and Kockelman, 1997). Furthermore, the primary focus of the study is not about the built environment impact on mode choice decisions, but rather to differentiate between the roles of structural and psychosocial factors in the mode switches between SOV and carpool. Thus, it is felt that density can be used as a proxy in this study to represent not only the congestion effect but also a range of amenities an area offers (Papas et al., 2007). Higher density usually suggests an environment unfavorable for single vehicle driving.

The means and standard deviations (S.D.) of these two variables are presented in Table 5. While the baseline carpoolers have a relatively higher level of employment density than the baseline SOV users, there is no discernible difference in terms

Table 5
Density (persons/square miles) summary.

Mode transition	Baseline		Change in	
	ln(employment density)	ln(population density)	ln(employment density)	ln(population density)
SOV–carpool N = 65				
Mean	7.58	7.74	−0.31	0
S.D.	2.09	0.97	2.04	0.53
SOV–SOV N = 1510				
Mean	7.69	7.63	−0.1	−0.04
S.D.	1.83	1.21	1.19	0.43
Carpool–SOV N = 137				
Mean	8.34	7.78	−0.15	−0.12
S.D.	2.14	1.11	0.68	0.6
Carpool–carpool N = 92				
Mean	8.51	7.19	0.03	0.01
S.D.	2.08	1.41	0.87	0.26

of population density. Though the magnitudes of the change in these two built environment variables are quite small, carpool stayers appear to experience increases in both population and employment density. In contrast, decreases in both variables are associated with carpool to SOV switchers and SOV stayers. We also note that overall, decreases in population and employment densities override increases—probably reflective of a pattern of de-densification associated with suburban sprawl in the region during the study period (Limanond and Niemeier, 2003).

4. Model specification

Structure Equations Modeling (SEM) was employed to capture the interdependence between changes in attitudes and mode switching behavior between SOV and carpool. SEM has the advantage of inferring relative causality (regression effects) between multiple endogenous variables. The three endogenous variables in our model are: $\Delta COMP1$—change in the perceived difficulty of carpool (Component 1), $\Delta COMP2$—change in the feelings of carpool (Component 2), and demand for the mode switch between SOV and carpool. Demand for the mode switch is a latent variable related to the observed mode switching behavior. The model is depicted in Fig. 1.[6]

The demand for mode switch has different meanings depending on the primary commute mode in baseline wave. If the baseline mode is SOV, it refers to the demand for switching to carpool; if the baseline mode is carpool, it is the demand for switching to SOV. We developed two SEMs for those who used carpool and SOV in the baseline wave, respectively. These two models are identified as: carpool-to-SOV model and SOV-to-carpool model. In the carpool-to-SOV model, the observed mode choice can be viewed as an ordered-categorical variable, such that if the latent demand for switching exceeds a threshold τ, the person would be observed to have switched to SOV; otherwise, he/she stayed with carpool. This threshold τ can be generally seen as the "cost" of switching—the time needed to adapt to a new mode, or the psychological tension experienced when the attributes of the mode change, etc (Calem and Mester, 1995; Farrell and Shapiro, 1988). The same reasoning applies to the SOV-to-carpool model.

Three socio-demographic variables are included: change in the number of the employed ($\Delta NUMEMP$), change in the number of vehicles per person ($\Delta AVRVEH$), and change in household income (ΔINC). We expect a decrease in the number of employed, or an increase in the number of vehicles per person or household income will result in a higher level of likelihood of choosing SOV. The built environment effect is measured by two density variables: change in population density at home TAZ ($\Delta LNPOPCEN$) and change in employment density at workplace TAZ ($\Delta LNEMPDEN$). Increases in these two variables are expected to be associated with a lower likelihood of choosing SOV. To obtain the proper scale, these two density variables are log-transformed. Serving as a proxy for flexibility in work schedule, the number of working hours ($\Delta DURATION$) is also included, indicating the effect of flexibility has on behavioral change. The findings on this construct are mixed: Cervero and Griesenbeck (1988) found that flexible work time hinders the formation of carpools; on the other hand, it tends to make people concern less about the uncertainty in travel time by carpool (Giuliano, 2007). Trip chaining can also potentially affect behavioral changes: Bhat (1997), for example, showed that solo-drivers who made more stops during commute were less likely to switch to other alternatives. To account for this, we use the number of stops during a work tour ($\Delta NUMSTOP$) to measure trip chaining behavior. Lastly, commute time ($TIME$) is introduced into the model as a measurement of separation between home and workplace. From a cost perspective, a larger separation between home and work is likely to be associated with carpool. On the other hand, a long trip may magnify some unfavorable characteristics of carpool, like discomfort, thus making carpool worse off.

