Autonomous Vehicle Impacts on Travel-Based Activity and Activity-Based Travel

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ABSTRACT

This paper undertakes a deep dive into the kinds of activities that individuals are likely to pursue when freed from the task of driving in the fully automated vehicle (AV) era. We refer to such activities as travel-based activities (TBAs) and examine the potential effects of TBA participation on activity-based travel (ABT). Two aggregate ABT characteristics are considered: additional local area travel (ALT) and additional long distance travel (ALDT). TBAs and the two ABTs are jointly modeled in a parsimonious fashion using psycho-social latent constructs, individual characteristics, and built environment (BE) attributes. The data used in this study is drawn from a 2019 "emerging mobility" survey administered in the Austin, Texas metropolitan area by the research group. Our study indicates that "productive use of time" is not necessarily always tied with activities such as work and study; rather, being able to partake in relatively chill activities (such as sleeping, relaxing, and gazing out the window) is also considered as good use of time. This suggests caution in the interpretation of what are traditionally referred to as "productive" activities and also a need for scholarly restraint in the use of the label "multi-tasking" to exclusively refer to non-passive activities. We suggest that the field move away from subjective/ambiguous terms such as multitasking and "productive" activities, and adopt the more neutral label of "travelbased activity". The results also support the notion that the option of opening up travel to pursue work/study activities may itself be engendering stress in individuals; that is, as the option to pursue "non-chill" activities increases in an AV environment, that itself may produce angst in individuals and lead to less enjoyment in travel. This also highlights a need to examine TBAs in the broader context of emotional well-being and quality of life. Indeed, AVs may further erode into our time of tuning-out from the "chatter" of routine life and make it less possible to partake in "calm and mindless" activities. Finally, our study cautions against the use of simple and uniform (across individuals) value of travel time savings (VTTS) factor modifications to study AV impacts on ABT.

Keywords: Travel-based activity, activity-based travel, multi-tasking, autonomous vehicles, ranked probit, psycho-social constructs.

1. INTRODUCTION

Automated Vehicles (AVs) are viewed by many observers and even scholars as heralding and ushering in a new era of benefits to travelers. These include roadway safety benefits due to removing human judgment error and drunk driving instances in the driving task (Shinar, 2019 and Arvin *et al.*, 2021), and accessibility benefits by providing increased mobility options for those who are currently mobility-challenged (such as the elderly and the physically other-abled; see Levy, 2020 and Litman, 2020). Additionally, travel time reliability benefits may also accrue because of the possibility of enhancing roadway capacity without physical expansion, through the elimination of human perception-reaction time and vehicle platooning possibilities (see Litman, 2020 and Pinjari *et al.*, 2013). AVs may also facilitate the more productive use of travel time by re-channeling the driving effort to more enjoyable or useful activities (see Singleton, 2019a and Moore *et al.*, 2020).

On the last issue of AV-facilitated productive travel time use (sometimes also referred to as the worthwhile use of travel time or multitasking), there has been a recognition for at least a couple of decades now that, even in the context of the current human-driven travel environment, there may be some positive value associated with travel (see Mokhtarian and Salomon, 2001). Ironically, while any positive valuation of travel time in today's human-driven environment may be attributed, at least in part, to a "forced" lowering of productivity and mental stimulation, and a consequent elevation in mental well-being, the situation is different in an AV environment. In such a case, individuals either can continue to pursue mentally calming activities (including sleeping) that may provide a heightened sense of well-being, or, alternatively, may partake in one of a substantially expanded set of activity possibilities. In the latter case, VTTS may be lowered because travel time is being used effectively to release time elsewhere during the day to pursue other enjoyable activities (effectively increasing time availability and reducing time pressure) or even simply provide a sense of time control. But the valuation may rise because of the very pressure to use travel time productively rather than pursuing mentally calming activities and/or "switching the mind off." That is, as the option to pursue "non-chill" activities increases, that itself may produce angst and guilt if individuals sleep or just watch the landscape go by, leading to potentially less enjoyment in travel than the original option of not being able to partake in the "non-chill" activities.

Interestingly, the scholarly literature almost exclusively assumes a lower VTTS in the AV era compared to today's human-driven environment (that is, considers that the ability to partake in multiple activities during travel is viewed positively). Note that our use of the term AV in this paper corresponds to the case of fully automated vehicles when the human can yield full control to the automated vehicle system, which corresponds to Level 4/5 in the Society of Automation Engineers or SAE automation scale; in addition, our use of the AV label corresponds to the case of no regulatory requirement that there needs to be a human "safety driver behind the wheel" paying attention at all times.¹ Indeed, simulation studies abound that consider VTTS value reductions of 50-100% relative to current car driver VTTS when examining the potential AV impacts on travel (see Hawkins and Nurul Habib, 2019, Soteropoulos *et al.*, 2019, and Harb *et al.*,

¹ By this definition of AVs, which is a combination of technology availability for full non-human driving as well as no regulatory requirement of a human "safety driver" to be present, AVs have just about become operational in three metro areas in the US: San Francisco, Phoenix, and Austin. These services, offered by Waymo and General Motors-backed Cruise, are still in a pilot stage, and offer service as robo-taxis within specified spatial pockets in the three metro areas. In Austin, the service is also confined currently between 10:30 pm to 5 am in the morning, though there are no such temporal restrictions currently in the other two metro areas. These truly AV experiences started up in late Fall 2022.

2021 for extensive reviews of such studies). Some recent studies, including Singleton (2018) and Moore et al. (2020), however, question this level of VTTS reduction, and suggest a much more modest reduction. Indeed, Moore et al. (2020), in their empirical study based on a stated preference survey of AV use, suggest a VTTS reduction closer to the order of 25-30%. Some of the reasons suggested in these studies for a more modest VTTS decrease include potential elevated motion sickness considerations in an AV, and the limited ability to pursue certain types of activities (such as reading or working) in a small, confined space. Other reasons include the finding among today's transit passengers that they do not necessarily value the usefulness of the ability to pursue specific activities during travel as much as they simply pass the time during travel (see, for example, Lyons et al., 2016), and that travel is viewed by some as a "gift" for transition time, switch off time, and/or enjoying the landscape in peace and quiet (Jain and Lyons, 2008, Lyons et al., 2007, and Cyganski et al., 2015). Besides, as Singleton (2019b) and Asmussen et al. (2020) note, the lack of driving control and perceived autonomy associated with AVs by at least some segments of the population can itself lead to a reduction in feelings of independence and a loss in eudaimonic subjective well-being. To these possible explanations, we add the need to be cautious about any reductions in VTTS in AVs simply due to the mental agony (or even guilt) from "chilling" during travel, especially when one can pursue one of many "productive" activities. In fact, a similar point is also made by Pudane et al. (2019), who do find some respondents in their focus group worrying that they may be caught in a new conflict between maximizing productivity and maximizing wellbeing in the pursuit of activities. This is particularly so as information and communication technologies become ubiquitous and allow a whole range of activity possibilities when traveling, blurring the divide between travel time and activity time (Wardman et al., 2019).

The discussion above forms the motivation for the current study. Unlike extant studies that apply an arbitrary VTTS reduction value to examine AV effects on activity-travel behavior (see, for example, Childress *et al.*, 2015; Davidson and Spinoulas, 2015; Bernardin *et al.*, 2019; Kröger *et al.*, 2019; Vyas *et al.*, 2019; and Dias *et al.*, 2020), or study potential VTTS changes directly using stated preference games that include times and costs as attributes of AV and other existing modes (see Kolarova *et al.*, 2018, Krueger *et al.*, 2019a, de Almeida Correia *et al.*, 2019, and Lavieri and Bhat, 2019), we explicitly recognize that VTTS is by itself a complex and nuanced aggregation of multiple considerations, each of which require careful investigation by itself. To that extent, we attempt to study travel-based activity (TBA) behavior when traveling in an AV environment.²

² Throughout this paper, we will use the terminology of "travel-based activity (or TBA)" rather than "worthwhile use of travel time" (see Wardman et al., 2019) or "multitasking during travel" (see Singleton, 2018, Malokin et al., 2019, Krueger et al., 2019b, Keseru and Macharis, 2018, and Varghese and Jana, 2019), or "productivity while traveling (Pawlak et al., 2017). This is because the words "worthwhile" or "productive" can be subjective, and the word "multitasking" can be misleading. For instance, while "working and studying" may be viewed as worthwhile or productive activities that activate cognitive functions in the brain, it could be legitimately argued that so is "gazing out the window". Similarly, the term "multitasking" as Srna et al. (2018) point out in their psychological science study, is often a matter of subjective perception because individuals cannot actually perform multiple non-automatic tasks simultaneously. So, what is typically referred to as "multi-tasking" is simply activity switching behavior even if the switching happens at a very fine time scale. Moreover, multi-tasking has a connotation of proactively and deliberately engaging in multiple tasks within a certain duration of time. While we appreciate the fact that, as Circella et al. (2012) explain, activities undertaken during travel necessarily represent the overlaying of those activities during travel, we prefer not to consider such an overlaying as multi-tasking, each of which warrants cognitive/physical resource investments. From that standpoint, it would be questionable if sleeping on a train should be considered multitasking, though it would be an activity of interest in an activity-based travel model framework. In any case, we do not feel a need to attach labels of any kind to the more general terminology of "travel-based activity" (TBA).

In addition to trying to "peel the onion" regarding why there may be changes in VTTS by expressly investigating TBA when in an AV, we also focus directly on TBA for another reason. As indicated by Pudāne *et al.* (2019), "a simple reduction in the travel time penalty does not fully capture the potential impact of on-board activities on daily activity-schedules of travelers". If we hope to capture AV effects on activity-travel behavior relatively accurately, it should be based on a study of the actual kinds of activities pursued during travel, rather than simply through a VTTS reduction. In this regard, the activity-based approach is grounded on space-time prisms and temporal constraints; activities pursued at one point in time affect activities performed during other points in time during a day, and so TBA in an AV should be explicitly considered as but part of the larger activity space-time continuum of an individual. The current paper contributes toward this end, by focusing on the types of activities pursued during travel, and not just on an aggregate sense of potential time value savings accrued because of the ability to pursue activities during travel.

For our current effort, we use the data drawn from a 2019 "emerging mobility" survey administered in the Austin, Texas metropolitan area by the research group. Our modeling of travelbased activity (TBA) is based on examining the activity types (or purposes) individuals state they would pursue when traveling in an AV. A rank-ordered probit model, which is efficient, allows unobserved correlation across different activity purposes during travel, and is a more appropriate analytic tool for rank-choice data than the traditionally used rank-ordered logit model, is employed.³ In addition to studying TBA within an AV, we also jointly model and relate TBA to two aggregate measures of activity-based travel (ABT) in a future AV environment: (1) Additional local area trips generated (local area trips are those that are not characterized as long distance trips; a long distance trip was defined in the survey as a trip more than 75 miles one-way; these trips primarily constitute the regular mandatory and discretionary trips which are frequent in nature), and (2) Additional long distance road trips beyond the local area (these trips primarily constitute more of the infrequent trips such as long-distance recreational or social trips). We do so to investigate if, and by how much, the ability to pursue TBA affects ABT, which can provide insights for further downstream analysis of traffic congestion and safety-related impacts. Important to note is that we model the TBA and ABT components jointly to accommodate any endogeneity in TBA based on ABT desires, so that the TBA impacts on ABT are "cleansed" effects after accounting for any association between TBA and ABT due to unobserved factors. For example, individuals who are intrinsically relaxation-oriented and chill may want to "enjoy the scenery and sleep" when traveling (a TBA option) and the same chill unobserved factor of the individual may lead to a high number of long-distance trips. That is, a chill individual (an unobserved factor) may be predisposed to enjoying the scenery and sleeping, as well as may frequently make long distance trips, even without an AV (by potentially choosing current travel modes that facilitate enjoying the scenery and sleeping). This intrinsic association needs to be controlled for before estimating the "true" causal effect of "enjoy the scenery and sleep" on the number of long-distance trips in a future AV setting. This jointness in TBA and ABT is accommodated in the current paper through latent psycho-social constructs that not only provide important behavioral insights into the drivers of TBA and ABT, but also allow for a parsimonious correlation structure among the TBA and ABT dimensions.

