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Examining Factors Influencing the Use of Shared Electric Scooters

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Abstract: Shared e-scooters have the potential to increase access, complement transit, and replace automobiles, all while reducing emissions and congestion. However, there are concerns worldwide over the mode's safety issues and risks. In this paper, we explore both the motivations and barriers to using e-scooters. Data are collected from a stated preference survey, using a sample consisting of mostly university staff and students in Singapore. Three logit models with varying specifications of e-scooters' speed and lane use and one's prior experience of conflict with a personal mobility device (PMD) are estimated. Overall, the three models have a very comparable fit (adjusted R^2 of about 0.55) and consistent results. The results indicate preferences for e-scooters if they are faster and off the sidewalk. However, a bad or unsafe experience with a PMD would negatively affect use to a greater degree, although it varies across individuals. Our study suggests diverting scooters off the sidewalk and increasing the speed may not always be effective in encouraging behavioral shifts toward this alternative mode. Other solutions such as improving the services and enhancing traffic safety should be explored and considered instead.

Keywords: e-scooter; shared mobility; micro-mobility; transportation safety; mode choice; stated preference surveys

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1. Introduction

Worldwide, electric scooters (e-scooters) have gained popularity both as a private mode and as part of a sharing system. It is expected that by 2025, e-scooters would comprise a $30 billion market with much of the demand generated from China, Europe, and the U.S. [1]. Collectively with other small-transportation solutions, such as e-bikes, mopeds, unicycles, and skateboards, they are known as personal mobility devices (PMD) or micro-mobility. E-scooters are easy to use and have several advantages which make them a perfect mode for trips such as short commutes or leisure rides. Compared to other motorized modes, such as cars, they are much more affordable, compact, and eco-friendly. Therefore, they are often considered a promising alternative and/or additional sustainable mode of transport, which could contribute to less air pollution worldwide.

1.1. The Increasing Trend of Shared E-Scooters

In addition to privately owned e-scooters, there has been an increasing use of shared e-scooters. In the U.S. for example, in 2018, e-scooters overtook bikes as the most preferred dock-less sharing system, accounting for about 38.5 million trips [2]. Shared e-scooters offer an added benefit in that they can be accessed on an on-demand and as-needed basis. By enabling riders to shared scooters, there is great potential to improve mobility and accessibility within urban areas while reducing congestion and emissions. Shared e-scooters are also sustainable because they could incite significant modal shifts from private automobiles in some cases. For example, it was found that shared e-scooters, on short trips between half and two miles, have major advantages over cars because they are not much slower, but they are more cost-effective and may even be more time-competitive in parking-constrained environments [3]. For these reasons, they could potentially contribute to increasing the number of car-free households [3]. Moreover, a study by the Portland Bureau of Transportation [4] showed actual shifts of "34% of resident scooter riders [in Portland who] would have otherwise driven a personal car or taken a taxi or TNC if a scooter hadn't been available for their most recent trip". At the same time, shared e-scooters may reduce the demand for active transportation modes, such as walking, as well. According to the same study, in Portland, nearly 37% of scooter users would have walked if a scooter were not available for their last trip. Still, even if more people switched from walking than from private automobiles, any switch from cars would be positive in the net effect on traffic congestion alleviation, because cars take up much more space than a scooter.

1.2. Barriers to the Use of Shared E-Scooters

Unfortunately, several barriers exist which can hinder the use of e-scooters—safety concerns being a critical one. An alarming number of studies have discussed the dangers and health costs of these vehicles (e.g., [5–7]). A continuing problem is the potential conflicts with pedestrians when scooters are allowed on sidewalks. Several accidents have already happened, including one in Singapore which resulted in a fatality [8]. To make matters worse, in an event of an accident, most of the shared scooter companies foist the cost of accidents and injuries on the user and the public [9].

One problem with e-scooters is that there is no clear place for them. Do they belong on the sidewalk with pedestrians or on the street with cars and motorcycles? Because they are motorized, they are fast (up to 30 kmph or about 20 mph), but they are not as fast and as heavy-duty as other motorized vehicles. They are easy to dismount, so people frequently switch between riding and walking them. Incidents, including some fatal accidents, led to a ban on their use on all sidewalks in several places such as Singapore, the U.K., Japan, and France. As local authorities build up the infrastructure and eventually lift the ban, should they split the sidewalks (painted paths), while reducing the maximum speed of these scooters? Or should they allow scooters alongside other motorized vehicles on the road, while mandating that riders follow the same traffic laws? Under these two scenarios, what would be the demand for shared scooters? What other factors would affect the demand for shared e-scooters, and how do they compare with each other?

In this paper, we strive to answer these questions by estimating choice models using data from a stated preference (SP) survey conducted in Singapore. We asked respondents for their preferred mode for a specific first/last mile trip, assuming a given set of modal characteristics (e.g., faster speed on the road and shorter travel time or slower speed on the sidewalk and longer travel time). We applied several choice models, including one that also accounts for inter-person heterogeneity and panel effects. Our findings could provide policy insights as to how to further encourage and enable the use of shared e-scooters and determine where we should carve out a place for e-scooters.

2. Literature Review

There is extensive literature on micro-mobility, especially on shared bikes, a micro-mobility with perhaps the most resemblances to shared scooters (e.g., [10–15]), and other kinds of PMDs, such as shared moped scooters (e.g., [16]). In much of the literature, logit models were estimated to test various factors including service quality and existing infrastructure, built environment, socio-demographics, and personal attitudes. They found that some of the potential factors are related to the service and infrastructure. For example, increasing the number of stations, bike racks and capacity would greatly increase ridership because users would have shorter access time or wait times. Additionally, there may be disparities between different users; it was found that having more bike racks impacts women more than men, and such service improvements can reduce the gender gap in shared bike use [17]. Furthermore, improved traffic safety and traffic climate or even perceived traffic safety (e.g., fewer pedestrian and bike crashes) are also proven to greatly influence use [10,11,18]. Other factors not related to the service or infrastructure are instead related to the geography or environment. Job density, proximity to public transit, and proximity to recreational areas are directly correlated with higher use [17]. In terms of socioeconomic factors, frequent users tend to be younger, upper to middle-income, and with higher levels of education [19]. Finally, personal attitudes play a role as well; Li and Kamargianni [20] found attitudes about the environment, such as one's "willingness to be a green traveler", to have significant positive impacts on the preferences for shared bikes.