[6] We also tried multiple model specifications modeling the change in components score as a function of structural factors, but no structural factors seemed to enter the model significantly in explaining the change in component score, which is consistent with the findings by Ben-Akiva et al. (2002). To reduce the complexity of the model, we excluded those links our final models.

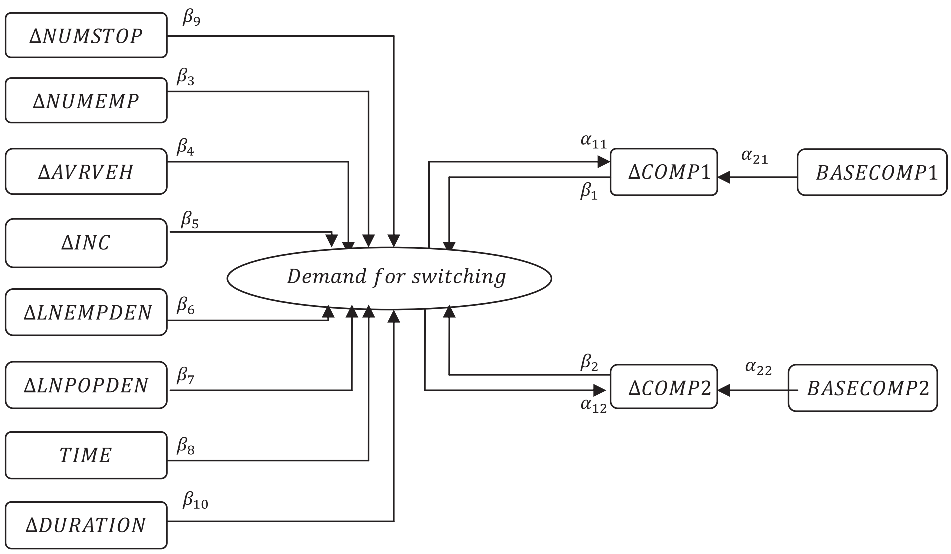

Fig. 1. Conceptual framework of interdependence between changes in attitudes and SOV and carpool mode switch. *Note*: Δ*NUMEMP* is the change in the number of the employed in a household, Δ*AVRVEH* is the change in the number of vehicles per person, Δ*INC* is the change in household income groups, Δ*LNEMPDEN* is the log form of change in the employment density at workplace TAZ, Δ*LNPOPCEN* is the log form of change in the population density at home TAZ, *TIME* is the commute time in minutes between home TAZ and workplace TAZ, *BASECOMP*1 is the baseline value of perceived difficulty of carpool and *BASECOMP*2 is the baseline value of feelings of carpool. Δ*NUMSTOP* is the number of stops in a work tour. Δ*DURATION* is the number of work hours.

The baseline values of the two attitudinal components (identified as BASECOMP1 and BASECOMP2 in the model) enter the equations to control the regression to mean effect. Because attitudinal responses are capped between 1 and 7, a lower/higher score is more likely to increase/decrease. The addition of these baseline values ensures that the changes in the attitudinal components are not due to the regression to mean effect. Thus, α_{21}, and α_{22} are expected to be negative.

The bi-directional relationships between changes in attitudes and mode switching behavior are captured by four parameters: β_1, β_2, α_{11}, and α_{12} If attitudes are changed to match mode switching behavior, α_{11}, and α_{12} will be significant for "perceived difficulty of carpool" and "feelings of carpool", respectively. On the other hand, if people switch modes due to changes in attitudes, these effects from attitudes to mode switching behavior are captured by β_1 and β_2 for "perceived difficulty of carpool" and "feelings of carpool", respectively. If the built environment and attitudes affect mode switching behavior as covariates as the existing literature suggests (Handy et al., 2005; Schwanen and Mokhtarian, 2005), both the built environment estimates (β_6 and β_7) and the attitudes estimates (β_1 and β_2) would be significant.