³ Additional dimensions relevant to TBA behavior, such as durations of each activity and sequencing, are left for future research. In the rest of this paper, TBA behavior will imply the singular issue of the combination of activities pursued regardless of time allocation or sequencing.

2. LITERATURE OVERVIEW AND THE CURRENT STUDY

The notion of performing activities during travel has received quite a bit of attention over the past two decades. A meta-analysis by Keseru and Macharis (2018) reviews 52 studies focusing on what they refer to as multi-tasking during travel. Another review by Harb *et al.*, 2021 identifies several studies concerning AV adoption and influence, focusing on ten studies that analyze driving and in-vehicle behavior. Readers are referred to these comprehensive resources for much earlier work on the topic, though we will summarize a few key findings from the two studies and subsequent studies. Broadly speaking, earlier studies on TBA in non-AV contexts either focus on the factors affecting TBA or on how TBA itself may impact ABT.

The first group of studies on studying TBA focuses predominantly on public transportation users. This is, of course, to be expected because private car trips in the developed world are typically single occupancy and would prevent the human driver from partaking in activities other than listening to music or the radio. The general findings from this literature have been that gender and age do have an impact on the type of activities pursued on public transportation systems. Men appear to engage more in such Information and communication technology (ICT) devicefacilitated activities as listening to music or watching videos (Bjørner, 2016, Berliner et al., 2015), while women, in the developed world, partake more in social conversations with fellow passengers or read or talk/text (Lyons et al., 2016, Keseru et al., 2015, Frei et al., 2015). However, Varghese and Jana (2019) found that women in Mumbai, India, engage less in conversation with fellow passengers, emphasizing the importance of local contexts in TBA. In terms of age, older individuals are more likely to engage in activities that do not involve the use of ICT devices (such as reading or talking with fellow passengers), while younger individuals use ICT devices for entertainment and communication (Varghese and Jana, 2019, Lyons et al., 2016, Clayton et al., 2016, and Frei et al., 2015, Kreuger et al., 2019b). Full-time employed individuals are more likely to read, while highly educated individuals (bachelor's/professional degree or higher) are less likely to talk over the phone (Krueger et al., 2019b). Trip duration and trip purpose may also have an impact on the type of activity pursued during travel (Krueger et al., 2019b, Bjørner, 2016). As should be evident from above, demographics have been used extensively to explain TBA in non-AV contexts. However, earlier studies have rarely considered comfort-related and attitudinal effects on TBA (see Keseru and Macharis, 2018). The few studies that consider comfort factors suggest that seated passengers pursue a higher level of non-idle activities (Zhang and Timmermans, 2010), and jerkiness on a bus leads to more non-reading/non-writing activities such as the use of smartphones (Guo et al., 2015). Attitudinal effects have been confined to polychronicity (or the desire/preference to be engaged in multiple activities) and pro-technology disposition, with both of these elevating ICT-facilitated TBA (see Berliner et al., 2015 and Hislop, 2012).

The polychronicity subjective measure has also been used as a determinant of mode choice in the second group of studies examining TBA effects on ABT, with the expected result that a higher level of polychronicity leads to a greater preference for non-solo-auto modes of travel (see, for example, Choi and Mokhtarian, 2020 and Malokin *et al.*, 2019). In fact, all the studies that we are aware of in this second group of how TBA affects ABT focus on commute travel mode choice as the singular ABT dimension. These studies represent TBA effects on mode choice in the form of a polychronicity measure (as just described) or examine how VTTS varies based on the specific TBA purpose pursued. Strictly speaking, even this latter group of VTTS studies do not actually study the impact of TBA on ABT as much as they deduce VTTS for different types of TBA participations. As an example of extracting VTTS from TBA participation, Etezady *et al.* (2019) interact use of laptop/tablet during travel with the time coefficient in a commute mode choice model for North California and observe that VTTS drops by about 20-30% for laptop/tablet-users relative to non-users of a laptop/tablet. Wardman *et al.* (2019) use a stated preference survey by presenting different scenarios (packages) of ATB participation to similarly derive VTTS from non-business rail users in Great Britain. Varghese and Jana (2018) undertake another similar study but using revealed preference data from motorized users in Mumbai, India, segmenting the population of motorized trips into those partaking in idle TBA (sleeping, relaxing, gazing out the window, etc.) and those pursuing non-idle TBA. Using mixed logit models for mode choice on the motorized trips, they estimated a 26% lower VTTS on trips with non-idle TBA activities.

Overall, the results above do provide insights on TBA behavior, mostly on public transportation modes, with some rather limited efforts to investigate TBA effects on ABT behavior. Interestingly, none of the studies above analyze both TBA behavior as a function of relevant exogenous variables as well as examine TBA behavior effects on ABT behavior. Further, to our knowledge, these earlier studies do not explicitly recognize the potential endogenous nature of TBA when studying TBA effects on ABT. Such a joint consideration of TBA and ABT behaviors, and a trace-back of such behaviors to observed demographic variables, is key to obtaining important behavioral insights for forecasting and policy action. Also, previous studies have been focused on public transportation-related TBA or on TBA effects on commute mode choice. On the other hand, insights about TBA and TBA impacts on ABT is literally non-existent in the context of AVs, even if the notion that the ability to pursue TBA in AVs is invoked many times to assume/justify a lower VTTS in the upcoming AV era. There have been some descriptive analysis studies of intended TBA behavior in AVs, as discussed in Wadud and Huda (2019), but these do not relate TBA behavior to demographics or examine TBA effects on ABT.

The one study closest to the current effort is the qualitative investigation of Pudāne *et al.* (2019), who elicited information in a focus group setting from 27 respondents who primarily use the car or a public transport mode for travel. The results do suggest that motion sickness is a deterrent to partaking in activities such as reading in an AV (which is similar to what was found in Sivak and Schoettle, 2015 and Diels *et al.*, 2016). Activities associated with relieving time pressure (such as work and even sleep) receive high priority as desirable TBA pursuits, while entertainment-oriented activities (play board games, sing, spend time with friends, etc.) are lower priority. Respondents did suggest that the "saved time" effect in AVs will make them change their activity-travel schedules, even if they could not specify the exact form of the rearrangement/reshuffling of activities. Also, respondents were not sure that their travel distances would get longer or that they would make more trips in their immediate local area, though there was a clear consensus that respondents would travel longer and more often for long distance social/leisure trips, a finding also observed recently by Dannemiller *et al.* (2021).

2.1 The Current Study

The current paper develops a survey-based modeling approach to investigate stated intentionsbased TBA behavior in an AV, along with the potential effects of TBA on two (admittedly aggregate) ABT dimensions corresponding to (a) additional local area trips (ALT), and (b) additional long-distance road trips (ALDT). TBA is elicited in the survey by asking individuals to rank up to three activities in response to the following question: "Suppose you are traveling [alone to work*] in an AV. Which of the following would you do in the vehicle during your trip? Select up to three activities".⁴ The options were:

- (1) Work or study
- (2) Talk on the phone/ send or read text messages/ teleconference
- (3) Read
- (4) Sleep
- (5) Watch movies/TV/other entertainment
- (6) Play games
- (7) Eat and drink
- (8) Interact with other passengers [show only on scenarios that this option is applicable]
- (9) Enjoy the scenery
- (10) Watch the road, even though I would not be driving

The trip purpose scenario (marked by an asterisk above) was varied across individuals, and included one of five possible trip purpose-accompaniment combinations: (1) traveling alone to work or study location, (2) traveling alone to the store, (3) traveling with family members to a neighborhood park, (4) traveling long distance alone, and (5) traveling long distance with family members. The two ABT responses; ALT and ALDT; were captured on a five-point Likert scale – from very unlikely to very likely. Respondents were asked to assume that they have access to an AV. The question was "Imagine a future when you can access an AV. How likely would you change in each of the following ways?":

(1) Make additional trips that I do not make now (Additional local area trips or ALT for short)

(2) Make more long distance road trips (Additional long distance trips or ALDT for short).⁵

To our knowledge, we are the first to model TBA in an AV and jointly also examine the effects of TBA on ALT and ALDT. Additionally, there are several other unique aspects of our study. *First*,

⁴ In the survey, a description of an AV was provided as follows: "An Autonomous Vehicle (AV) is a vehicle that drives itself without human supervision or control. It picks up and drops off passengers including those who do not drive (e.g., children, elderly), goes and parks itself, and picks up and delivers laundry, groceries, or food orders on its own. When AVs become available, ride-hailing companies (e.g., Uber and Lyft) will use them to provide rides without a human driver in the vehicle. When answering the questions in this section, please assume a future in which autonomous vehicles (AVs) are widely adopted, but human-driven vehicles are still present." Additionally, the reader will note that we do not have a separate activity category of "social media". This is because "social media", per se, is a platform to undertake activities, not an activity category by itself. For example, social media may be a source of entertainment, or as a means to talk/chat/video-call, or a means to play games, and much more.

⁵ Because we are eliciting information in an environment that is barely existing today (except in a pilot fashion and in confined spatial regions of three regions of the country), there may be some concern regarding the reliability of the responses. But there is considerable evidence in the social-psychology and information sciences literature that psycho-social attitudes toward a new product or experience (such as, for example, safety concerns or interest in productive use of travel time), subjective norms and lifestyle preferences (including individual demographics and having a "chill" relaxed temperament), and perceived usefulness of a product (related to tech-savviness and ease of use) all have a substantial bearing on behavioral intentions and actual behavioral action. As discussed later, we accommodate such psycho-social attitudes in our analysis. In fact, these concepts are at the foundation of the Theory of Planned Behavior (TPB; Ajzen, 1991) and the traditional Technology Acceptance Model (TAM) (Davis, 1989; Venkatesh and Davis, 2000). Extensive studies in consumer behavior have validated the use of the above-mentioned psycho-social identities of individuals in explaining the use of, and response to, other automated technology developments (see, for example, Astroza *et al.*, 2017, Foroudi *et al.*, 2018, Marikyan *et al.*, 2019, and Gunden *et al.*, 2020).

we consider not only individual socio-demographics and built environment (BE) variables as determinants of TBA and ABT, but also consider four psycho-social attitudinal measures as well as trip purpose/accompaniment effects. The psycho-social measures are related to observed demographics, so that the proposed model can be employed in forecasting mode. This also provides important insights to identify the "what", and pathway effects of "how", demographics influence TBA and ABT. Second, we consider TBA to directly influence ABT, rather than employing a simplistic and singular aggregate notion of VTTS reduction as the sole predictor of ABT. This is important because the precise nature and context of TBA has important consequences of how ABT may be re-arranged or adjusted. Third, even as we use TBA as a determinant variable for ABT, we also recognize the joint nature of TBA and ABT, where ABT itself may influence TBA. That is, the TBA variables are considered as endogenous explanatory variables. This jointness in TBA and ABT is achieved in a parsimonious manner through the effects of the stochastic psycho-social constructs on TBA and ABT. Fourth, rather than focus on the choice among existing travel modes as the ABT dimension, as has been the case in literally any previous study of TBA effects on ABT, we focus here on the trip generation considerations associated with both local travel as well as long distance travel. Finally, from a methodological standpoint, we adopt Bhat's (2015) generalized heterogenous data model (GHDM) model to jointly model TBA and ABT stated behaviors with the TBA dimension being a rank-ordered variable. In this model, jointness is achieved in an econometrically parsimonious manner through the stochasticity of the psycho-social latent constructs.

