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Will Customers' Understanding of the Trolley Dilemma Hinder Their Adoption of Robotaxi?

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Abstract: Robotaxi, coined from "robot" and "taxi", refers to a taxi service with vehicles controlled by self-driving algorithms instead of human drivers. Despite the availability of such a service, it is yet unknown whether customers will adopt robotaxi, given its immaturity. Meanwhile, the potential customers of the robotaxi service are facing an inescapable ethics issue, the "trolley dilemma", which might have a strong impact on their adoption of the service. Based on the necessity of understanding robotaxi adoption, especially from an ethical point of view, this study aims to uncover and quantify the antecedents of robotaxi adoption, taking the trolley dilemma into consideration. We applied a modified Unified Theory of Acceptance and Use of Technology (UTAUT) framework to explore the antecedents of robotaxi adoption, with a special focus on customers' understanding of the trolley dilemma. We conducted online surveys (N = 299) to obtain the customers' opinions regarding robotaxis. Aside from measuring standard variables in UTAUT, we developed four proprietary items to measure trolley dilemma relevance. We also randomly assigned the participants to two groups, either group A or group B. Participants in group A are told that all robotaxis are programmed with a utilitarian algorithm, such that when facing a trolley dilemma, the robotaxi will conditionally compromise the passenger(s) to save a significantly larger group of pedestrians. In the meantime, participants in group B are informed that all robotaxis are programmed with an egocentric algorithm, such that when facing a trolley dilemma, the robotaxi will always prioritize the safety of the passenger(s). Our findings suggest that both performance expectancy and effort expectancy have a positive influence on robotaxi adoption intention. As for the trolley dilemma, customers regard it as of high relevance to robotaxis. Moreover, if the robotaxi is programmed with an egocentric algorithm, the customers are significantly more willing to adopt the service. Our paper contributes to both adoption studies and ethics studies. We add to UTAUT two new constructs, namely trolley dilemma relevance and trolley dilemma algorithm, which can be generalized to adapt to other new technologies involving ethics issues. We also directly ask customers to assess the relevance and algorithm of the trolley dilemma, which is a meaningful supplement to existing ethics studies that mostly debate from researchers' perspectives. Meanwhile, our paper is managerially meaningful as it provides solid suggestions for robotaxi companies' marketing campaigns.

Keywords: robotaxi; trolley dilemma; UTAUT; utilitarianism; egocentrism

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1. Introduction

It is a genuine possibility that the next time you call for a taxi, the driver could be a robot. Thanks to the advancement of self-driving technology and its marriage with taxi services, robotaxis (coined from "robot" and "taxi") are around the corner. A robotaxi is basically a shared autonomous vehicle. It integrates not only the advantages of a sharing economy, such as efficiently allocating resources and reducing overall costs (with Uber as a typical example) but also the advancement of AI technology that further enhances operation automation (e.g., UiPath). To be specific, robotaxis are expected to alleviate traffic jams by enhancing road throughput capacity with more efficient vehicle operation and reduced car accidents [1,2]. Therefore, the benefit of robotaxis is hardly controvertible [3,4].

The development of robotaxi is still in its primary stage. In October 2023, a serious accident happened in downtown San Francisco involving a vehicle belonging to Cruise, one of the leading US robotaxi companies, resulting in the state of California suspending Cruise's operations. However, robotaxi companies have been increasingly competing to deploy such services around the globe. For instance, Apollo, the self-driving platform of the Chinese technology company Baidu, accumulated more than 5 million robotaxi orders in China as of December 2023. Moreover, regulators in places like Phoenix, Beijing, and Shanghai now allow these vehicles to drive without human safety operators.

Despite the availability of such a service, it is yet unknown whether customers will adopt robotaxi, given its immaturity. Because extant research addressed the significance of understanding customers' early adoption of disruptive technologies such as Internet banking [5], autonomous vehicles [6], and seated electric scooters [7], it is expected that an adoption study about the incoming robotaxi technology from customers' perspective will generate great insight and value for the business world.

While the antecedents in a typical adoption study may be well captured by applying the Unified Theory of Acceptance and Use of Technology (UTAUT) formulated by Venkatesh et al. [8], the potential customers of robotaxi services are facing an inescapable ethics issue, the "trolley dilemma", which might have a strong impact on their adoption of the service. The trolley dilemma, invented by the British philosopher Philippa Foot [9], refers to the hard decision of a driver on a runaway tram. The driver can only steer from one narrow track to another; five men are working on one track and one man on the other; anyone on the track entered is bound to be killed.