5. Results

The two SEM models were estimated in AMOS, a SPSS SEM application software. AMOS applies the Bayesian estimation method for SEM. In Bayesian method, a uniform prior distribution is set up for any unknown parameter. The prior distribution is continuously updated based on the information from the empirical data to obtain a posterior distribution. The updating process will not be terminated until the convergence statistic, is less than 1.002—meaning that the model has converged (Amos Development Corporation, 2007). The posterior mean (point estimate) is obtained by drawing random samples from the posterior distribution using a simulation technique called Markov Chain Monte Carlo (MCMC). The overall fit is measured by the reported posterior predictive *p* value. The *p* values for the SOV-to-carpool model and carpool-to-SOV model are 0.19 and 0.46, respectively, which are acceptable (Amos Development Corporation, 2007).

5.1. The carpool-to-SOV model

The carpool switching model was estimated on a sample of 229 individuals who carpooled in the baseline wave. Among them, 137 switched to SOV in the subsequent wave. The results of estimation are presented in Fig. 2 and only those coefficients that are significant at 0.05 level are shown. Dotted lines represent those links tested in the model but found insignificant.

As expected, an increase in the number of the employed discourages switching and an increase in the access to personal vehicles encourages switching. Income change, however, does not appear to have a significant effect on the probability of switching. The insignificance of the income effect may be attributed to the limitation of the dataset: As noted earlier, the only consistent cutting point across the three selected waves was $35,000, resulting in only two income groups. For the built environment effect, the results show increases in either population density at home TAZ or employment density at work TAZ discourages switching. This is expected, as higher density creates an environment favorable for non-SOV modes. It is also observed that employment density at workplace TAZ appears to exert a slightly smaller influence than population density

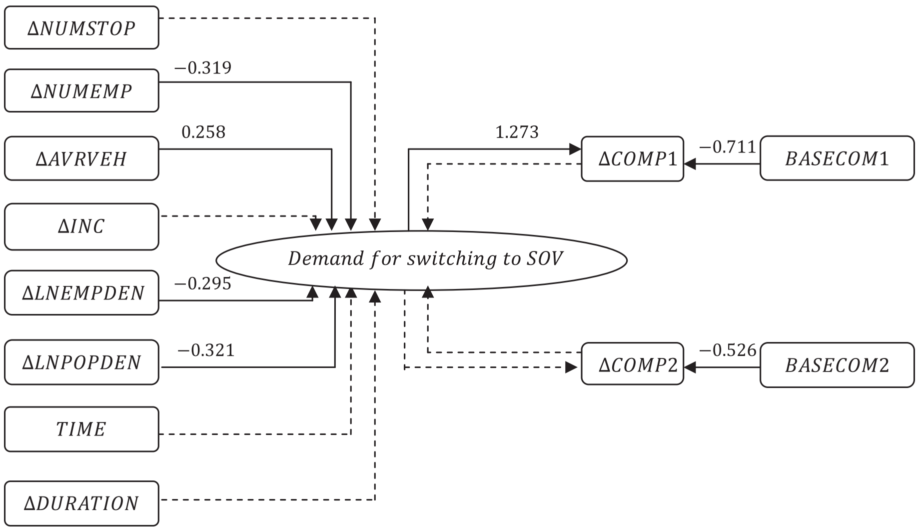

Fig. 2. Interdependence between changes in attitudes and mode switching behavior in carpool switching model.

at home TAZ on mode switching choice. While this result is consistent with findings from some studies (Kockelman, 1997), it is noted that other studies have shown a larger effect of employment density than that of population density (Chen et al., 2008; Zhang, 2004). The coefficients associated with the two baseline values of attitudinal components are significant and negative, conforming to our expectation that lower/higher baseline values are more likely to increase/decrease. The two variables measuring the level of flexibility (Δ*DURATION*) and trip chaining (Δ*NUMSTOP*) are not significant. The former could be a neutralized result of the two aforementioned opposite impacts of work schedule flexibility on carpooling (Cervero and Griesenbeck, 1988; Giuliano, 2007). The latter finding may be specific to work trips, which may involve a limited number of stops.