The model includes 12 indicator variables (allowing the estimation of the psycho-social latent constructs) as well as the ranked TBA outcome (with seven possible alternatives) and two ABT ordinal variables (ALT and ALDT). The resulting GHDM entails an integral dimension of the order of 20 in a maximum likelihood inference context. To estimate the model, we use a composite marginal likelihood approach that provides a consistent and asymptotically normal (CAN) estimator under the same regularity conditions needed for the CAN property of the maximum likelihood estimator (Bhat, 2014). To our knowledge, this is the first instance in the econometrics literature of the use of a joint mixed model based on latent constructs that includes a ranked variable. Further, we use a rank-ordered probit (ROP) model for modeling the ranked data. The ROP model constitutes a more appropriate and flexible behavioral structure relative to the rank-ordered logit (ROL) approach used commonly in the econometric and transportation literature. As discussed in detail by Nair *et al.* (2019) and Mondal and Bhat (2021), conceptually speaking, the ROL model is an "impossible" structure for ranking data analysis, based on Luce and Suppes's (1965) impossibility theorem, and, therefore, should be avoided when analyzing ranking data.

3. METHODOLOGY

3.1 The Survey

A 2019 "emerging mobility" survey administered in the Austin, Texas metropolitan area by the research group was used and analyzed in this study. The survey was distributed using multiple techniques: a list of 15,000 emails was purchased from a local firm (InfoGroup), advertisements were presented through social media outlets (Facebook), and local area professional networks were messaged. To incentivize the completion of the survey, the first 250 respondents were offered a \$10 Amazon gift card, while the remaining respondents were entered into a raffle for one of one-hundred \$10 Amazon gift cards. The recruitment effort resulted in a final pool of 1,127

respondents, of whom 970 provided information on the outcome variables (the TBA ranked variable and the ALT and ADLT variables)

The survey included questions concerning respondents' individual demographic information related to gender, age, whether or not the respondent holds a driver license, employment type, education level, household income, household size, presence of children in the household, and the number of vehicles available in the respondent's household. The survey also sought the address of the respondent's home location, either as an actual address or the closest major cross streets. As part of data preparation, the home locations were geocoded, mapped to census block groups (CBG), and then bestowed with built environment (BE) attributes as obtained from the U.S. Environment Protection Agency (EPA) Smart Location Database (Ramsey and Bell, 2014). Additionally, respondents were asked to answer a number of attitudinal/life-style questions by presenting a statement to the individual and soliciting a response using a five-point Likert scale ranging from "very unlikely" to "very likely."

In terms of the main outcomes of interest, this study utilizes a TBA scenario question related to the activities the respondent would pursue when traveling in an AV. Five different combinations of trip purpose-trip accompaniment are generated, as already discussed, to recognize that TBA behavior may vary based not only on psycho-social and demographic variables, but also based on the trip purpose-accompaniment contexts. The combination of "traveling alone to work/study" is considered as a possibility for presentation only for those who indicated that they are employed or a student. The specific combination presented to each individual is, in general, randomly generated during the survey administration, though we also metered this presentation during the survey deployment phase to target about an equal number of respondents to each of the five trip purpose-accompaniment combinations. We were quite successful in this effort, with the number of responses as follows for each combination: (1) alone to work or study location -184(19.0%), (2) traveling alone to the store -204 (21.0%), (3) traveling with family members to a neighborhood park -203 (20.9%), (4) traveling long distance alone -188 (19.4%), (5) traveling long distance with family members - 191 (19.7%). Respondents then ranked up to three TBA activities from a list of alternatives, which provided the ranked TBA outcome. As discussed in Section 2.1, respondents also provided information on the two ABT outcomes of interest.

3.2 The Analytic Framework and Sample Description

3.2.1 Analytic Framework

The analytic framework focuses on understanding the inter-relationship between the TBA and the ABT choice decisions, while considering individual-level demographics (individual and household characteristics), BE attributes, as well as attitudes/lifestyle factors (also referred to as psycho-social factors or latent constructs). These psycho-social factors are not directly observed, and so are viewed as latent stochastic constructs manifested through a suite of observed indicators (we will use the terms psycho-social factors and latent constructs interchangeably in the rest of the paper). In the current study, four such latent constructs are used (these are discussed in more detail later): (1) an individual's technology-savviness (tech-savviness), (2) concern with AV safety (safety concern), (3) being chill (chill outlook), and (4) interest in productive use of travel time (IPTT). These latent constructs are likely to impact TBA behavior through comfort levels and trust in the use/reliability of ICT devices, attitudes related to time pressure, the need to be (interest in being) productive during travel, and general personality temperament. While being intuitive, these constructs were also based on earlier studies of technology uptake/use based on our review of the transportation, time use, information science, technology adoption, and the more general

psychology/ethnography fields (see, for example, Astroza *et al.*, 2017, Li and Kamargianni, 2020, Ge *et al.*, 2019, Marikyan *et al.*, 2019, and Gifford and Nilsson, 2014). Other latent constructs, including those associated with security concern, privacy sensitivity, green lifestyle propensity, time sensitivity, and variety seeking were also considered. But our analysis of "within construct" and "between construct" variance (based on the battery of indicators), along with the testing of the larger set of developed constructs as they impacted the main outcomes, indicated that the most appropriate set were the ones finally used in the current paper. This is, of course, due to a similar set of indicators loading on the many theoretically-developed latent constructs. Overall, in the current study, based on a combination of an exploratory factor analysis process and a subsequent confirmatory factor analysis, four such latent constructs (with their most suitable indicators) are identified. Section 3.2.4 further discusses the latent constructs and the choice of indicators.

Figure 1 provides a diagrammatic representation of the analytic framework, where we suppress the indicators of each latent construct to avoid clutter. There are two components to the GHDM model: (1) the latent variable structural equation model (SEM), and (2) the latent variable measurement equation model (MEM). The SEM component defines each latent construct as a function of individual characteristics and an unobserved error term. The error terms across the four latent constructs are collected in a vector $\mathbf{\eta}$. We assume $\mathbf{\eta}$ to be multivariate standard normal with a mean vector of $\mathbf{0}$ and a correlation matrix of $\mathbf{\Gamma}$ (due to identification considerations, the variances of the individual η elements need to be normalized to 1; see Bhat, 2015). The SEM model relationship between the individual characteristics and the latent constructs, as well as the correlation matrix elements of Γ , are not directly estimable, but are estimated through observations on the latent construct indicators (not shown in Figure 1) and the main endogenous outcomes of interest (that is, the TBA and ABT dimensions shown toward the right side of Figure 1). The individual characteristics, the BE attributes, and the trip purpose-accompaniment characteristics (which constitute the exogenous variables in our model system; see left side of Figure 1), along with the latent constructs affect the TBA and ABT main outcomes in the MEM relationship (the loadings of the four latent constructs on the 12 indicators, not shown in Figure 1, also constitute a part of the MEM; thus, the final loadings of the indicators on the latent constructs is undertaken within the framework of the GHDM). Overall, the individual characteristics have both a direct effect on the main stated intentions outcomes as well as an indirect effect (through the mediating role of the latent constructs). For ease of presentation, the mathematical formulation of the GHDM framework used in the paper has been relegated to an online supplement which can be found at https://www.caee.utexas.edu/prof/bhat/ABSTRACTS/TBA/OnlineSupp.pdf. Importantly, once estimated, the GHDM can be used to forecast TBA and ABT outcomes for any individual without the need for the latent construct indicators (the latent construct indicators are important to "derive" the latent constructs and estimate the SEM relationship between individual characteristics and the latent constructs; once estimated, the indicators do not appear anywhere in the forecasting process, as discussed in Bhat (2015)). The individual characteristics, BE attributes, the latent constructs, and the main outcomes are discussed in turn in the next few sections (the trip purposeaccompaniment characteristics have already been discussed earlier).

3.2.2 Individual Characteristics

When compared with the information from the U.S. Census Bureau (2019) for the Austin, Texas, metro area, our sample does reveal an over-representation of women (64.9% in the sample relative to 49.0% reflected from the Census) and young individuals aged 18 to 29 years of age (60.0% in the sample relative to 11.2% from the U.S. Census Bureau). Our sample also shows a markedly

lower percentage of individuals who have completed high school or less (14.3% compared to 29.0% from the Census) and a higher percentage of individuals who have completed some college or technical school (35.1% relative to 25.0% from the Census). However, the distributions of those with an undergraduate degree or a graduate degree are very comparable to those from the Census.

The discrepancy between our sample statistics and the Austin metro population statistics may be attributed to a number of factors, such as the survey recruitment via the use of social media platforms, the lure of a financial incentive in the form of a \$10 Amazon gift card, and the survey topic pertaining to emerging technology. Each of these factors may have contributed to the over-representation of younger and lower-income individuals. But this sample skewness is not of much consequence in the current analysis for estimating individual-level causal effects (how changes in exogenous variables impact the endogenous variables of interest) because our sampling strategy was not based on the endogenous outcome (TBA and ABT) variables; that is, our sample corresponds to the case of exogenous sampling. In this situation, the unweighted approach is the preferred one because it is more efficient (provides more precise parameter estimates; see Wooldridge, 1995 and Solon *et al.*, 2015).

3.2.3 BE Attributes

The BE attributes corresponding to each respondent's residential CBG included population density (people/acre), employment density (jobs/acre), retail density (retail jobs/acre), land use mix index based on five sectors of employment (retail, office, industrial, service, entertainment), street network density (links/acre), distance to nearest transit stop (meters from the centroid of CBG to the nearest transit stop), transit access (whether the distance to the nearest transit is less than/equal to 3/4 of a mile or over), and living environment (urban, suburban, or rural).^{6,7} All variables are continuous variables, except the transit access variable (dummy) and the living environment variable (categorical). Of these variables, only the living environment variable turned out to have a statistically significant impact on the main outcomes of interest in our empirical model system, and even that only for the TBA dimension of additional local area trips (ALT).