Over the past five years, there has been widespread growth in studies on e-scooters. Two studies provide a comprehensive literature review of growing research on PMDs and summarized the overall general perspectives as they relate to various areas, such as trip patterns, modal share, user demographics, riding and parking behavior, regulation and policy, and safety [21,22]. A Populus report published in 2018 provides a general overview of the service based on data collected from 11 major U.S. cities [23]. The authors claim that many consider shared e-scooters as a useful means "to get around without the hassle of owning a car", "a substitute for short driving trips", or "a complement to public transit". The majority of people (up to 70%) view shared e-scooters positively, and it is no surprise that adoption rates have been increasing rapidly [23]. Privately owned scooters are well received as well. Early adopters often actively engage and discuss product features with their peers, which has been known to accelerate demand [24]. In addition to personal use, sometimes scooters are also used for the delivery of goods in urban areas [25].

Several studies (e.g., [24–29]) examine usage patterns of shared scooter services. In an analysis of more than 8000 scooters serving over 425,000 rides in Indianapolis, Matthew et al. looked at trip durations, distances, speeds, and schedules (i.e., time-of-day and day-of-the-week) [27]. The authors find that scooters typically serve a particular trip purpose, mainly, short, last-mile travel as most trips are about 14 min in duration and 1 km (nearly 0.7 miles) in distance. They are usually ridden no faster than 10 km/h (about 6 miles/h) although they can go up to 25 km/h (≈15 miles/h). Moreover, peak periods on weekdays are between 4:00–9:00 pm. McKenzie [28] analyzed spatial characteristics in the usage patterns of e-scooters in Washington D.C. Based on the trip origin and destinations, they conclude that shared scooters do not have the same functions as other modes such as shared bikes, because they are not primarily used for commuting to and from work. An analysis of e-scooters in Austin, Texas found similar results [26].

A number of factors were found to affect the usage of e-scooters. Mathew et al. focus on the potential impacts of the weather in Indianapolis and find that in the winter, there are fewer scooter trips and slightly shorter distances and duration [29]. Additionally, there is even less demand when temperatures drop below freezing and during snowfall than during rain. Jiao and Bai [30] investigate the relationship between several built environment indicators and utilization. Their results suggest that the number of shared e-scooter trips is directly correlated with the population density, the proximity to the city center, the street and transit connectivity (i.e., presence of transit stations), and the proportion of higher educated residents. Interestingly, neighborhoods with more young residents tend to have fewer e-scooter trips. Meanwhile, areas with high employment as well as areas with bicycle infrastructure seem to be associated with shared e-scooter use [26]. Degele and colleagues performed customer clustering of many of the service processes from registration to scooter reservation, and the ride itself [31]. The authors indicate that the market can be grouped into four customer segments to improve the business development of the e-scooter-sharing model. While these analyses present relevant factors that may influence the use of shared scooters, none has examined the factors related to scooter safety.

Few of the existing literature, with the exception of medical journal papers, such as Rix et al., 2021, do consider scooter safety [32]. In a study about how e-scooters can be better incorporated into everyday travel, Hardt and Bogenberger distribute six scooters to nearly 40 individuals to use for eight weeks and then ask survey participants to rate statements such as "scooters should be allowed all over [a particular area]", "scooters should be allowed to drive 60 km/h", and "scooters disrupt traffic flow" [33]. Their results suggest that subjective safety is a restrictive attribute that can be improved by traffic regulations and their enforcement. Other authors investigate rider and pedestrian behaviors when riding or encountering e-scooters [34,35]. Specifically, Che et al. present scenes of a scooter traveling at different speeds and encounters from the same or opposite directions using virtual reality headsets [34]. They then ask respondents to rate their level of perceived safety and frustration. They find that most riders consider current scooter speeds to be too slow, while most pedestrians (and some riders) would not feel safe if the scooters were faster. Meanwhile, Tuncer and co-authors use an ethnomethodological approach to analyze riding behavior from video recordings [35]. The riding behaviors include how riders accelerate, decelerate and dismount from scooters. They find that riders sometimes consider themselves as a pedestrian and sometimes as a road user, and thus intermittently switch to whatever is most convenient. Ptak M. et al., 2022, simulated road accidents involving PMDs and focused on users' kinematics [36].

The studies reviewed above, especially those from the medical community, cover safety issues as they pertain to the number and types of crashes and injuries, while several others focus on policy and rider and pedestrian behaviors. However, they did not measure how much safety concerns and rider behavior may affect the use of e-scooters. After seeing that previous research analyzes safety and rider behavior in isolation from the demand for or use of shared e-scooters, this study thus seeks to fill this gap to better integrate the multiple overlapping areas of research on PMDs. Particularly, we are interested in how much the perceptions of safety, along with other relevant factors related to the mode performance (i.e., speed, time-saving) as well as attitudes on sustainability, influence one's willingness to use the devices.

3. Materials and Methods

3.1. The Study Context

At the forefront of sustainable transportation, Singapore has introduced a number of measures aimed at drastically reducing the country's reliance on private automobiles. One facet of the initiatives directly focuses on improving and enabling more active transportation alternatives (e.g., walking, cycling, and other PMDs). Examples include a 700 km cycling network under development and to be completed by 2030, and various piloted shared bike and shared scooter programs. Furthermore, public transit passengers are allowed to bring foldable bicycles and other vehicles onboard the trains and buses [37]. While the use of PMDs is highly encouraged, safety conducts relating to these devices are also seriously considered. In 2015, the country set up the Active Mobility Advisory Panel to establish the codes and regulations for PMD use and the sharing of sidewalks by pedestrians, cyclists, and PMD users. They enacted legislation mandating all PMDs be registered and meet several criteria such as maximum weight, width, and speed, and certified to a Device Safety Standard. Since May 2018, PMDs are to be ridden only on the sidewalk and off the roads. Then as a result of a series of related incidents and accidents, in February 2019, they reduced the PMD speed limits on sidewalks from 15 km/h to 10 km/h [38]. In April 2020, following a fatal accident, PMDs became prohibited on sidewalks [38]. As Singapore continues to develop and progress its policies to both promote the use and maintain safe interaction, there are many lessons to be learned and challenges to overcome, but there is also great potential to improve and expand PMD use. For these reasons, Singapore makes a perfect setting for our case study.