Among the bi-directional links between behavior and attitudes, only one—the link from the demand for switching to SOV to the changes in the perceived level of difficulty of carpool, was significant and positive. In other words, the carpool to SOV switchers adjusted their perceived levels of difficulty toward carpool upward after switching to SOV. This result is consistent with the theory of cognitive dissonance (Festinger, 1957) and the findings from a carpool study in the Netherlands (Vugt et al., 1996).

5.2. The SOV-to-carpool model

The SOV switching model was estimated to a sample of 1575 people who used SOV in the baseline wave. Among them, only 65 people switched to carpool in the subsequent wave. The small number of people who switched to carpooling is partially responsible for the fact that many variables in the model are insignificant. It may also indicate that SOV is a fairly

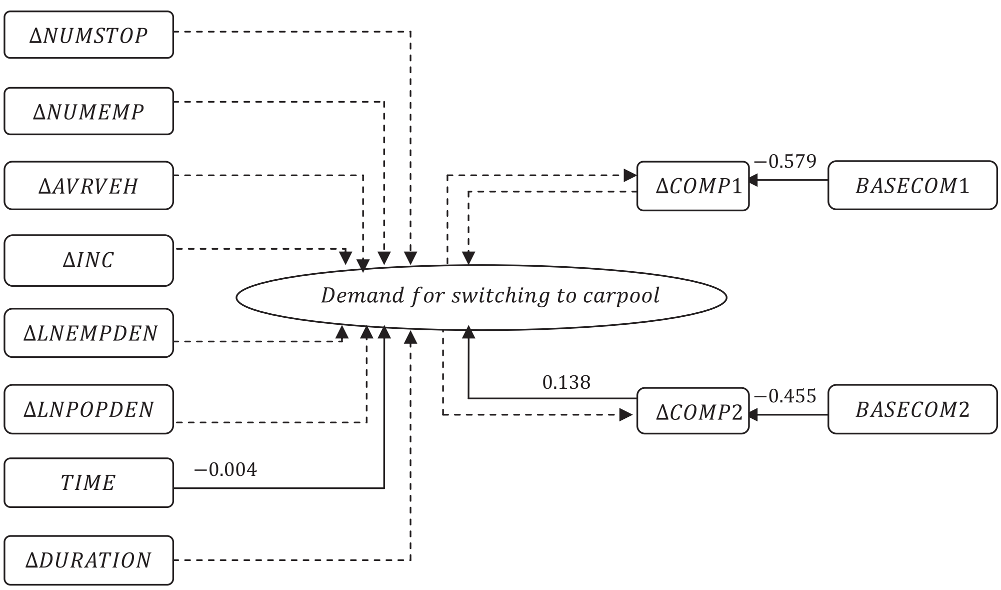

Fig. 3. Interdependence between change in attitudes and mode switching behavior in SOV switching model.

"sticky" mode—once the habit of using SOV is developed, it is hard to change even though the circumstances change (Dargay, 2001). The estimation results are shown in Fig. 3 and only those coefficients that are significant at 0.05 level are shown. Same as the carpool switching model, dotted lines represent those links tested in the model but found insignificant.

As in the carpool switching model, the coefficients associated with the two baseline values of attitudinal components are significant and negative, controlling for the regression to the mean effect.

The only significant structural factor is the commute time in explaining the demand for switching to carpool. The negative coefficient suggests that people tend to stay with SOV as the commute time becomes longer. The negativity does not support the cost-driven hypothesis, which will suggest a positive association between a longer trip and the likelihood of carpool (Pisarski, 1997). It is possible that the congestion-driven hypothesis is at work, in which case, carpooling only appears in small numbers for those trips with slower speeds (New York State Department of Transportation, 1979), operating on certain corridors (Texas Transportation Institute, 1990),[7] arranged to take advantage of HOV incentives (Pisarski, 1997). It is also possible that the two groups differ from each other in terms of their attitudes toward carpool. Comparing the demographic characteristics of the two groups (SOV stayers and SOV to carpool switchers) suggests that a higher percentage of the SOV to carpool switchers live in the urban area and they tend to have more people working and have larger household sizes.