3.2.4 Stochastic Latent Constructs and their Indicators

The first latent construct in Figure 1, tech-savviness, is a measure of how educated, well-informed, and experienced a respondent is with technology. Those who are tech-savvy are likely to have technology deeply embedded into their daily lives/routines and would be eager to adopt new technologies and use those technologies to obtain travel and other information (Nair and Bhat, 2021; Capasso da Silva *et al.*, 2019; Lavieri and Bhat, 2019; Asmussen *et al.*, 2020), potentially elevating the propensity to undertake ICT-enabled TBA activities. Figure 2 presents the indicators for the tech-savvy (and other) latent constructs. Over 70% of the sample do not agree that learning how to use new technology is frustrating, while over 75% (close to 60%) of the respondents are in somewhat or strong agreement about their desire to be among the first to use the latest technologies and the importance of having an internet connection at all times.

⁶ The land-use mix index is a continuous variable between 0 and 1, as obtained from the U.S. EPA Smart Location Database. This index is computed using an entropy approach (see Ramsey and Bell, 2014 for details).

⁷ The living environment characterization is determined based on activity density, which represents the total number of jobs and dwelling units per unprotected acre for each CBG. Based on Ramsey and Bell (2014), CBGs with an activity density less than 0.5 activity units per unprotected acre of land are classified as rural, while those with activity densities higher than 6 units per unprotected acre are classified as urban; all other CBGs are classified as suburban.

The second latent construct, AV technology-related safety concern, has been well established as an important factor in an individual's adoption of an AV. Many individuals just do not trust technology adequately to put a machine in control of their lives (see McAllister *et al.*, 2017, Nazari *et al.*, 2018, and Asmussen *et al.*, 2020). Within the context of TBA, individuals with a high AV technology-related safety concern may be more inclined to pay attention to the road or at least not get fully immersed in cognitively-intensive TBA activities. Figure 2 shows a sample that is considerably safety concerned, with less than 30% strongly or somewhat strongly agreeing that they would be comfortable sleeping while traveling in an AV or would feel safer being on the streets as a pedestrian or a cyclist in an AV environment, about three-quarters apprehensive of AV technology, and less than a fifth feeling comfortable having AVs pick-up or drop-off children without adult supervision.

The next latent construct, chill outlook, is one that we have not seen in the earlier literature, and represents an individual's ease and repose when travelling. An intrinsic part of being chill/ relaxed comes with being comfortable, leisurely, and feeling pleasure (Lattas, 2007). Another study by Ladegaard in 1998 associates a relaxed individual with being "laid back", "easygoing", and "calm." When one is relaxed, they are more inclined to make choices that do not require as much effort or work (Ahlgren *et al.*, 2004). Chill respondents may be more likely to pursue such TBA activities as sleep or gazing out the window rather than working. The attitudinal indicators for this latent construct are based on the connection between being chill and the feeling of relaxation. Figure 2 suggests a rather chill sample, with about half the sample in some or strong agreement about doing one thing at a time, travel time providing useful transitions between activities, and wait times being useful pauses in their day.

Lastly, interest in productive travel time (IPTT), captures an individual's perception toward productive use of travel time. This latent construct is not to be confused with tech-savviness, as tech savviness accounts for an individual's ability to pursue technology-related activities and tasks, while IPTT accounts for an individual's desire to use travel time effectively. Individuals who are tech-savvy may not be interested in productively using their travel time. Additionally, IPTT does not require a technological component, and can include one's desire to partake in the entire range of activities represented as TBA possibilities in this paper. The sample does show a high IPTT, with about 70% of the respondents agreeing that they find the level of congestion bothersome and make good use of travel time. To avoid clutter, the choice of indicators used (in a tabular format) and their loadings for each of the latent construct is available in an online supplement (available at: https://www.caee.utexas.edu/prof/bhat/ABSTRACTS/TBA/OnlineSupp.pdf).

3.2.5 Main Outcome Variables

The TBA Dimension

The ranked approach used in our study to elicit information on TBA has the advantage of allowing respondents to provide more than one activity that they undertake during the trip, while also providing much more information for model development relative to a single "first choice" only approach. Nair *et al.* (2019) and Mondal and Bhat (2021) discuss the many advantages of the rank-ordered approach, especially when working with moderate sized samples and multiple design blocks (that is, the five trip purpose-accompaniment combinations in our study). To be sure, in our study, the survey question asks respondents to provide up to three TBA activities they may pursue in an AV, which may be viewed as a tied-ranking scheme where the TBA alternatives. This tied-ranking scheme falls within the usual rank-ordered framework, but with important modifications as

discussed in the online supplement (see https://www.caee.utexas.edu/prof/bhat/ABSTRACTS/TBA/OnlineSupp.pdf).

In our preliminary analysis, we noticed that retaining the original TBA ten-alternative classification scheme leads to very few sample points for some of the alternatives. Accordingly, we collapsed the original ten-alternative TBA variable into a seven-alternative variable, with the alternatives relabeled for convenience as (1) Work/Study (WS), (2) Talk/Text (TT), (3) Read, (4) Entertainment (including "play games", "watch movies/TV/other entertainment" and "eat and drink"), (5) Relax ("sleep" and "enjoy the scenery"), (6) Social (interaction with other passengers), and (7) Road-fixated (RF). Of these, the social option, which basically involves interaction with fellow family members, is presented as an available option only if there is trip accompaniment. Thus, there are six TBA options when traveling alone and seven when traveling with company. Note that if any elemental alternative in the ten-way classification scheme appeared within the top three picks, the corresponding aggregate alternative in the seven-way classification scheme was also immediately designated as appearing within the top three picks.

Table 1 provides the distribution of TBA picks. The top row panel provides the number of times each activity was picked within the top three choices (note that some individuals only picked one activity purpose or two purposes). The top three activities picked most often are relax, talk/text (TT), and entertainment, while read is the least likely to be picked (the social purpose has the lowest magnitude, but the social purpose is available only for the 394 scenarios of traveling with family, representing a 42.6% pick rate relative to the 19.0% pick rate for the "read" purpose). The top pairings correspond to the pairwise combinations among relax, TT, and entertainment. The "read" and "social" purposes are almost always combined with one or two TBAs from among relax, TT, and entertainment, as well as with each other themselves. Overall, the descriptives suggested that the five purposes corresponding to non-work and non-RF activities represent a block of "relax/leisure/social/communication" activities (which we will refer to as "chill" activity purposes in the rest of this paper), with the work and RF purposes rather distinct and the most likely to be undertaken as the sole TBA purposes (see bottom row panel of Table 1). However, there are substantial instances (569) of work/RF purpose also combined with one or more of the chill activity purposes (as we will discuss later, in our empirical analysis, we considered the effect of many different TBA combinations on ABT, but, very interestingly, the coefficients on the many combinations only reinforced the notion that the non-work and non-RF purposes constitute a kind of a "chill" block in the TBA context). There are 50 instances of a single chill purpose being provided as the sole response, and 278 instances of multiple chill purposes without the presence of a work/study (WS) or road-fixation (RF) instance. Also to be noted is that there was no instance of work/study being combined with an instance of road-fixation.

The ABT Outcomes

The response splits for the two ABT outcomes -- how likely are you to make additional local trips (ALT) and additional long distance trips (ALDT) are as follows:

- ALT: Very unlikely (16.3%), Somewhat unlikely (24.7%), Neutral (19.8%), Somewhat likely (29.4%), and Very likely (9.8%)
- ALDT: Very unlikely (10.4%), Somewhat unlikely (16.4%), Neutral (18.6%), Somewhat likely (34.2%), and Very likely (20.4%)

The above univariate statistics immediately reinforce the overall finding from Dannemiller *et al.* (2021) as well as Pudāne *et al.* (2019) that individuals appear to be much more likely to make more long distance trips than local area trips.⁸

4. MODEL RESULTS

The loadings of the latent constructs on the construct indicators are not of primary interest in this paper and are available in the online supplement. Suffice to say that the loadings were significant and had the expected sign. The other results are discussed next, starting first with the SEM results relating the individual-level variables to the latent constructs, and then proceeding to the results for the main outcomes. In some cases, we have retained variables that were marginally statistically significant, because of their intuitive interpretations and important empirical implications, as well as because of the moderate sized sample used in the analysis.

4.1 Latent Constructs

Table 2 presents the results for the latent constructs. Cells marked with "--" indicate the corresponding row variable has no direct impact on the column latent construct.

The results show that women, compared to men, are less tech-savvy, more safety concerned, and more interested in the productive use of travel time. Women typically are known to have an apathetic view of technology (Acheampong and Cugurullo, 2019; Marth and Bogner, 2018), likely due to the gender gap in technology access in the digital age and a culture that promotes technology orientations in boys and men and discourages such orientations in girls and women (Neokosmidis *et al.*, 2013; Mushtaq and Riyaz, 2020). The result concerning technology-related safety concern and lack of technology trust may be attributed to women's general risk-

⁸ A note here about our question framing to elicit information regarding both the TBA and ABT dimensions. With respect to TBA, we only ask respondents to provide the top three activity categories they would be most likely to participate-in in an AV. We do not ask any further details about likely durations or ask respondents to rank-order their top three activity categories. Similarly, with respect to ABT, we only ask for the likelihood of making more trips using an ordinal scale. We do not ask for percentage changes in trip-making. Our reason for such a framing of the questions is because of the high degree of innovativeness of an AV, because of which it is difficult to specify detailed product configuration characteristics (for example, vehicle size, vehicle internal space and space organization, and automation functionality). In such "blurry" technology product situations, the consumer research and survey methodology fields are clear that attempting to elicit detailed micro-information related to preferences/intentions may be of limited value, and that it may be more appropriate to focus on broad stated functional use intentions (see Zmud et al., 2016, Dawid et al., 2017, Park and Lee, 2014, and Dawid and Delli Gatti, 2018). That is, it is much better to get a high-level sense of intentions, and elicit consumer responses in broad (and non-numerical) response categories rather than "box" respondents and force them to respond in fine numerical response categories. Further, in the context of TBA, for the same reason, asking respondents to provide a detailed ranking would be a challenge relative to simply asking respondents to choose three top activities. At the same time, as already discussed, our way of eliciting responses corresponds to a "tied" ranking scheme that has the benefit of providing substantially more information related to TBA preferences than simply a top choice activity. Finally, we do not frame, by design, TBA questions in an AV in the context of a specific current trip context. This is because, the survey, focusing forward on a futuristic AV environment, did not collect detailed information on any specific current trip of the respondent or detailed time-use information. The intent was to have a survey framing approach that would elicit overall TBA intentions in an AV environment, while recognizing broad characterizations of the nature of travel (such as the trip purposeaccompaniment combination) rather than increasing cognitive burden by cramming a whole lot of specific trip-related characteristics for an intention elicitation far into the future (as Cherchi and Hensher, 2015 indicate, too much specificity can itself introduce analyst study bias as well lead to respondent disengagement). Besides, our approach has the benefit of posing questions within a trip purpose-accompaniment combination that we specify, which resulted in obtaining adequate responses over the entire range of trip purpose-accompaniment combinations (see the last paragraph of Section 3.1).

averseness in anticipation of negative consequences. Prior results confirm this heightened sense of dread and lack of trust in AV technology among women (see, for example, Asmussen *et al.*, 2020 and Rosenbloom, 2021). Besides, women are most comfortable driving by themselves when traveling with children, rather than yielding that control to anyone else, let alone a machine (see Ciciolla and Luthar, 2019). The enhanced safety concern among women in the presence of children in the household, as represented by the interaction term "female*presence of children in the household, as represented by the interaction term "female*presence of children in the household" reinforces this perspective. The result regarding a higher IPTT among women without children may be attributed to the general time poor nature of women, especially because they shoulder much of the household responsibilities even as they increasingly work outside the home (Craig and Mullan, 2010). However, women with children, while they may become more time poor, may rather choose to use travel as a period of "peace and quiet" away from the humdrum of childcare demands and related responsibilities.