3.2. SP Survey and Scenario Design

Our review of the previous studies shows that e-scooters are often used for short trips and/or first/last mile trips. Therefore, in our study, we focus on the potential use of e-scooters for first/last-mile trips on a university campus where public transport is relatively less accessible. The National University of Singapore's (NUS) University Town (U-Town) is thus selected as a case study, in which its students and staff are the target sample. Located on the NUS campus, U-Town is a hub with not only teaching facilities but also residential and recreational spaces. There are food courts, the university bookstore, study clusters, and athletic facilities at U-Town. The Campus for Research and Technological Enterprise (CREATE), which houses a number of research centers, is also situated there. The NUS campus also has a rail station called the Kent Ridge MRT that is located about 2.3 km (nearly 1.5 miles) from U-Town (Figure 1).

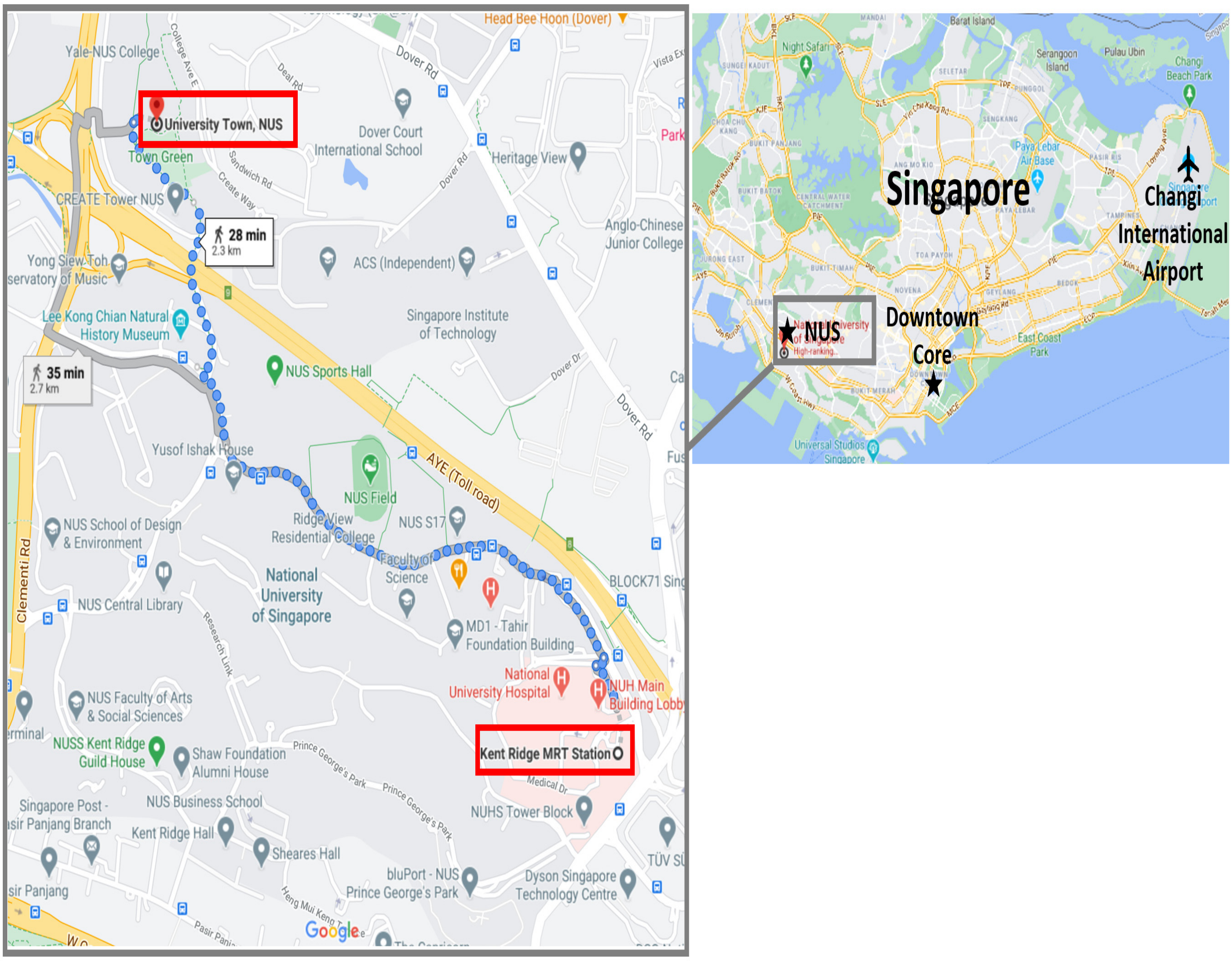

Figure 1. Map of U-Town and the Kent Ridge MRT Station on the NUS Campus.

For the SP survey in this study, we selected the trip from Kent Ridge MRT station to U-Town. While there are several transport options for this route, most are far from ideal, but the distance is suitable for e-scooters. We ask respondents for their preferred mode for this trip, given the choices of shared e-scooter, walk, Grab ride (a popular Transportation Network Company (TNC) ride-hailing service in Singapore), bus, and NUS bus. Modal characteristics include travel time, access time, wait time, and cost. We generated different profiles by varying the modal characteristics (the rules for the profile generations are shown in Table 1), and each respondent is randomly shown one of these profiles.