The trolley dilemma has its robotaxi variation, such that the programmer has to tell the self-driving algorithm in advance, in case of extreme situations, whether to always prioritize the safety of the passenger(s) or to conditionally compromise the passenger(s) to save a significantly larger group of pedestrians [10]. How customers' intention to adopt robotaxi may change upon knowing this ethical issue, as well as upon knowing the algorithm of the programmer, remains an intriguing but unanswered question.

Based on the necessity of understanding robotaxi adoption, especially from an ethical point of view, this study aims to uncover and quantify the antecedents of robotaxi adoption, taking the trolley dilemma into consideration. To this end, we first conducted a literature review on robotaxi, UTAUT, and the trolley dilemma and then formulated our theoretical framework based on UTAUT plus two new constructs, namely trolley dilemma relevance and trolley dilemma algorithm. We proposed that robotaxi adoption intention is positively influenced by performance expectancy, effort expectancy, and social influence. Additionally, we proposed that robotaxi adoption intention is negatively influenced by its relevance to the trolley dilemma and the implementation of a utilitarian algorithm.

To test the above hypotheses, we conducted online surveys to obtain the customers' opinions regarding robotaxis. We discovered that both performance expectancy and effort expectancy have a positive influence on robotaxi adoption intention. As for the trolley dilemma, customers regard it as of high relevance to robotaxis. Moreover, if the robotaxi is programmed with an egocentric algorithm, such that when facing a trolley dilemma, the robotaxi will always prioritize the safety of the passenger(s), the customers are significantly more willing to adopt the robotaxi.

This paper contributes to both adoption studies and ethics studies. As an adoption study, this paper adds to UTAUT two new constructs. Although these two constructs are robotaxi-specific, they can be generalized to "relevance plus choice" to adapt to other new technologies involving ethical issues. Meanwhile, as an ethics study, this paper directly asks customers to assess the relevance and algorithm of the trolley dilemma, which is a meaningful supplement to existing ethics studies that mostly debate from researchers' perspectives. Besides these theoretical contributions, this paper is managerially meaningful as well, as it provides solid suggestions to robotaxi companies for their marketing campaigns.

1.1. Robotaxi

A robotaxi is basically a shared autonomous vehicle (AV) or SAV. To assess the autonomy of AVs, the Society of Automotive Engineers (SAE) established a classification system on a scale from Level 0 to Level 5 [11], with robotaxi having a level of at least Level 4 [12]. Level 4, termed high automation, does not require any human interaction in the vehicle's operation; the vehicle may not have a steering wheel or pedals.

The benefit of a robotaxi is hardly controvertible. As a high-level AV, robotaxis are expected to alleviate traffic jams by enhancing road throughput capacity with more efficient vehicle operation and reduced car accidents. But more importantly, because robotaxis are owned by service-providing companies, with customers only paying by mileage, the current high price of AVs can be reasonably distributed among stakeholders, making the business model of AVs workable and, thus, the final target of Level 5 (full automation) reachable [13]. In this sense, understanding the adoption of robotaxis is of both technological and societal significance.

The three leading countries/regions for robotaxi testing are the US, China, and the Middle East. In the US, there are currently four cities where people can take a robotaxi: San Francisco, Phoenix, Los Angeles, and Las Vegas. China started testing robotaxis later but now has over 10 cities open to robotaxis. The Middle East is also quickly gaining a foothold in the sector with the help of Chinese and American companies such as Pony.ai. Regardless of nations, at present, robotaxis still face the challenge of reliability and profitability.

1.2. UTAUT

As was mentioned, in a typical adoption study, the antecedents of the adoption of a new technology may be well captured by UTAUT, a theoretical framework incorporating multiple antecedents (e.g., performance expectancy), consequences (e.g., behavioral intention), and moderators (e.g., gender) [8]; see Figure 1 for the complete model. According to Venkatesh [8], in general, use behavior is influenced by behavioral intention and facilitating conditions, whereas behavioral intention can be predicted by performance expectancy, effort expectancy, and social influence. Furthermore, some of the above relationships are moderated by gender, age, experience, and voluntariness of use.