The age effects in Table 2 suggest that older respondents (those 65 or older) are less likely to be tech-savvy (see Marth and Bogner, 2018 and Pásztor and Bak, 2020 for similar results) and more safety concerned. Younger individuals have been raised in an environment of ubiquitous technology availability, while learning to use and adapt to technology can feel overwhelming for some older individuals (Correa *et al.*, 2010). Further, older individuals are more resistant to any kind of change, given the feeling of self-control and calm they experience in regular preset life rhythms (Marikyan *et al.*, 2019). This can also result in a general cynicism with the functional capability and reliability of new gadgets (Peretti-Watel *et al.*, 2009; Dohmen *et al.*, 2011) that contributes to older adult's averseness to AV technology (Charness *et al.*, 2018; Haboucha *et al.*, 2017). The higher IPTT levels among middle-aged and older individuals relative to the very young (less than 30 years of age) may be a reflection of a more focused protection and use of time relative to the youngest generation's almost round-the-clock distraction-laden lifestyle (Cho, 2016; Looker and Naylor, 2010).

In addition to the age and gender effects, the results reveal that employed individuals display a higher IPTT, presumably because of overall time constraints combined with the amount of travel time spent during the commute. Students, on the other hand, are likely to be "chill" in their outlook, potentially a combination of not having the time stress of familial responsibilities, while also having a supportive social interactive network of like-minded individuals who all communally foster a relatively carefree living environment (Shirom, 1986).

Among household demographics, individuals from high income households (\geq \$100,000 per year) exhibit a higher level of tech-savviness and a lower level of safety concern, and appear less chill, relative to individuals from low income households. These results reflect the generally higher exposure to technology among high income individuals (Lavieri *et al.*, 2017; Liu and Yu, 2017), and the typically higher levels of work/career stress among such individuals (Begum, 2004). Finally, that single parents are less likely to have a chill outlook compared to adults from two-parent households and childless homes should not be surprising, given the time-poor nature and stressed life of single parents (see Asmussen and Larson, 1991 and Jacobs and Gerson, 2001).

The correlations of the unobserved factors across the latent constructs are presented at the bottom of Table 2, and indicate statistically significant correlations across the latent constructs. Of these, the only surprise may be the finding that intrinsically chill individuals are more interested in IPTT. But this could also simply reflect how individuals interpreted the attitudinal indicator question of "I try to make good use of the time I spend traveling". People who are intrinsically chill may view the "chill time" during travel as time used well.

4.2 Main Outcomes

Table 3 represents the coefficients estimated for the two types of main outcomes – TBA and ABT. These coefficients refer to the impact on the utility of alternatives (for the ranked TBA model) and the propensities characterizing the ordinal ABT outcomes. Cells marked with "--" indicate the corresponding row variable has no direct impact on the column outcome variable.

4.2.1 Latent Construct Effects

The latent construct effects indicate that tech-savvy individuals are more likely (than their less tech-savvy counterparts) to participate in chill TBAs (excepting for TT and social interaction when traveling with family) relative to work/study (WS) and road fixation (RF) TBAs. Also, those not very trusting of technology (as reflected in their safety concern levels) are generally unlikely to partake in chill activities (except for TT) and much more likely to be road-fixated (RF). These results are intuitive, because partaking in chill activities (such as reading and entertainment) today entails a certain comfort level with technology, given that the primary medium for reading when traveling is via e-readers, and entertainment is associated with the ability to be relatively adept with the culture of ICT devices (Peicheva *et al.*, 2017).

On the other hand, individuals who are safety concerned are generally likely to be too nervous to be doing anything other than be road-fixated, though TT may be an activity that helps them take away some of the anxiety edge. Also, safety concerned individuals are not likely to make additional trips in AVs, as reflected in the negative signs on the "safety concern" latent construct for both the ALT and ALDT dimensions. Interestingly, from the standpoint of the personality traits of tech-savviness and being safety-concerned, the trace-back to the results from the previous section implies that women, older individuals, and those from lower income households are the least likely to partake in chill activities (except for TT), more likely to be road-fixated, and not very likely to make additional local area of long distance trips in an AV environment.

"Being chill" elevates the propensity to participate in chill activities relative to work/study and RF, even though there is no positive impact on social interactions when traveling with family. With regard to the latter result, there are suggestions in the literature that some of the most positive and stress-free familial relationships are associated with individuals having a "chill" personality without irritability bursts, and that stress-free relationships are also marked by the ability to enjoy and thrive in silence with family members. There is a Japanese word for this kind of comfort in prolonged silence: shiin (Kosaka, 2010). A "chill" family may be comfortable enough with one another that they need not interact, but can simply enjoy each other's presence and the shiin associated with it. The "being chill" trait, not surprisingly, leads to a stated increase in both local area and long distance trip-making in an AV environment. Tracing back to the previous section, students, low income individuals, and those who are not single parents tend to be more "chill", and so partake in chill activities more so and are likely to travel more in an AV environment because of this specific personality trait.

Finally, in the group of latent constructs, those with a high IPTT have a higher disposition to partake in relax, work/study, and social interaction TBAs relative to other TBAs. The positive association between IPTT and work/study is to be expected, given the cognitive investment and productivity connotation intrinsically associated with work/study (Keseru and Macharis, 2018). The positive association with relax and social interaction reinforces the positive correlation found between the "Being Chill" and "IPTT" latent constructs in the previous section, suggesting that those with an IPTT interest need not only be those who view productivity strictly in the context of work/study stimulation, but may also view "chill time" as productive time. Besides, those with a

high IPTT tend to be employed, who might value the use of travel time for not only work/study activities, but also as a "chill time" transition between home and work activities (Olsson *et al.*, 2012). Overall, an elevated IPTT also increases ALT and ADLT trip-making, because of the potential use of travel time in a productive manner.

The effect of demographics through the many latent variable effects highlights the benefits of incorporating psycho-social constructs, because it provides partitioned effects due to different personality traits on TBA. These partitioned psycho-social pathway effects may or may not reinforce each other, and provide a good picture of why specific demographic groups may partake in specific TBA activities. Of course, some demographic variables also appear in the next section as direct effects after accounting for the effects through the four psycho-social constructs. The overall net effect of a demographic group would consider both the latent variable-mediated effects and the direct effects below. In the next section, we will discuss the results in the context of individuals with identical personality traits on the four psycho-social constructs, while selectively discussing the differential pulls of personality traits and the direct effects.

4.2.2 Effects of Individual Demographics

According to the results in Table 3, women are more likely than men to talk/text and read during their travel in an AV environment, which aligns with the results of Lyons *et al.* (2016). Women, either because of socially-learned behavior or societal expectations or the traditional role of keeping the family "together", appear to value social interactions more so than men (Borland *et al.*, 2018). Talking on the phone and texting others is a modern day socialization facilitator, which appears to reinforce the latent construct-based tendency among women to talk/text (TT) to alleviate safety-related anxiety concerns when traveling in an AV. On the other hand, the direct positive reading effect for women contrasts with the negative reading effect originating from the higher AV safety concern among women, with the net effect being positive (that is, overall, women are more likely to spend their travel time in an AV reading than men).

In terms of age, the base age category we use is those in the age group of 29 years or younger, except we further refine the base to be those 29 years or younger with a driving license. This interaction specification as the base is to examine if those who do not hold a driving license have different TBA and ABT propensities than those who do, while also recognizing that almost all those who do not hold a driving license are aged 29 years or younger (106 individuals in this age group of the 117 individuals in the sample without a driver's license). That is, it can be assumed that those without a driving license are youngsters who have never experienced personal human driving. As can be observed from Table 2, we found no statistically significant effect (even at a 68% confidence level or a t-statistic of 1.00) of the "age 29 years of age interacted with no driving license" variable on TBA, suggesting that driver license holding has no differential effect on TBA propensities in young individuals.⁹ Across age categories, there is an effect on TBA propensity,

⁹ Similarly, we did not find any statistically significant effect of license holding among young individuals even in the latent construct effects in Table 2, and hence driving license does not appear in any form in Table 2. We do include this effect in Table 3, because, as discussed later, driving license holding among young individuals has an effect on the two ABT dimensions. The suggestion is that driver license holding (or not) among young individuals is itself not associated with differential TBA propensities, but a reflection of other preferences. Indeed, Le Vine and Polak, (2014) and Schoettle and Sivak (2014) point out that the major deterrents among young adults to obtaining a driving license are the time and cost associated with learning to drive and owning a license, along with the mental fatigue and insurance-related considerations associated with driving. Of course, the lack of any driving license effect on TBA in our study could also be because we are trying to tease out the effect from a small sample size of young individuals with no driving license, and the presence of six or seven TBAs in the set from which to choose up to the top three.

which is reflected by the "30-64 years" and "65 years or older" variable effects in Table 3 in the TBA columns. Specifically, while there are no direct effects of being middle-aged (30-64 years) relative to being younger on TBA, older individuals (65 years or older), based on direct effects, have a lower propensity to partake in work/study and entertainment activities during AV travel. The lower direct propensity for work/study reinforces a similar propensity among older individuals because of safety concerns (and the consequent inability to focus on tasks that require a high level of cognitive focus), each of which (and both when combined together) dominate the higher propensity to partake in work/study due to the higher IPTT among older individuals. The lower tendency to participate in entertainment among older individuals due to direct effects reinforces the lower tech-savviness levels in such individuals. Also, the reduced road-fixation (RF) tendency of older individuals due to factors unrelated to safety concerns dominates over the heightened road fixation due to safety concerns. That is, for an old and young individual with the same safety concern levels, the older individual appears to associate less utility to road-fixation, perhaps as a means to particularly value the exhilaration that comes from travel at a time when day-to-day stimulations and excitements may be on the decline for them. In terms of ABT effects, those young individuals without a driving license today indicate that they would make more local and longdistance trips in an AV era than young individuals with a driving license, as also observed in the studies by Harper et al. (2016) and Kim et al. (2022). This effect may be attributed to mobility constraints experienced by those without a driving license as imposed by their current mode of use (such as transit not serving specific regions within a local area well) or just a generic preference among individuals without a driving license today to be traveling alone than in the company of others. Also, across the depressed additional trip-making propensity due to heightened safety concerns, the increased trip-making propensity due to elevated IPTT, and the reduced trip-making propensity due to direct effects, the overall net age effect is clearly reduced trip-making propensity among older individuals.¹⁰

Employed individuals indicate that they would be less likely than their not-employed counterparts to participate in social interaction activities when traveling with family, though this direct negative effect is less than the elevated social interaction participation utility of employed individuals through the IPTT effect (the net effect on social interaction utility is 0.453*0.180–0.053=+0.029). This suggests that, while there is tension between perhaps unwinding and being in one's own personal mental space after the inevitable instances of socializing in the office (whether one likes it or not) on the one hand, and the opportunity to catch up with immediate family on the other, the net effect is an elevated social interaction participation relative to other TBAs among employed individuals.