Table 1. SP Survey Design for Profile Generation.

	Shared E-Scooter	Walk	Grab	Bus	NUS Shuttle Bus
Travel Time	12 min on footpath (Q1) OR 6 min on road (Q2)	25 min	{3 min, 4 min}	7 min	7 min
Access Time	{4 min, 5 min, 6 min} by walking	0 min	1 min by walking	10 min by walking	2 min by walking
Wait Time	0 min	0 min	5 min	5 min	{7 min, 10 min, 20 min}
Cost	{$0.25, $0.50, $0.75, $1.00}	$0	{$6.00, $7.00, $8.00}	$0.13	$0

Respondents face a number of tradeoffs among the alternatives. For example, the NUS shuttle bus is free, but they typically have the longest wait times compared to the other modes. The local buses have shorter wait times than the NUS shuttle buses, however, they have the longest access time because their stops are sparsely distributed at the campus. Grab will be the fastest mode in terms of in-vehicle travel time but is the most expensive and waiting times could be longer during peak hours. Walking takes the longest, does not cost anything, and can be good physical exercise, yet it can be strenuous, especially during hot, humid, or rainy weather. Compared to the other modes, shared scooters have relatively moderate travel time, access time, and cost.

Each respondent was asked to complete two SP survey questions. In the first question, we assume that scooters can only be ridden on the sidewalk at a maximum speed of 10 km/h, while in the second question, they are assumed to be ridden on the road at a higher maximum speed (20 km/h). We refer to the two scenarios respectively as Questions 1 and 2 or Q1 and Q2. We did not explicitly emphasize the difference in the scooter's speed, but it is reflected in the travel time—the travel time via scooter on the road in Q2 is much shorter because they can be ridden faster. An example of the profile in the first and second SP survey questions are respectively in Figures A1 and A2 in the Appendix A.

3.3. Data Collection

To collect data, we conducted an online survey in March (pilot tests) and April 2020 (main survey). The decision to opt for an online survey was due to the fact that at the time the main survey was conducted, Singapore, where the study was conducted, was entering into a lockdown due to COVID-19. We acknowledge some disadvantages of the online survey method such as respondents may not understand the questions fully or may not put enough effort into answering the questions. However, compared to the alternative in-person survey, which is time- and labor-intensive, online surveys are much more cost-effective. Furthermore, respondents can complete the questionnaire at their own time and pace, enabling a more comfortable situation for them to give better answers and evaluation.

Survey links were distributed via mailing lists to all NUS staff and students, as well as affiliated research institutes' staff. Posters and flyers about the survey were also posted around the campus. To compensate their time, we rewarded each participant of the survey with a $10 e-voucher for ridesharing by a major TNC in Singapore. Nearly 1000 respondents participated in the self-completed online survey. After excluding individuals who did not fully complete the survey or who took less than 5 min to complete the survey, the final sample size is 765.

In addition to the SP survey, we inquired about the individual's personal/socio-demographic information (e.g., gender, age, education, occupation, car ownership (household), PMD ownership), and whether he/she has experienced an accident or incident with PMDs (as a user or non-user/pedestrian). To understand respondents' attitudes toward the environment, we presented the following statements: "I am concerned about environmental destruction", "I am concerned about climate change", "I am willing to spend more to buy or use an eco-friendlier product or service", and "I would change my behavior if it could help reduce negative environmental impacts" and asked respondents to rate how much they agree with each of the statement on a five-point scale. Then we took the average rating and considered the individuals with averages above 3 to have strong environmental values. According to the Theory of Planned Behavior, beliefs, attitudes, and behavioral intentions do influence people's behaviors. This theory was tested in Javid et al., 2022, on actual behaviors with regard to the use of electric vehicles [39]. We want to test some of the attitudes toward the environment and sustainability on the use of PMDs.

3.4. Variables Selection

As discussed, several factors could affect the use of e-scooters. In this study, however, we took into account these factors in developing our choice models: travel time, access time, wait time, cost, user's primary mode of transport, household ownership of a car or a PMD, and previous experience with other shared mobility modes such as shared scooters, bikes, cars, TNCs, or pooled TNCs. In addition, we included the following variables: Q1 vs. Q2 (10 km/h on the sidewalk vs. 20 km/h on the road), whether one has experienced conflict with PMDs, and the interaction of the two. Note that the shared e-scooter alternative in Q1 and Q2 are assumed to be the same choice, but only differ in speed or travel time and surface type. Carrara et al., 2021, identified many of the same variables as key sustainable parameters (KSPs) to measure PMD performance [40]. Finally, we incorporated panel effects in order to control for individual heterogeneity, because we ask each person two SP questions. We assumed the coefficients (of Q1 vs. Q2, whether one has experienced conflict with PMDs, and the interaction of the two) are normally distributed and estimated the mean and standard deviations. The last set of variables are the alternative specific constants (ASC) for each mode.

3.5. Utility Specification

We estimated three different multinomial logistic (MNL) regression models [41]. As the scooter speed is actually reflected in the travel time, we did not include both Q1 vs. Q2 and travel time. In the first model (M1), we tested for Q1 vs. Q2 and the interaction of experienced conflict and Q1 (the effect of having experienced conflict in Q1 vs. Q2). Meanwhile, in the second model (M2) we included travel time instead of Q1 vs. Q2. In the third model (M3), we also tested for Q1 vs. Q2 and the interaction effect (like in M1), but we additionally incorporated panel effects. The main specifications of the utilities and the notations are presented in Equations (1)–(3) below. We assume that the ASCs may vary for different groups of people (e.g., they differ for males vs. females or individuals who have or have not experienced conflict). Therefore, we interact the ASC with all the variables that are not mode-specific. Furthermore, we fix the ASC of a shared scooter to be 0, making it the base. Thus, all the other ASCs are relative to the shared e-scooter alternative.