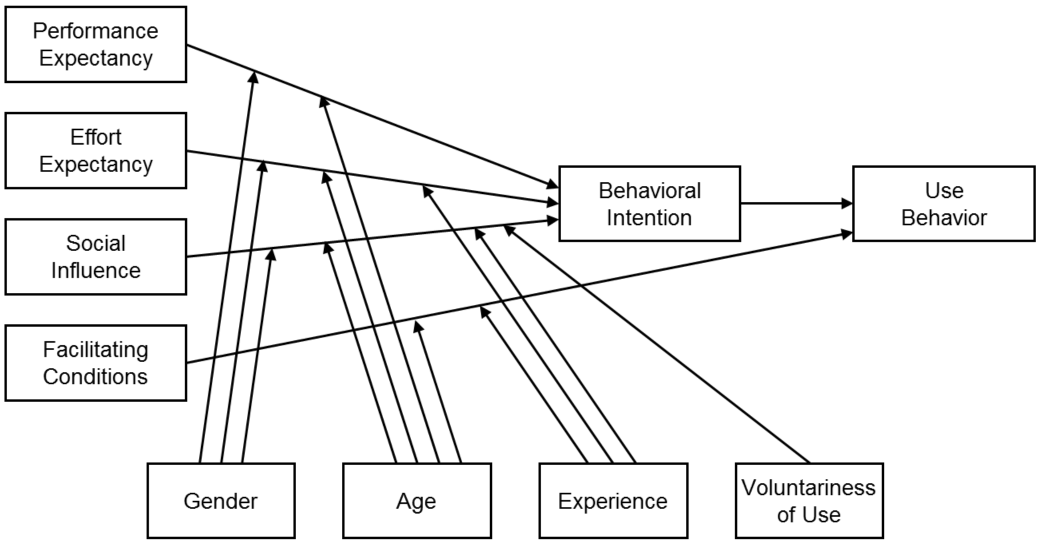

Figure 1. UTAUT model [8].

UTAUT was proposed to unify the eight earlier acceptance theories and models, such as the technology acceptance model (TAM) [14]. These models were extremely helpful in explaining customers' intention to adopt robotaxi technology [12], as well as many other new technologies [15–17]. For example, Liu et al. [12] studied Chinese customers' adoption intention of robotaxi using TAM. Their research revealed that perceived usefulness, perceived ease of use, and social influence have significant positive correlations with customers' behavior intentions to use robotaxis, which provided an important benchmark for this study.

To further enhance the explanatory power of adoption models, researchers increasingly combine proven models with ad hoc constructs to facilitate in-depth understanding. For instance, Martin and Herrero [18] integrated innovativeness into the UTAUT framework to account for users' online purchase intention in rural tourism. Similarly, in Mohammadyari and Singh's [19] study about the intention of individuals to continue using e-learning and their performance, they merged the concept of digital literacy with UTAUT. Therefore, for this study, it is reasonable to add to UTAUT new constructs regarding the trolley problem.

1.3. Trolley Dilemma

The ethical value of the original trolley dilemma [9] has long been acknowledged, but researchers are now debating its relevance in an AV scenario. Here is a typical version of the trolley dilemma involving AV:

> *An AV is proposed to be driving with passengers on board and some pedestrians suddenly appear in its path with no time to brake and completely stop. It has to decide between staying the course and running over the pedestrians or swerve to the side and hit a barrier that kills the passengers* [20].

Those against applying the trolley dilemma to AV argue that the trolley dilemma represents extremely rare situations, which should give way to more common cases [1,21]. However, others consider the trolley dilemma as a critical ethical issue to be solved before AV implementation [22–29]. Yet, the majority of these studies, regardless of their point of view, debate the relevance of the trolley dilemma from the researchers' perspectives without adequately hearing from potential customers. Because AV/SAV implementation depends on customer adoption, it is equally important to know customers' attitudes towards the relevance of the trolley dilemma.

There is a secondary debate about the AV trolley dilemma, given its relevance: how should an AV be programmed to decide the appropriate action in a trolley dilemma? Should the AV always prioritize the safety of the passenger(s) or conditionally compromise the passenger(s) to save a significantly larger group of pedestrians? Several studies obtained answers from potential customers [30,31]. In an experimental study where participants experienced modified trolley dilemmas as drivers in virtual reality environments, Faulhaber et al. [31] revealed that participants, in general, made decisions in a utilitarian manner. Utilitarian ethics is about maximizing overall happiness while minimizing overall suffering [26]. That suggests that in an AV trolley dilemma, at least some potential customers are willing to sacrifice themselves (as passengers) to save more pedestrians. But this is followed by the question of whether we should collectively mandate a specific ethical setting for the whole of society, or should each driver within configure their own ethical setting? Gogoll and Müller [2] argued that mandatory ethics setting is an optimal choice compared with personal ethics setting because the latter would most likely result in a prisoner's dilemma. Moreover, in a robotaxi (SAV) scenario, companies are most likely to adopt a mandatory ethics setting, given the shared nature of robotaxi, which could make this study less complicated. Still, how customers' intention of robotaxi adoption may change upon knowing the algorithm of the programmer remains an unanswered question, which will be addressed by this study.