The final two individual demographics correspond to student status and education. Students are more likely than non-students to partake in work/study, as they navigate through and absorb knowledge during their formative education years. Further, while there is a small direct and depressed propensity among students to engage in reading activity, this is more than made up for the positive "being chill" effect for students, such that the net effect (=0.542*0.271–0.068=+0.079) is that students are likely to partake in reading activities more so than non-students in the upcoming AV era (though work/study is still the most likely TBA pursued by students relative to non-students). Also, while there is a pull toward more long distance trip-making due to the "being chill" effect of students, the direct negative tendency among students to pursue long distance trips

¹⁰ Note that almost all older individuals have a driving license. Thus, while the net reduced trip making tendency among older individuals holds relative to all younger individuals, this net reduced trip making is particularly the case for the group of older individuals relative to the group of young individuals without a driving license.

is the more dominant effect, leading to fewer projected long distance trips in AVs for students relative to non-students. In contrast, highly educated individuals, particularly non-students, have an increased propensity to make long distance trips.

4.2.3 Effects of Household Demographics

Individuals from high income households, after controlling for tech-savviness and "being chill" effects, have a direct positive predisposition for the entertainment TBA. This direct effect reinforces the positive entertainment tendency due to higher tech-savviness levels among individuals from high income households and negates the negative entertainment tendency because of "not being chill". The net effect is a strong disposition for entertainment (relative to other TBAs) in individuals from high income households, which may be a simple reflection of the entertainment buying and access power of money. Additionally, household structure effects are present, with nuclear family households more likely to pursue work/study activity, single parents being more road-fixated, and individuals with children less likely to relax and pursue additional local area trips in the AV era. These observations may be related to the generally more responsibility-laden, and time-poor lives of single parents and those with children in the household (Maasalo *et al.*, 2019).

4.2.4 Built Environment Effects

In terms of built environment effects, and relative to individuals residing in rural and suburban environments, respondents in urban environments are less likely to fixate on the road and more likely to participate in other TBAs. Urban dwellers are more familiar with ride hailing services and taxis, in which driving control is already relinquished. This familiarity with handing over control may roll over to the world of AVs where urban area residents feel more relaxed and have less of a need to be road-fixated. Further, given the extensive traffic delays and stress driving in urban areas, it is only natural that urban dwellers express a higher inclination to pursue additional local area trips when they do not have to drive in the AV era.

4.2.5 Trip Purpose and Accompaniment Variable Effects

In addition to the above variables, trip purpose and accompaniment impacts TBA and ABT behaviors. When compared to traveling alone to a work or study location, individuals appear to have a higher road-fixation tendency and lower work/study participation tendency when traveling alone to a store or to the park with family (note the positive sign of traveling alone to the store for the RF TBA relative to the base of all other TBAs, and the negative signs on all TBAs except social interaction relative to the base RF TBA for traveling to the park with family). Trips to the neighborhood store or to the park are typically shorter than the commute, which may make it difficult to pursue work/study activity, and may also entail more road attention.

Individuals traveling long distance are likely to want to "zone out" from work/study and may also avoid talking/texting as a means to unplug from the rhythms of daily babble, as evidenced in the results in the lower participation in such activities relative to other TBAs (while long distance was not expressly tied with a vacation trip in the survey, this is likely to be how the travel context was perceived by respondents). Finally, when traveling long distance with family, social interaction is the most likely TBA participated in. Other travel/activity related variables such as the current commute time or employed individual's work hours were also tested, but they turned out to be insignificant and were eventually dropped from the final specification.

4.2.6 Effects of TBAs on ABT dimension

As discussed earlier, we attempted many different combinations of TBAs in their effects on the ALT and ALDT dimensions, also ensuring that we had enough observations of actual choice in the sample for each TBA combination. The specifications were considered using the road-fixation (RF) only TBA (that is, the only TBA selected was RF) as the base, because of the expectation that other TBAs will generally lead to a positive effect on ALT and ALDT. But as we pursued the many combinations, the effect of the work/study only TBA (on ABT) did not turn out to be statistically different from the sole RF base. So, we combined the two as a single base category. Further, as we introduced combination categories of the five categories of "chill" activity, they all provided similar positive effects on each of the ALT and ADLT dimensions, except for differences based on whether these chill activities are pursued alone, or are combined with other chill activities with no instance of work/study and no instance of RF, or combined with an instance of work/study or RF. Within the last combination category, we also tested for differences between (a) the combination that had a single chill activity combined with an instance of RF/work study, and (b) the combination with two chill activities and an instance of RF/work study. However, the effects for both these combinations were very similar in magnitude (and not statistically significantly different) for both the ABT dimensions, and so are combined into a single combination category.

The final (and rather simple) specification for TBA effects is as provided toward the bottom of Table 3. These TBA effects provide the influence on ABT, after controlling for the association between the TBAs and the ABTs through the correlations engendered by the stochastic latent constructs. That is, these TBA effects represent the "cleansed" effects of the TBAs after accounting for spurious correlations among the TBAs and ABTs. We first explain these spurious correlations before proceeding to a discussion of the cleansed effects. To do so, note that, for example, the stochastic component embedded in the "being chill" latent construct immediately permeates into the propensities for the chill activities (relax, TT, read, and entertainment), and generates a positive correlation among these chill activities because of unobserved factors. At the same time, "being chill" also positively impacts ALT and ALDT, engendering a positive covariance between the chill activities and VMT and each of the ALT and ALDT dimensions. Similar correlations are generated by the effect of other stochastic latent construct effects on TBAs and ABTs.

The overall implied correlation matrix among the TBAs and ABTs may be developed from the estimates in Table 3. In general, unobserved factors that increase the utility to participate in any chill activity (relative to the road fixation TBA) also increase the propensity to participate in other chill activities, with these correlations ranging from +0.234 to +0.639 (this is to be expected, given the similarity in the direction of effects of each latent construct across the chill activity purposes). Also, unobserved factors that elevate the utilities of the chill activities (except TT and entertainment) reduce road fixation utility, due to the effect of the safety concern latent construct. As importantly, the stochastic latent construct effects are such that they engender a general positive correlation between all the non-RF activities and the ALT/ALDT dimensions, while there is a negative correlation between RF activities and ALT/ALDT. That is, as discussed in the introduction section, individuals who intrinsically (after controlling for observed demographics) are likely to make fewer trips in an AV environment appear to be the ones more likely to partake in RF activity (primarily because of AV safety concerns). In contrast, those more likely to make a higher number of trips in an AV environment are the ones more likely to partake in chill activities, because, for example, they are not very concerned about AV-related safety. If these "spurious" correlations are ignored, the result will be an overestimation of the effect of participating in the chill activities themselves on ALT/ALDT. That is, AV-related safety concern differentials get manifested (incorrectly) as exaggerated productivity-based impacts on ALT/ALDT (because of being able to undertake chill or work/study activities rather than being fixated on the road as in today's human-driven environment). In simpler terms, the VTTS because of the ability to pursue TBAs in AVs would be exaggerated. We demonstrate this effect further in Section 4.4.

After accommodating for the self-selection in TBA choices and ABT discussed above, the "true" impacts of TBAs on ABT are shown toward the bottom of Table 3.¹¹ The results indicate that TBA participation in any activity combination other than solely being road-fixated (as in the current human-driven conditions, even if some individuals do participate in activities such as TT today) positively increases the inclination to make local area and long distance trips in an AV environment. The extent of this shift is a function of whether a chill activity is done in isolation (least impact), or a chill activity is combined with a work/study or RF episode (medium impact), or multiple chill activities are combined together without a work/study/RF episode (highest impact). Importantly, in our analysis, we explored interaction effects of demographics (including whether the respondent had or did not have a driving license), the latent constructs, and the trip purpose/accompaniment combinations with the TBA combinations to test for variations in TBA effects based on demographic or travel context, but did not find statistically different effects. This is an interesting result, though it is possible that the small sample size may have contributed to this result. For example, we had only on the order of 200 observations in each trip purpose/accompaniment combination, which may have made it difficult to tease out differences in TBA impacts (on ALT/ALDT) across demographic groupings and purpose/accompaniment combinations. Future research needs to explore TBA impacts on ABT based on more disaggregate classifications of the travel context, as well as with larger data sets that enable teasing out variations in TBA impacts on ABT propensity based on demographics.

4.3 Model Goodness of Fit

To ensure that the insights gained from the joint modeling of TBAs and ABTs are valid and accurate, it is important to consider the data fit provided by such a model relative to a naïve model that completely ignores jointness among these two dimensions. For such an evaluation, the performance of the proposed GHDM model may be compared with that of a restricted model (that is, an independent model) that does not consider latent constructs (and consequently also ignores any type of dependency among the outcomes because of unobserved factors). In the restricted independent model, we model the main outcomes of the paper independently in the form of an independent rank-ordered probit model (for the TBA outcomes) and two ordinal outcomes for ALT and ALDT. This restricted model takes the form of an independent rank-ordered and ordered probit (or IROP) model. For each of the endogenous outcomes in the IROP model, we include all the determinants of the latent constructs (from the GHDM) as exogenous variables in the main outcome equations (so that the primary difference between the GHDM and IROP models is whether jointness in the outcomes is considered or not). The GHDM model and the IROP model are not nested, as the latter model does not provide a mechanism to incorporate the latent constructs. Therefore, for a fair comparison between the GHDM and IROP models, we compute the predictive likelihood at convergence for only the main outcome variables in the GHDM. Our joint model and the independent model may be then compared using a predictive Bayesian Information Criterion (BIC) statistic [= $-\mathcal{Z}(\hat{\theta}) + 0.5$ (# of model parameters) log (sample size)]

¹¹ The constants and the thresholds at the bottom of Table 3 do not have any substantive interpretations. The constants simply adjust for the range of the continuous latent constructs, while the thresholds simply map the underlying ordinal propensities for the ALT and ALDT dimensions to the corresponding five point Likert scale ordinal categories.

 $(\mathcal{Z}(\hat{\theta})$ is the predictive log-likelihood at convergence). The model with a lower BIC statistic is the preferred model. In addition to the comparison using the BIC value, an informal predictive non-nested likelihood ratio test may be used to compare the models. The adjusted likelihood ratio index of each model of the joint and independent models is first computed as follows with respect to the log-likelihood with only the constants in the outcomes:

$$\overline{\rho}^2 = 1 - \frac{L(\theta) - M}{L(c)} \tag{1}$$

where $L(\hat{\theta})$ and L(c) are the predictive log-likelihood functions at convergence and at constants, respectively, and M is the number of parameters (excluding the constants) estimated in the model. Let the corresponding values be $\bar{\rho}_{GHDM}^2$ and $\bar{\rho}_{IROP}^2$. If the difference in the indices is $(\bar{\rho}_{GHDM}^2 - \bar{\rho}_{IROP}^2) = \tau$, then the probability that this difference could have occurred by chance is no larger than $\Phi\{-[-2\tau L(c) + (M_{GHDM} - M_{IROP})]^{0.5}\}$, with a small value for the probability of chance occurrence suggesting that the difference is statistically significant and the model with the higher value for the adjusted likelihood ratio index is preferred.

We also evaluate the data fit of the two models intuitively and informally at the disaggregate level. To do so, we first compute the multivariate predictions for each of the outcomes. Then, for the joint model, we compute an average (across individuals) probability of correct prediction based on the appropriate one-dimensional, two-dimensional, or three-dimensional level based on the response of each individual (this is done because individuals had the opportunity to provide only up to three TBA responses). A similar disaggregate measure is computed for the independent model.