MODEL 1

$$V_j = \text{Common Variables}_\text{j} + \beta_{\text{Q1}} \times \text{Q1} + \beta_{\text{Exp.conflict}} \times \text{Exp.conflict} + \beta_{\text{INT}_{\text{Exp}}\text{.conflict}_{\text{Q1}}} \times \text{Exp.conflict} \times \text{Q1} \quad (1)$$

MODEL 2

$$V_j = \text{Common Variables}_\text{j} + \beta_{\text{Travel Time}} \times \text{Travel Time}_\text{j} + \beta_{\text{Exp.conflict}} \times \text{Exp.conflict} \quad (2)$$

MODEL 3

$$V_j = \text{Common Variables}_\text{j} + \beta_{\text{RND\_Q1}} \times \text{Q1} + \beta_{\text{RND\_Exp.conflict}} \times \text{Exp.conflict} + \beta_{\text{RND\_INT\_Exp.conflict\_Q1}} \times \text{Exp.conflict} \times \text{Q1} \quad (3)$$

where

$$\text{Common Variables}_j = \beta_{\text{Access Time}} \times \text{Access Time}_j + \beta_{\text{Wait Time}} \times \text{Wait Time}_j + \beta_{\text{Cost}} \times \text{Cost}_j + (\text{ASC}_j + \beta_{\text{Prim.Mode\_Transit}} \times \text{Prim.Mode\_Transit} + \beta_{\text{Prim.Mode}_{\text{CarDriver}}} \times \text{Prim.Mode\_CarDriver} + \beta_{\text{Prim.Mode}_{\text{CarPax}}} \times \text{Prim.Mode\_CarPax} + \beta_{\text{Prim.Mode}_{\text{PMD}}} \times \text{Prim.Mode\_PMD} + \beta_{\text{UsedSharedScooter}} \times \text{UsedSharedScooter} + \beta_{\text{UsedSharedBike}} \times \text{UsedSharedBike} + \beta_{\text{UsedSharedCar}} \times \text{UsedSharedCar} + \beta_{\text{UsedTNC}} \times \text{UsedTNC} + \beta_{\text{UsedPooledTNC}} \times \text{UsedPooledTNC} + \beta_{\text{Gender}} \times \text{Gender} + \beta_{\text{Age}} \times \text{Age} + \beta_{\text{Education}} \times \text{Education} + \beta_{\text{Occupation}} \times \text{Occupation} + \beta_{\text{StrongEnv.Values}} \times \text{StrongEnv.Values} + \beta_{\text{PhysicallyActive}} \times \text{PhysicallyActive})$$

j: Shared e-scooters, Walk, Grab, Bus, and NUS Shuttle Bus
$\beta_{RND\_Q1} \sim N(\beta_{MEAN\_Q1}, \beta_{STD\_Q1})$: coefficient of Q1 (10 km/h on sidewalk)
$\beta_{RND\_Exp.conflict} \sim N(\beta_{MEAN\_Exp.conflict}, \beta_{STD\_Exp.conflict})$: coefficient of Exp.conflict
$\beta_{RND\_INT\_Q1\_Exp.conflict} \sim N(\beta_{MEAN\_INT\_Exp.conflict\_Q1}, \beta_{STD\_INT\_Exp.conflict\_Q1})$: coefficient of interacted Exp.Conflict and Q1.

4. Results

4.1. Descriptive Statistics

Table 2 presents some descriptive statistics about the survey participants. There are more females than males (60% vs. 40%) in the sample, a gender bias commonly found in surveys with random samples. The majority of respondents (nearly 80%) are between the ages of 18 and 30, whereas about 20% are over 30 years old. Most respondents (about 56%) have at least some college education. While students account for 63% of the sample, the research staff account for 20%, and the rest are non-research/technical staff, unemployed, other, or retired. This is all to be expected as our survey was conducted in a university setting. We had a large share of respondents who had access to a car in their household (51%), considering the national average is only about 11% [42]. This could probably be due to the fact that the study site (i.e., the university campus) is located relatively far from bus and train stations. Note that car ownership is highly regulated in Singapore (e.g., the permit to own and register a car (COE) can be up to $26,000 USD [43]). The fee to register a PMD at $20 is nowhere as much as the COE, and among our survey participants, 20% own a PMD.

In Singapore, public transit (bus and rail or Mass Rapid Transit (MRT)) is the main mode of travel, accounting for about 67% of the modal share in 2019 [44]. This is also reflected in our sample with 80% of respondents indicating public transit as their primary mode. A fairly large number of respondents have also tried new mobility or shared alternatives. Specifically, 35% have used a shared scooter, 52% have used a shared bike, 10% have used carshare, and 79% and 64% have used TNCs and pooled TNCs respectively. Most claimed that they have never experienced conflict (an accident or incident) with PMDs (86%). This includes both PMD users and non-users/pedestrians. Finally, nearly all of the respondents exercise regularly and have strong environmental values.

Table 2. Descriptive Statistics of the Final Sample, N = 765.

Variable	Share (%)	Variable	Share (%)
Gender		Primary Mode is Car (Pax)	
Male	41	Yes	4
Female	59	No	96
Age		Primary Mode is PMD	
below 18	0	Yes	<1
18–30	79	No	>99
31–40	15	Used Shared Scooter	
41–50	4	Yes	35
51–60	2	No	65

Table 2. *Cont.*

Variable	Share (%)	Variable	Share (%)
61 and up	0	Used Shared Bike	
Education		Yes	52
Postgraduate	26	No	48
University	30	Used Shared Car	
High School	0	Yes	10
Secondary or Less	44	No	90
Occupation		Used TNC	
Research Staff	20	Yes	79
Non-Research/Technical Staff	13	No	21
Student	63	Used Pooled TNC	
No Employment	1	Yes	64
Other/Retired	3	No	36
Car Ownership (household)		Experienced Conflict	
Yes	51	Yes	14
No	49	No	86
		Exercise Frequency	
PMD Ownership		Daily	17
Yes	20	Occasionally	76
No	80	Never	7
Primary Mode is Transit		Strong Environmental Values	
Yes	83	Yes	88
No	17	No	12
Primary Mode is Car (Driver)			
Yes	3		
No	97		

4.2. Mode Choices

Table 3 shows the distributions of the chosen modes from the two SP questions and whether the respondent has or has not experienced conflict with a PMD. To reiterate, in Q2, we assumed that scooters can be ridden faster (20 km/h) and on the road instead of 10 km/h on the sidewalk. The faster speed off the sidewalk means shorter travel time and fewer interactions with pedestrians. When we changed the speed and surface, we saw an increase in demand for shared scooters from 11% to 17%. The majority of the shift seems to be from the NUS shuttle buses. People are willing to switch from the shuttle buses probably because of the travel time savings and the fact that they do not have to navigate between pedestrians on the sidewalk.