Among the four possible links between attitudes and mode switching behavior, only one link—the link from the feelings of carpool to demand for switching to carpool is significant and positive. It means that the more positive affective bias people feel for carpooling, the more likely they are to switch. In other words, behavioral change, in this case, the switch from SOV to carpool, largely results from change in attitudes. This result confirms the leading role of attitudes in determining the choice decision for an environment-friendly commute mode (Handy, 2012).

5.3. Comparisons of the two models

Four of the six structural factors are found significant for the carpool-to-SOV model, while only one is significant in the SOV-to-carpool model. No attitudinal variables are found to have an effect on the carpool to SOV switch, whereas a higher level of affection toward carpool is found to significantly increase the likelihood of a mode switch from SOV to carpool. While the insignificance of the structural factors in the SOV to carpool model is likely partially attributed to the small number of people who switched from SOV to carpool, these findings—the insignificance of attitudinal variables in affecting the mode switch from carpool to SOV and the significance of "feelings of carpool" variable in determining the mode switch from SOV to carpool—support our first hypothesis that the noncooperative choice (SOV) and the cooperative choice (carpool) appear to be attributed to structural factors and psychosocial factors differently, or more specifically, structural factors play a dominant role in the mode switch from carpool to SOV while attitudinal factors are critical in explaining the switch from SOV to carpool.

In the two models, the directions of the relationship between mode switching behavior and attitudes are reversed—while feelings of carpool explains the switch from SOV to carpool, those who switched from carpool to SOV are found to adjust their perceived levels of difficulty toward carpool upward accordingly. This finding lends support to our second hypothesis—the behavioral mechanisms appear to be different for the two choices. This finding is consistent with some recent studies arguing that behavior heterogeneity results from the fact that different segments of population make use of different choice paradigms (Hess et al., 2011). These results are consistent with the theory of cognitive dissonance (Festinger, 1957) and Vugt et al.'s (1996) finding that solo drivers were found to downgrade their attitudes toward carpool after the construction of a carpool lane. In our study, we observe that the carpool to SOV switchers adjust attitudes to match behavior, while the SOV to carpool switchers adjust behavior to match attitudes.

6. Discussion

Using the concept of social dilemma, we cast SOV and carpool as the noncooperative option and the cooperative option. In this framework, the mode switch from carpool to SOV can be considered personally benefiting but socially undesirable, while the switch from SOV to carpool is a socially desirable choice. We hypothesize that these two choices are attributed to different factors and underlay by different behavioral mechanisms. In particular, structural factors play a dominant role in the noncoperative choice from carpool to SOV and attitudinal factors play a critical role in the cooperative choice from SOV to carpool. These two hypotheses challenge the assumptions of most of the existing studies: Mode choice decisions are static and symmetric. The results of the analysis of the first three waves of the Puget Sound Transportation Panel between 1989 and 1996 support our hypotheses.

Self-justification of the perceived level of difficulty is an exemplary attribute of those people who chose to switch from carpool to SOV. Yet, they only significantly adjusted the perceived levels of difficulty toward carpool, not the affections towards carpool. How so? This phenomenon may be explained by the difference between the two attitudinal variables (Koppelman and Lyon, 1981)—perceived level of difficulty toward carpool is an evaluative assessment while feelings of carpools reflects one's affective bias toward carpool; evaluations are more likely to be constrained by the specificity of the

[7] During the study period, Washington State operated two HOV lanes on urban corridor: I-5 and I-405 Texas Transportation Institute (1990) High-Occupancy Vehicle System Development in the United States. College Station, Texas.

scenario at hand and the dimensionality of the judgments that were made. Put it in plain words, even though individuals like to maintain a favorable view toward carpool (Van Lange, 1991), such tendencies are often constrained by the constraints they face in reality (Vugt et al., 1996).

For SOV to carpool switchers, the illustrative point is that their choices appear to be driven, not by structural factors, not a reduced level of perceived difficulty toward carpool, but by their affective biases toward carpool. Apparently, the switch from SOV to carpool follows after an increase in their affection toward carpool. Yet, it is unknown to us how they developed the affection toward carpool. Was the increase in affection the result of a direct experience of carpooling, an indirect observation of others' carpooling, increased awareness of its personal and societal benefits, or social or peer pressure? How long will their affection last? And will maintained level of affection lead to sustained use of carpooling in the long run? Our study results provoke these interesting and important questions for future research.