The results of the disaggregate data fit evaluation are provided in Table 4. The BIC values, predictive adjusted likelihood ratio indices, the corresponding informal non-nested likelihood ratio statistics, and the average probability of correct prediction from the joint model very clearly indicate the superior fit of the GHDM relative to the IROP model.

4.4 Average Treatment Effects (ATEs)

The estimates in Table 3 provide the effects of variables on the propensities of pursuing each TBA activity and the effects of TBA activity participation on ABT outcomes. However, one may further translate the estimates into the effects of the individual characteristics and BE attributes on the (1) actual participations in each of the TBAs and (2) each of the two ABTs. Further, these effects will further differ by the trip purpose-accompaniment combination because there are seven TBAs in the case of travel with family and only six in the case of traveling alone. Additionally, each of the above effects of exogenous variables on each of the TBAs and on two ABTs (that is, ALT/ADLT) can be further partitioned into separate pathway effects by each latent construct and through a direct effect. But, of course, this would lead to a total of 42 tables across the six or seven TBA alternatives, two ABT alternatives, and five trip purpose-accompaniment combinations. So, to conserve on space, we focus here on a third effect of the influence of participating in each of the TBA combinations on ALT and ADLT. This may be achieved by computing the average treatment effects (ATEs) of the effects of each of the TBA combinations in Table 3. ATE is a metric that computes the impact on a downstream posterior variable of interest due to a treatment that changes the state of an antecedent variable from A to B. In our case, we change the state from "RF only" (which is the base category for TBAs) to participation in each of the other TBA combination states in Table 3. The impact of this change in state (from "RF only" to each of the other TBA

combinations) is measured in terms of the percentage change in the shares of the outcomes of interest between the case where all individuals in the dataset are in state A and the case where all the individuals in the dataset are in state B.¹² For presentation ease, we compute the percentage change in shares for the combined "somewhat likely" and "very likely" categories for the ALT and ALDT outcomes (we will refer to this combined category as the "likely" category). We also focus only on the trip purpose-trip accompaniment combination corresponding to "Traveling long distance with family members".

The percentage ATE (PATE) effects are presented in Table 5 for both our GHDM model that accounts for the endogeneity of TBAs in ABT and the IOP model that ignores the endogeneity. The first numeric entry of 42% in the GHDM model indicates that if 100 individuals who participate in either only road-fixation or only work/study activity in an AV suddenly shifted to participate in one chill activity in the AV, 42 more among the 100 would likely increase their local area trip-making. Alternatively, and equivalently, a random individual who participates in a chill activity rather than in road fixation or work/study in an AV would be 42% more likely to make additional local area trips. Other figures in the table may be similarly interpreted. As discussed earlier, we did not find any statistically significant difference in trip-making between road-fixation and work/study. The results clearly indicate that participation in chill activity, especially when combined with other chill activities with no RF or work/study instance, leads to higher ALT and ALDT. While joint participation in RF or work/study with one or more cool activities also increases ALT and ALDT relative to RF only or work/study only, this effect is not as high as when only a combination of chill activities is pursued. Clearly, the specific TBA pursued has an impact on ALT/ALDT. Implications of these findings are discussed in the next section. Also, as alluded to earlier, the independent model overestimates the percentage increase in ALT and ALDT due to TBAs relative to our model, for the reasons identified earlier. This overestimation in the independent model ranges from 16-26% for TBA effects on ALT and from 20-40% for TBA effects on ALDT, underscoring the importance of jointly modeling TBA preferences and ABT (rather than considering TBA choice as being purely exogenous to ABT).

5. CONCLUSIONS

This paper is the first to our knowledge that undertakes a deep dive into the kinds of activities that individuals are likely to pursue when freed from the task of driving in the fully automated vehicle (AV) era. We refer to such activities as travel-based activities or TBA. The study also examines the potential effects of TBA participation on possible additional local area travel (ALT) and additional long distance travel (ALDT). In contrast, the extant scholarly literature more commonly sidesteps such a careful and rigorous analysis when examining the potential impacts of AVs on activity-travel characteristics, by a priori assuming that there will be a lowering in the value of travel time savings (VTTS). Different from this vast body of literature, we suggest that the issue of VTTS effects in the AV era is way more complex and a much more nuanced aggregation of multiple considerations, each of which requires careful investigation by itself.

Our empirical analysis is based on a survey undertaken in Austin, Texas. In addition to demographics that are typically used in earlier studies to investigate TBA (and most commonly in

¹² Because of the non-linear nature of the model system, the ATE effects of the TBA on ABT will vary based also on demographic variables (even though the TBA effects on ABT propensity in Table 3 do not vary at all by demographics). But rather than computing the ATE effects separately for each possible combination of demographics and travel contexts, we compute a single ATE across all individuals.

the context of public transportation), we also consider four psycho-social latent constructs (or personality traits). While three of the latent constructs: tech-savviness, AV-related safety concern, and interest in productive use of travel time (IPTT); have been used in the earlier AV literature, we construct a fourth construct: being chill; that we have not seen used in earlier AV literature. Those who are students, from low income households, and who are not single parents appear to be more chill in their outlook relative to other individuals. Regarding the other latent constructs, women and older individuals tend to be less tech-savvy, more safety-concerned (less trusting of AV technology), and more interested in the productive use of travel time (the last of which implies that women and older individuals exhibit more frustration with traffic delays and an elevated interest to make good use of travel time).

In turn, latent constructs have a substantial impact on TBA and ABT. In general, techsavvy individuals and those with a chill personality are more likely to engage in non-work chill TBAs (chill TBAs include sleeping, gazing out the window, talking/texting, reading, eating, playing games, watching movies/TV/other entertainment, and interacting with family members when traveling together). On the other hand, those who are AV safety concerned are unlikely to participate in work as well as most chill TBAs, and are more likely to be road-fixated. A high IPTT translates primarily to partaking in relaxing, work/study, and social interactions, clearly indicating that "productive use of time" is not necessarily always tied with activities such as work/study; rather, being able to partake in relatively chill activities is also considered as productive use of time. This suggests caution in the interpretation of what are traditionally referred to as "productive" activities and also a need for scholarly restraint in the use of the label "multi-tasking" to exclusively refer to non-passive activities. We suggest that the field move away from subjective/ambiguous terms such as multitasking and "productive" activities, and adopt the more neutral label of "travelbased activity" as used in our paper. Besides, this would also better reflect the fact that instances of the so-called passive relaxation activities (sleep and gazing out the window) are very frequently combined with work/study, road-fixation, and other chill activity instances.

In terms of latent construct effects on ABT propensity, those who are safety concerned are unlikely to travel more in an AV environment than they currently do, while individuals with a chill personality and with a high IPTT are likely to make more trips in an AV environment for both local travel and long distance travel. Some demographic variables also appear as direct effects after accounting for the effects through the psycho-social constructs. For example, women are more likely than men to talk/text and read during their travel in an AV environment; older individuals partake less in work/study and entertainment TBAs, and express less inclination for additional travel in an AV environment. Not surprisingly, those from high income households are likely to have an elevated level of entertainment activity participation relative to those from low income households, while single parents are more likely to be road-fixated and less likely to make additional local area trips than other individuals. There are also variations in TBAs based on the trip purpose-accompaniment combination, with road fixation propensity being higher during local solo trips to the store relative to local work/study trips, and work/study unlikely to be participated in during non-work trips compared to work trips, and especially so for long distance trips. Social interaction is a common TBA when traveling with family.

Our average treatment effects analysis of TBA on ABT indicate that, while the option to, and the ability to, partake in the work/study TBA is substantially enhanced in an AV, this does not translate to any additional inclination to travel more, both locally and long-distance, relative to road fixation (which may be viewed as the base case, given it is the nominal state in the current human-driven travel environment). On the other hand, an individual partaking in chill activities

during travel in an AV is likely to increase both local and long distance trips (that is, increase ALT and ALDT), especially when not combined with a work/study or an RF instance and when combined with other chill activities. Thus, if partaking in work/study as the TBA, it does not increase ALT/ALDT, though participating in chill activities does. In the context of AVs, any increase in ADLT/ADT due to the freedom from driving may be related to the relatively higher enjoyment of travel (or at least the lessening of travel burden) compared to human-driving, which is after all the reasoning for expecting any reduction in the valuation of travel time savings in AVs. What our results indicate then is that travel enjoyment is increased (travel burden is reduced) when partaking in "chill" activities, though the freed-up time if used for work/study does not lead to such a travel enjoyment increase (or reduction in travel burden). This may be traced back to angst feelings (and a lack of enjoyment) when pursuing travel-based work/study activities. These findings further support our original thesis that the option of opening up travel to pursue work/study activities may itself be engendering stress in individuals. This also highlights a need to examine TBAs in the broader context of emotional well-being and quality of life. Indeed, AVs may further erode into our time of tuning-out from the "chatter" of routine life and make it less possible to partake in "calm and mindless" activities.

Overall, our study cautions against the use of simple and uniform (across individuals) VTTS factor modifications to study AV impacts on ABT, given the differential effects of different combinations of TBA on ABT and the variations across individuals in TBA participation choices. Of course, as with any research effort, our investigation raises as many questions as answers. There is a need to examine TBAs in different contexts with larger sample sizes, so that the travel context (including a more disaggregate categorization of trip purpose and accompaniment combinations) can be more comprehensively considered. Also, while some of our results may be useful for AV designers in terms of the type of vehicular design that may be particularly suitable for undertaking the most desired TBAs, the preference for participation in a set of TBAs itself would be influenced by vehicular design. Future studies that use a richer virtual reality-based presentation mechanism of different vehicular design possibilities to elicit TBA preferences may be a valuable direction of research. Other possible ways of eliciting information about what individuals may do in an AV can also be explored in future studies, such as examining what people may do in a chauffeur-driven environment or in a simulator environment. Each of these possible ways of obtaining data has some limitations, as with the SP data used in the current paper (see Bhat, 2022). For example, these alternate ways of collecting data may not be able to provide a good diversity and size of respondents. And a problem is that what individuals pursue when alone in any space can be quite different from what individuals pursue in the presence of others; this latter effect, sometimes referred to as the audience effect in the social-psychological literature is well-established (see, for example, Hamilton and Lind, 2016 and Wu et al., 2020).¹³ Another possibility that is likely to become increasingly valuable is to obtain information through responses from individuals who have traveled in recently initiated AV pilot exercises in three metro areas of the US (the San Francisco, Phoenix, and Austin areas). While these exercises are still contained in space within the areas, such services are likely to expand to other regions within these metro areas and to other metro areas. But, for now, while offering potentially some insights on TBA activities, the

¹³Additionally, in recent years, it has become increasingly difficult to predict the decisions of individuals in the future based on the few abstracted "today" characteristics that can be derived from RP surveys. The main reason for this is the accelerating pace of technology development in the transportation industry. In such a fast moving technological landscape, the assumption of temporal porting and stability of behaviors into a new future brings into question validity issues, as discussed in Mata *et al.*, 2018 and Arslan *et al.*, 2020.

simultaneous effects on ABT may not be easily discernible from such responses because the services are still not mainstream. Also, the number of individuals who have used such services is likely to be limited, leading to sample size problems for analysis. In any case, as AV services become increasingly available across the country, they start providing an additional valuable source of information that can be harnessed for studying TBA and ABT activities (and the interactions between the two).