However, what if they have had an accident or incident with PMDs? Would they be more hesitant to use the scooters? We see a slight difference of about 2% between people who have and have not experienced conflict. Perhaps the experience of conflict does discourage the use of scooters. Upon closer look, this difference appears to be from Q2, when the scooter speed is higher and the surface type is the road. In Q2, 7% choose scooters if the person has experienced conflict, and 9% choose scooters if they never experienced conflict, whereas, in Q1, 5% choose scooters if they have or have not experienced conflict. This hints that perhaps the experience of conflict is only activated when the speed limit is increased or when we switched to the scenario in Q2. We hoped to test these hypotheses in our model.

Table 3. Distribution of Chosen Mode, N = 765.

Variable	Share (%)	
SP Questions 1 and 2	Q1	Q2
Shared E-Scooter	11	17
Walk	4	3
Grab	<1	0
Bus	7	6
NUS Shuttle Bus	78	73
Experienced Conflict?	Yes	No
Shared E-Scooter	12	14
Walk	5	3
Grab	0	1
Bus	6	6
NUS Shuttle Bus	76	76

5. Discussion

We estimate the model using BIOGEME [45] and discuss the results in this section. Table 4 reports the results of our model estimation. Overall, the three models have a very comparable fit (adjusted R^2 of about 0.55) and consistent results, namely travel disutility (i.e., travel time, wait time, access time, cost) and safety concerns have negative impacts on the preferences for shared scooters, while one's previous experiences with PMDs (i.e., whether they privately own one or have trialed a shared scooter) and with shared modes have positive impacts. Across the different models, the signs of the estimated coefficients of the mode characteristics are the same while the magnitudes only vary slightly. There are a few exceptions; for example, the estimated coefficients of the alternative specific constant for the walk alternative and the experienced conflict variable do not have the same signs across models, which may be due to the large standard errors in the estimated coefficients. As expected, we find that longer travel time, access time, wait time, and higher cost have significant negative influences. Similar to existing studies on PMDs, in particular on shared bikes, which revealed that service and infrastructure are significant factors, our results suggest that we can achieve greater usage of scooters when we improve the service and infrastructure. Such improvements can be in the form of developing more bike lanes (to reduce travel time), as was shown in [26], or by adding more stations and increasing capacity (to reduce access time and wait time). Alternatively, we can improve the service by making it safer to ride, as was demonstrated by [10,18]; both confirmed significant differences in actual or perceived safety between bikeshare users and nonusers. In all three models, we too observe hindered use by individuals who have experienced conflict related to PMDs (although this effect is significant only in M3 when we account for inter-person heterogeneity). With multiple factors affecting use, another question we strive to answer is to what degree does each influence demand. In the shared bike context, users place nearly the same importance on the perceptions of bicycle convenience (i.e., operating conditions) and bicycle safety, suggesting a potential tradeoff between the two variables [10]. Unlike in [18], where the bike speed and travel time were held constant while the level of safety varied, in this study, both the speed or travel time and safety record are stochastic, which means we may be able to observe any tradeoff between increased convenience and safety. In the next paragraph, we will focus on M3 and compare the estimated coefficients between the two sets of variables to better understand the potential tradeoff.

Table 4. Estimation Results.

Category	Variable	Estimated Coefficients			
		Model 1	Model 2	Model 3	
1. Alternative Specific Constants (base: Shared Scooters)	Walk	−0.77	1.15	−1.34	
	Grab	2.71	2.47	3.08***	
	Bus	0.61	0.63	0.71	
	NUS shuttle bus	3.70 *,**,***	3.77 *,**,***	3.05 *,**,***	
2. Speed and surface (base: Shared Scooters)	Q1 (base: 20 km/hour on road or Q2)	0.54 **,***	-	Mean: 0.77 **,***	SD: −0.48
3. Trauma (base: Shared Scooters)	experienced conflict	−0.09	0.23	Mean: 1.06 **,***	SD:1.62 *,**,***
	experienced conflict × Q1	0.32	-	Mean: −0.18	SD: 0.12
4. Mode Characteristics	travel time (min)	-	−0.10**,***	-	
	access time (min)	−0.01	−0.01	−0.08	
	wait time (min)	−0.08 *,**,***	−0.08 *,**,***	−0.07 *,**,***	
	cost ($)	−0.74 **,***	−0.86 **,***	−0.84 *,**,***	
5. Primary Mode (base: Shared Scooters)	Transit	0.67 ***	0.67 ***	0.48 ***	
	car (driver)	−0.07	−0.10	−0.03	
	car (passenger)	0.21	0.20	0.06	
	PMD	−2.36 ***	−2.35 ***	−1.94	
6. Ownership of priv. vehicle (base: Shared Scooters)	own car (household)	−0.08	−0.08	−0.09	
	own PMD	−0.64 **,***	−0.63 **,***	−0.44 **,***	
7. Exposure to new mobility (base: Shared Scooters)	used shared scooter	−0.76 *,**,***	−0.75 *,**,***	−0.93 *,**,***	
	used shared bike	−0.38	−0.38	−0.32 ***	
	used shared car	−0.77 **,***	−0.77 **,***	−0.58 **,***	
	used TNC	−0.55	−0.54	−0.42 ***	
	used pooled TNC	0.44	0.44	0.43 **,***	
8. Sociodemographic status (base: Shared Scooters)	gender (base: female)	−0.19	−0.20	−0.25	
	age (base: over 30 years)	−0.02	−0.01	−0.18	
	education (base: less than college degree)	−0.70 **,***	−0.70 **,***	−0.72 *,**,***	
	occupation (base: non-students)	−0.60 ***	−0.61 ***	−0.53 **,***	
9. Environmental values (base: Shared Scooters)	Strong rating on 5-pt scale (base: rate 3 and below)	−0.27	−0.27	0.14	
10. Physical activity (base: Shared Scooters)	exercise frequency (base: never exercise)	0.11	0.12	−0.02	
R^2		0.58	0.58	0.56	
$\bar{R}^2$		0.55	0.55	0.54	

Note *,**,*** respectively, *p*-value for *t*-test at 0.01, 0.05, and 0.10 level; N = 765, number of obs. = 1530.