2. Material and Methods

2.1. The UTAUT Model and Hypotheses

Several constructs of the original UTAUT model do not fit the scope of this study and were removed, namely use behavior, facilitating conditions, experience, and voluntariness of use. See Table 1 for detailed reasons. The remaining constructs of the original UTAUT model were preserved, namely behavioral intention, performance expectancy, effort expectancy, social influence, gender, and age.

Table 1. Reasons for excluding some constructs of the original UTAUT model.

Constructs Not Included	Reasons
Use behavior	Because robotaxi has not been widely implemented, use behavior is rare, which may not generate statistically meaningful results.
Facilitating conditions	Facilitating conditions is expected to be an antecedent of use behavior but not of behavioral intention. With use behavior excluded, facilitating conditions is also removed
Experience	Because robotaxi has not been widely implemented, experience is rare, which may not generate statistically meaningful results.
Voluntariness of use	Because potential robotaxi customers are by no means compelled to hail a robotaxi, it is not necessary to assess voluntariness in this study.

Because robotaxi use behavior is still rare due to its immaturity, it is extremely meaningful to observe and understand robotaxi behavioral intention. One of the antecedents of behavioral intention is performance expectancy. Performance expectancy is the degree to which individuals believe that a technology will help them achieve gains in job performance and daily life [8,32]. Performance expectancy proved to be a strong predictor of behavioral intention of a variety of technologies ranging from food delivery apps [33] to wearable healthcare devices [34]. Therefore, it is hypothesized that performance expectancy has a positive influence on robotaxi adoption intention.

H1. *Performance expectancy positively influences robotaxi adoption intention.*

Gaining enhanced performance by adopting new technology is not without cost. Typically, users switching to a new technology will engage in learning costs. Such costs are captured by effort expectancy, defined as the degree of ease associated with the use of the technology [8]. Less effort required to master a new technology often means higher likelihood of adopting the technology, be it electric car-sharing system [35] or cloud classroom [36]. Hence, the following hypothesis is proposed.

H2. *Effort expectancy positively influences robotaxi adoption intention.*

While the above two antecedents are more or less individual, behavioral intention can also be triggered by significant others, termed as social influence. Social influence is defined as the degree to which individuals perceive that important others believe they should use a new technology [8]. Social influence plays an important role in technology diffusion because the influencers' word of mouth increases awareness and builds trust for the audiences [37,38]. In this sense, robotaxi adoption is also expected to be popularized under social influence.

H3. *Social influence positively influences robotaxi adoption intention.*

Gender and age are potential moderators of performance expectancy, effort expectancy, and social influence [8]. Moreover, Venkatesh et al. [8] gave recommended directions for the moderators such that the following hypotheses are formulated.

H4. *The influence of performance expectancy on behavioral intention will be moderated by gender, such that the effect will be stronger for men and younger individuals.*

H5. *The influence of performance expectancy on behavioral intention will be moderated by age, such that the effect will be stronger for men and younger individuals*.

H6. *The influence of effort expectancy on behavioral intention will be moderated by gender, such that the effect will be stronger for women and younger individuals*.

H7. *The influence of effort expectancy on behavioral intention will be moderated by age, such that the effect will be stronger for women and younger individuals*.

H8. *The influence of social influence on behavioral intention will be moderated by gender, such that the effect will be stronger for women and older individuals*.

H9. *The influence of social influence on behavioral intention will be moderated by age, such that the effect will be stronger for women and older individuals*.

2.2. The Effect of Trolley Dilemma and Hypotheses

Besides exploiting the UTAUT framework, this study also wishes to explore the effect of trolley dilemma on customers' adoption intention of robotaxis. Intuitively, it is supposed that potential customers do not regard trolley dilemma as strongly related to robotaxi because it is rarely heard that an individual refuses to ride a taxi because of trolley dilemma. Instead, customers unconsciously authorized human taxi drivers, who mostly share common ethic norms with them, to handle trolley dilemma situations, which barely occur in real life. However, because a robotaxi (as an AV) cannot completely eliminate accidents [2], the relevance of trolley problem to robotaxis, albeit weak, theoretically remains. It is, therefore, desirable to let potential customers appraise such relevance in this study. Meanwhile, it is naturally assumed that trolley dilemma relevance will negatively influence robotaxi adoption.