In conclusion, we would encourage approaching AV behavior from multiple data collection perspectives; insights can be obtained by pursuing carefully designed data collection mechanisms of different kinds. Additionally, our use of aggregate ABTs (that is, a general ordinal characterization of how likely an individual would be to increase local area trips and long distance trips) can be replaced with more disaggregate ABT measures (such as new activities undertaken by purpose, time-space shifts in current ABTs, and activity chaining effects). In terms of survey framing, in retrospect, it would have been good to alert respondents to the issue of motion sickness in vehicles, since the literature suggests that this does impact the types of TBA activities undertaken (see Section 2). Further, there is an important need to examine TBAs in the broader context of life rhythms, emotional wellbeing, and quality of life considerations. Finally, the nature of the sample and the design of the survey in the current study was oriented toward understanding what individuals who drive on a routine basis would do in an AV; that is, the focus of our study was on individuals who routinely experience human driving today (which, of course, is a vast majority of the adult population in Austin and much of the rest of Texas). But the number of young adults who are eschewing the driving act altogether and using other modes of transportation (such as public transportation and bicycling) has been increasing. Future studies need to examine TBA and ABT behavior in AVs among such currently non-driving segments of the population. While our study did not find any statistically significant difference between current drivers and nondrivers in their TBA behavior, or in influencing TBA effects on ABT propensity, this result may simply be an artifact of the low number of individuals in our sample without a driving license.

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Figure 1. Model Framework

Technology Savviness	Learning how to use new technologies is often frustrating for m I like to be among the first to have the latest technology. Having internet connectivity everywhere I go is important to m	e.	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Safety Concern	I would feel comfortable sleeping while traveling in an AV. AVs would make me feel safer on the street as a pedestrian or as a cyclist. I am concerned about the potential failure of AV sensors, equipment, technology, or programs. I would feel comfortable having an AV pick-up/drop-off children without adult supervision.	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Being Chill	I prefer to do one thing at a time. The time spent traveling to places provides a useful transition between activities. Having to wait can be a useful pause in a busy day.	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Interest in Productive Travel Time (IPTT)	The level of congestion during my daily travel bothers me I try to make good use of the time I spend traveling.	0%	10% Strongly	20% disagree	30% Somew	40% hat disagr	50% ee ∎Net	60% utral ∎S	70% o mewhat a	80% agree S	90% Strongly a	100% gree

Figure 2. Distribution of Attitudinal Indicators

Travel-Based Activities (TBAs)	Count	%
Univariate TBA participations		
Relax	531	54.7
Work/Study (WS)	364	37.5
Talk on/Use Phone (TT)	467	48.1
Read	185	19.1
"Entertainment"	423	43.6
Social Interaction with other Passengers (SI)	168	17.3
Road Fixated (RF)	349	36.0
Popular TBA Combinations		
Only Work/Study (WS)	36	3.7
Only Road Fixated (RF)	37	3.8
Only one chill TBA*	50	5.2
Chill TBAs with an RF or WS instance	569	58.7
Multiple chill TBAs without RF and without WS instance	278	28.7

Table 1. Sample Distribution of Travel-Based Activity (TBA) Combinations

*A chill TBA corresponds to either relaxing, talking/texting on the phone, reading, entertainment, or socially interacting with family members.

Table 2. Determinants of Latent Constructs

			S	tructural E	quations M	odel Compo	onent Resul	Results									
Variable (base catego	S Arry)	Tech-Sa	vviness	Safety C	Concern	Being	Chill	IPT	Т								
(base catego	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat									
Individual Demographics																	
Gender (male)																	
Female		-0.556	-15.26	0.767	33.96			0.183	8.07								
Female * Kids				0.213	8.72			-0.304	-9.63								
Age (younger than 30)																	
30 to 64								0.314	14.00								
65 or older		-1.291	-10.85	0.406	6.84				14.00								
Employment Type (unemployed, non-student)																	
Employed								0.180	9.52								
Student						0.271	15.41										
Household Demographics																	
Income (<\$100,000)																	
≥ \$100,000		0.308	10.66	-0.165	-7.97	-0.155	-8.25										
Household Structure (child	less home or																
nuclear family)																	
Single Parent						-0.302	-7.90										
	Construct	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat								
	Tech-Savviness	1.00		-0.32	-3.65	-0.24	-3.29	-0.13	-2.13								
Correlation Among	Safety Concern			1.00		0.19	1.91	0.21	4.67								
Latent Constructs	Being Chill					1.00		0.33	4.34								
	IPTT							1.00									

	Travel-Based Activities (TBA)							Activ	Activity-Based Travel (ABT)									
Exogenous Variables (base category)	Re	lax	Work/ (W	/Study VS)	Talk/Te	ext (TT)	Re	ead	Enterta	ainment	Soc Interac	cial tion (SI)	Road F (R	ixation F)	AI	Л	AL	DT
	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Latent Construct Effects	i	[i	i		i									,,				(i
Tech Savviness	0.247	5.51	l '	1 "	l '		0.092	3.17	0.039	2.16				1 '			I '	i !
Safety Concern	-0.456	-12.12	-0.413	-15.78	0.042	2.24	-0.063	-2.23					0.065	3.67	-0.209	-7.44	-0.127	-5.26
Being Chill	0.202	5.63	l !	1 /	0.312	10.29	0.542	15.24	0.271	9.82				1 '	0.205	6.40	0.123	2.95
IPTT	0.321	8.51	0.380	10.07	l '						0.453	12.82		1 '	0.240	5.88	0.384	7.21
Individual Demographics	l		l	<u>г</u>	l									ļ ,			l 1	í — – †
Gender (male)		1 !		1 "			l		J					1 '			1 '	i !
Female	l !	1 !	l !	1 "	0.089	4.22	0.325	10.86						1 '			l '	i !
Age (29 or less with a driver's license)	'		'	1 "	'		l							1 '			1	1
29 or less without a driver's license	'	1 1	'	1 "	'				J					1 '	0.223	8.23	0.133	4.14
30 to 64	!	1 !	l !	1 "	l !									1 '			-0.416	-11.02
65 or older	!	1 !	-0.910	-8.55	l !				-0.615	-7.81			-0.105	-3.06	-0.416	-11.13	-0.831	-14.91
Employment Status (unemployed,			'	1 "	'		1		J					1 '			1	1
nonstudent)	'	1 1	'	1 "	'				J					1 '			1 ¹	1
Employed	l !		l !	1 /	l '						-0.053	-2.85		1 '			I '	1
Student	l !	1 !	0.110	5.57	l !		-0.068	-3.70						1 '			-0.167	-4.09
Education Level (high school or less)		1 !		1 "			1		J					1 '			1 '	1
Higher Education	l '	1 1	l !	1 "	l '									1 '	'		0.266	8.04
Household Demographics				[]							İ d			ļ ,	İ		· · · · ·	í — – – – – – – – – – – – – – – – – – –
Income (<\$100,000)	'		'	1 /	'				J					1 '			1 '	1
>\$100.000	l !		l '	1 "	l !				0.144	5.62				1 '			I '	1
Household Structure (non-family unit or		1 !		1 "			1		-	-				1 '			1 '	1
a couple with no kids)	'	1 1	'	1 "	'				J					1 '			1 ·	1
Nuclear Family	l !		0.086	3.01	l '									1 '			l '	1
Single Parent	l !	1 !	· ·	1 1	l !								0.166	4.16			l '	1
Presence of Children (no children)		1 !		1 "			1		J				** · · ·	1			1 '	1
Children Present	-0.106	-4.91	l '	1 "	l '									1 '	-0.290	-10.06	l '	1
Built Environment Attributes	l		l	[]	l									· · · ·			l 1	í
Living Environment (rural or suburban)	'		'	1 "	'		1							1 '			1	1
Urban	l '		l '	1 "	l '								-0.055	-3.09	0.098	6.86	l '	1
Trin Purpose-Accompaniment Variables	l		l		l												 − +	í
(alone to work or study location is base)		1 !		1 "			1		J					1 '			1 '	1
Traveling alone to the store	'		-0.065	-1.97	'								0.152	7.22	NA		NA	1
Traveling with family members to the park	-0.063	-2.03	-0.206	-5.33	-0.160	-5.50	-0.074	-2.76	-0.119	-3.69	0.290	10.93			NA		NA	1
Traveling long distance alone			-0.103	-3.39	-0.114	-5.02						10		1 '	NA		NA	1
Traveling long distance with family members	l '		-0.234	-7.33	-0.150	-6.48					0.230	10.30		1 '	NA		NA	1
Effects of TBAs (only RF or WS is base)	l			· · · ·	0	· ·								├ ─── ′			<u> </u> − − +	í ———
Only one chill TBA	NA	1 !	NA	1 "	NA		NA		NA		NA		NA	1 '	0.338	7.20	0.268	5.18
Chill TBAs (w/ RF or WS)	NA		NA	1 "	NA		NA		NA		NA		NA	1 '	0.401	10.24	0.651	14.11
Multiple chill TBAs (w/o RF and w/o WS)	NA		NA	1 /	NA		NA		NA		NA		NA	1 '	0.556	12.77	0.901	16.53
Constant	l I		-0.384	-11.65	-0.138	-6.28	-0.423	-16.30	-0.515	-14.46	-0.376	-14.70	-0,086	-3.09				
Thresholds	l I		0.00.		0.120	0.20	020	10.00	0.010	1	0.070	1	0.000		 '		 −−−+	í ———
1/2	NA	1 1	NA	1 "	NA		NA		NA		NA		NA	1 '	-0.819	-21.28	-0.901	-15.55
213	NA		NA	1 /	NA		NA		NA		NA		NA	1 '	0.015	1.54	-0.177	-3.60
314	NA		NA	1 /	NA		NA		NA		NA		NA	1 '	0.510	10.39	0.410	6.72
4 5	NA		NA	1 /	NA		NA		NA		NA		NA	1 '	1.735	26.80	1.484	24.26

Table 3. Jointly Modeled Tied Ranking of Travel-Based Activities (TBAs) and Activity-Based Travel (ABT) Preferences

	Model					
Summary Statistics	Joint (GHDM) Model	Independent (IROP) Model				
Predictive log-likelihood at convergence	-10393.22	-10568.91				
Number of parameters	156	124				
Bayesian Information Criterion (BIC)	10929.65	10995.30				
Constants-only predictive log-likelihood	-11400.85	-11400.85				
Predictive adjusted likelihood ratio index	0.0747	0.0622				
Informal non-nested adjusted likelihood ratio test: Joint model versus Independent model	Φ[-17.78	8]≈0.000				
Average probability of correct prediction	3.358×10^{-5}	3.344×10^{-5}				

Table 4: Disaggregate Data Fit Measures

TBAs (relative to RF participation)	Joint (C Ma	GHDM) odel	Independent (IROP) Model			
	ALT	ALDT	ALT	ALDT		
Only one chill TBA	42%	28%	49%	39%		
Chill TBAs (w/ a RF or work/study instance)	50%	71%	63%	90%		
Multiple chill TBAs (w/o RF and w/o work/study instance)	71%	97%	86%	117%		

Table 5: % ATEs for TBA Effects on ALT and ALDT