Looking at M3, our results indicate that changing the scooter speed and surface from 20 km/h on the road to 10 km/h on the sidewalk will make other modes more attractive and discourage people to choose shared scooters. Again, this is probably because people want shorter travel times and fewer interactions with pedestrians. This is consistent with the findings in [34], that the maximum scooter speed of 10 km/h is considered too slow. However, increasing the speed and diverting scooters off the sidewalk will not always increase the demand. As in [34], riders and potential riders seem to be in conflict with the faster speed. On the one hand, they support it, but on the other, there is some reservation due to safety concerns. We find that those who have experienced conflict are less inclined to pick scooters, and this negative impact is greater in magnitude than the negative impact of decreased speed and change of surface type. Therefore, even though people much prefer the scenario in Q2 relative to Q1, they will be more turned off by a bad experience (accident/incident) with PMDs. This is true on average, but there is also more variability in the effect of having experienced conflict. In other words, there are some people who are more impacted by the experience of conflict with PMDs than by the change of the riding speed and surface, and some who are less impacted. Additionally, we hypothesized the impact of having experienced conflict to be more negative when the scooter speed limits are increased (i.e., when the speed limits are raised, the trauma discourages scooter use even more), but we did not find this effect to be significant.

Based on the other estimated coefficients, we see that the primary mode and access to a private car in the household do not affect respondents' choice of shared scooters unless the primary mode is transit or PMD. If they own a private PMD, however, they are more likely to choose shared e-scooters. This could be because PMD users are more familiar with the device and they are likely to be enthusiasts who actively learn about product features and even promote the device to their peers [24]. When they do not have their own PMDs with them, they would ride a shared scooter, e.g., for one-way trips. Perhaps private PMDs and shared PMDs may complement each other.

If the person has previously used shared services, they are also more likely to choose shared e-scooters. This includes shared services such as scooters, bikes, cars, and TNCs, but not pooled TNCs. Perhaps it is because pooled TNCs are the only service among these that requires sharing space with other individuals at the same time. What is more, those who are more willing to choose shared scooters tend to be students or have a minimum of some college education. Finally, strong environmental values and physical activity do not seem to have a significant impact on the mode choice. People do not ride scooters because they want to save the environment or want to get a workout; most likely they just like the convenience. There are some commonalities between the use of shared scooters and shared bikes and mopeds. Those who are most likely to use shared bikes and mopeds are also students, college-educated, or individuals who have used carsharing or bike sharing [16,19]. Moreover, Aguilera-Garcia et. al., [16] also did not find environmental personal attitudes to be a significant factor in their choices to use shared mopeds. In contrast, Shaheen et. al., [20] confirmed a significant positive correlation between personal attitudes toward the environment and the choice of bike sharing.

6. Conclusions

In this paper, we examined the factors influencing the use of e-scooters as a transport mode for first-mile/last-mile trips. We conducted an SP survey and estimated three logit models with different specifications of e-scooter speed/surface and previous negative experiences with PMDs. We found that people would much prefer scooters if they were faster and off the sidewalk (20 km/h and on the road as opposed to 10 km on the sidewalk). On average, this factor affects their choice to a lesser degree than the experience of conflict, although the effect of having experienced conflict varies a lot across individuals. Not only that, one's primary mode of transport, access to a private car in the household, strong environmental values, and physical activity do not seem to significantly affect scooter choice unless the primary mode is transit or PMD. Those who are more willing to choose shared scooters are people who have previously used shared modes (shared scooters, bikes, cars, rides) or are students and/or with a minimum of some college education.

Several useful implications could be taken from our study for transport policymaking to promote the use of e-scooters in urban areas in order to increase access, reduce private automobile use, and alleviate traffic congestion. First, our results suggest that ultimately, to encourage the use of e-scooters, we need to make the service better, e.g., by improving travel time, but not just by diverting scooters off the sidewalk. We were able to show that safety or subjective safety plays a greater role compared to travel time savings, and so while having faster scooters off the sidewalk would reduce travel time and interaction with pedestrians, some people who have experienced an accident or incident (as a rider or a pedestrian) will be traumatized and not want to use shared scooters. Unfortunately, increasing the speed in this way would do just that, increase the accident rate. For the policy to be effective, they must consider ways to improve e-scooter speed or travel time that do not come at the expense of increased safety risks, such as dedicated lanes or paths for example. Second, if there are limited resources to promote shared e-scooters (which in reality is usually the case), based on the results, it would be more worthwhile to direct the advertisements or marketing campaigns to individuals who have used PMDs or shared modes, or individuals who are students or with higher levels of education. These individuals were found to be the likeliest to use shared e-scooters, and so presumably it would require the least amount of effort or resources to capture that particular market. This discussion provides insights as to how to grow the demand for shared scooters so that we can reduce barriers to short first/last mile travel while limiting car usage and environmental impacts.

One of the limitations of our study is that our study sample was limited to only the staff and students of a university campus. This might cast doubt as to whether our results are applicable to the whole population. For example, the NUS shuttle bus alternative does not cost anything and they have been around longer than the shared scooters. It is extremely hard to compete with the free and longer standing alternative; thus, our results may be quite conservative and underestimate preferences for shared e-scooters. However, we decided to focus on university students and young professionals as they are one of the largest consumer groups of shared e-scooters. Furthermore, at the time of our project, shared scooters were only available in certain areas (including the NUS campus, where the target sample was recruited), which makes the individuals we interviewed some of the first people who were able to try these shared devices. They can give us initial insights as to how the general public will perceive these services.