The results of this study have important policy implications. Most of the existing programs promoting carpool focus on structural factors, for example, providing ride-matching services (Johnson et al., 2010; Washington State Department of Transportation, 2010), charging reduced or no fees for carpoolers on express toll lanes, and reducing parking costs for carpoolers. So far, many of these programs are found to have a minuscule impact (around 1%) on the region's trip-making pattern (Cambridge Sysmatics, 2000; Ferguson, 2000). The majority (over 70%) of the carpooling work trips involved a household member (Li et al., 2007; Morency, 2007; Pisarski, 1997; Ungemah et al., 2007). Clearly, more effective policies and programs need to put forth to encourage carpooling. Our study results suggest in addition to the programs that alter the objective features of a decision scenario by facilitating and incentivizing carpooling, those interventions that aim at influencing relevant attitudes and beliefs can also be important, a notion recently coined by Handy in her analysis of the role of attitudes in bicycling (Handy, 2012). Attitudinal factors were identified important in the choice of carpool in the early years when the share of carpooling peaked (Duecker et al., 1977; Horowitz and Sheth, 1978; New York State Department of Transportation, 1977). Yet, they seem to be lost in more recent studies and programs. Furthermore, our study shows that the role of attitudes differs between the choice from SOV to carpool and the reverse one.

There are many possibilities in designing psychologically based interventions that aim at influencing people's subjective assessment of a behavior. One may attempt to increase people's awareness of the personal and societal costs of using SOV and the benefits of carpooling, promote the ease of finding a ride partner by not only offering ride-matching services, but also influencing through other means, for instance, social support. We offer a few suggestions in designing these programs. First, they need to be specific, targeting a particular population and addressing their specific needs and concerns. Policies targeted to encourage SOV users to switch to carpool and those aimed at maintaining existing carpoolers are likely different. Second, they need to be grounded in theory. Studies in other areas such as public health have found that theory-driven interventions are often the most effective (Keller et al., 1999). In addition to the random utility theory that is most familiar to transportation researchers, other theories such as social cognitive theory (Bandura, 1986) and the theory of planned behavior (Ajzen, 1991), need to be brought in to understand the confluence of structural and psychosocial factors on behavior. Third, before and after data on both structural and psychosocial factors need to be collected to monitor the effectiveness of the implemented programs.

Three limitations of the dataset constrain the generalizability of the study findings. As noted earlier, only 65 SOV users in the baseline wave switched to carpool in the subsequent wave, compared to 1510 SOV stayers. The small sample size is likely at least partially responsible for the insignificance of the structural factors in the model. From this perspective, the support found in this study for the two hypotheses needs to be tested by additional studies conducted in other areas. Nevertheless, the support for these two hypotheses is consistent with theories in social dilemma, theory of cognitive dissonance, and empirical (Vugt et al., 1996) and anecdotal evidence (Johnson et al., 2010). Another limitation relates to the built environment the study is set in. The period from 1970s to 1990s in the Puget Sound Region is marked with de-densification (Limanond and Niemeier, 2003). As shown in Table 5, the change in population and employment densities from the baseline to the subsequent wave is characterized largely by decreases, rather than increases in density. A related complication is that few agencies in the country maintained historical records of the built environment (infrastructure and land use development), rendering us to using only density related variables. Lastly, the use of aggregates of attitudes instead of the latent constructs underlying the observed attitudinal variables in the study is not an ideal set up. We discussed earlier that this limitation should not affect our ability of analyzing the key interest of the study, which is to distinguish the directional process between attitudes and mode choice behavior in the carpool-to-SOV vs. the SOV-to-carpool choice. The results are also consistent with theories on social dilemma and cognitive dissonance. Despite this, it does have some important implications in the construction of attitudinal statements in household travel surveys. The current set of 23 questions reflects a dispersed process during which attitudinal statements appear to be randomly collected on many underlying dimensions. This approach is likely inferior to the one through which the underlying constructs are first hypothesized, followed by many questions (i.e., 8–10) on each construct (Oppenheim, 1992). This calls for a more theory- and hypothesis-based approach in developing attitudinal statements in household travel surveys.

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