Since the demographics of the respondents may not reflect the metropolitan area surveyed, future work should consider approaches applied in [46,47] to address this limitation. Using Census data, they added weights to adjust for demographics that may be under- or over-sampled (e.g., highly educated, young professionals). This helps to produce estimates that more closely resemble the target population.

Future studies can also extend this work by widening the focus to other cities and other trips (e.g., commuting and leisure rides). Incorporating additional potential factors such as the respondents' home location and built environment characteristics (e.g., population and commercial density, and diversity of the land use) is also worth exploring. We did not find significant impacts of environmental values on the use of these vehicles, but additionally, we could also test related variables such as one's level of sustainability (e.g., whether they own a hybrid or electric vehicle).

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Institutional Review Board Statement: The study was conducted in accordance with the Committee on the Use of Humans as Experimental Subjects (COUHES) and approved by the Institutional Review Board (or Ethics Committee) of the Massachusetts Institute of Technology.

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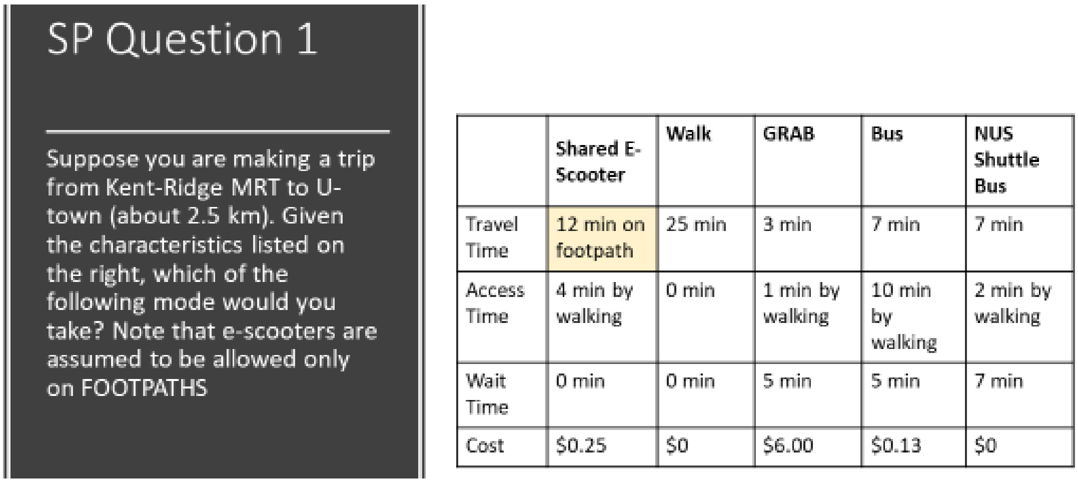
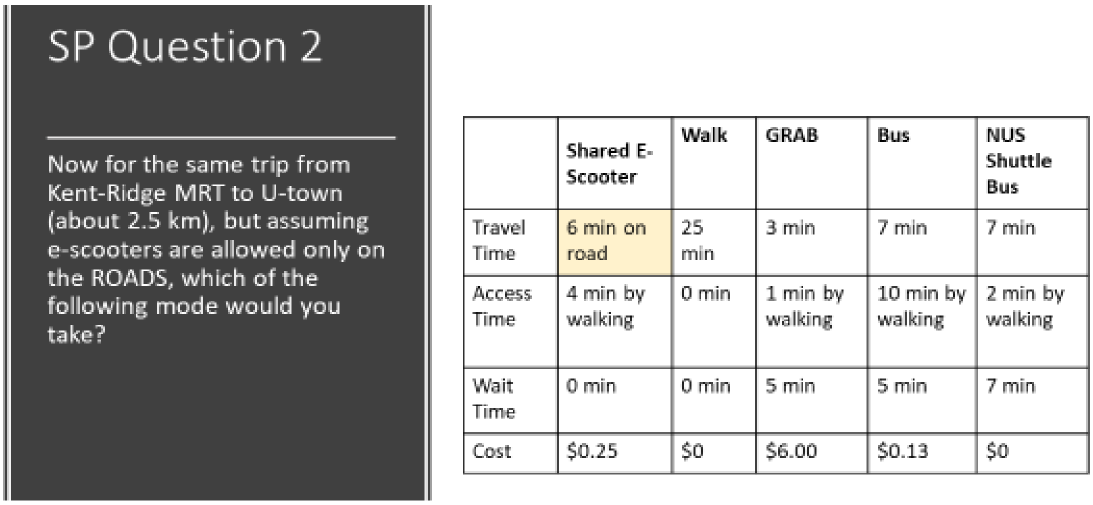
Appendix A



	Shared E-Scooter	Walk	GRAB	Bus	NUS Shuttle Bus
Travel Time	12 min on footpath	25 min	3 min	7 min	7 min
Access Time	4 min by walking	0 min	1 min by walking	10 min by walking	2 min by walking
Wait Time	0 min	0 min	5 min	5 min	7 min
Cost	$0.25	$0	$6.00	$0.13	$0

Figure A1. Example of a Profile in SP Question 1 (Scooters Only on Footpaths). Yellow cell: highlight the difference between questions 1 and 2.



	Shared E-Scooter	Walk	GRAB	Bus	NUS Shuttle Bus
Travel Time	6 min on road	25 min	3 min	7 min	7 min
Access Time	4 min by walking	0 min	1 min by walking	10 min by walking	2 min by walking
Wait Time	0 min	0 min	5 min	5 min	7 min
Cost	$0.25	$0	$6.00	$0.13	$0

Figure A2. Example of a Profile in SP Question 2 (Scooters Only on Roads and Faster Speed). Yellow cell: highlight the difference between questions 1 and 2.

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