H10. *The relevance to trolley dilemma negatively influences robotaxi adoption intention*.

Holding relevance constant, another provocative question is whether and to what extent the adoption intention varies with robotaxis' algorithm of decision-making when facing trolley dilemma. As was expounded, robotaxi companies are most likely to adopt mandatory ethics setting when tuning the algorithm before robotaxi implementation, without letting each customer decide how to respond. To this end, companies have to choose between utilitarianism (i.e., overall utility first) and egocentrism (i.e., passenger first) when formulating the algorithm a priori. Utilitarianism certainly has a strong position from an ethical point of view because it attends to the overall societal benefit and possibly a smaller insurance bill. However, pursuing utilitarianism inevitably removes passengers from top of the list in extreme situations, which could scare customers off if such criteria are disclosed to the public. Consequently, egocentrism may also keep a foothold in this ethical debate. From customers' perspectives, it is reasonable to propose the following hypothesis.

H11. *Implementing a utilitarian algorithm negatively influences robotaxi adoption intention. In other words, implementing an egocentric algorithm positively influences robotaxi adoption intention*.

Last but not least, gender and age are again expected to moderate the above two effects but, this time, are expressed in a neutral form without favoring one direction or the other.

H12. *The influence of trolley dilemma relevance on behavioral intention will be moderated by gender*.

H13. *The influence of trolley dilemma relevance on behavioral intention will be moderated by age*.

H14. *The influence of trolley dilemma algorithm on behavioral intention will be moderated by gender.*

H15. *The influence of trolley dilemma algorithm on behavioral intention will be moderated by age.*

Figure 2 summarizes the theoretical framework of this study.

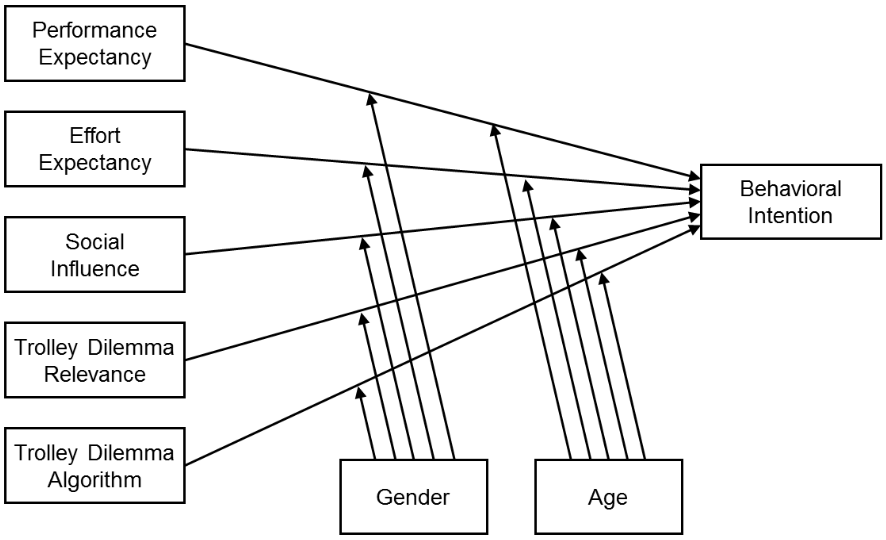

Figure 2. Theoretical framework.

2.3. Method

The objective of this study is to uncover and quantify the antecedents of robotaxi adoption, taking trolley dilemma into consideration. For this purpose, we conducted online surveys to obtain the customers' opinions regarding robotaxis. The samples were limited to residents in China to control national cultural differences. As we discussed, China is one of the three leading countries/regions for robotaxi testing. We believe such an adoption study in a Chinese context will bring instant insight to local business managers. The language of the questionnaire was Chinese but was later translated into English for the purpose of reporting the results in this paper.

We distributed the questionnaires on Credamo, a global intelligent research platform adopted by many other impactful studies [39,40]. We first released a preliminary questionnaire before we discovered that some technical expressions in the questionnaire were unclear in meaning, resulting in high percentage of invalid feedback. We subsequently modified the questionnaire to make it more understandable and launched a second release. See Appendix A for the entire questionnaire. This time, we received 328 pieces of feedback, among which 299 were valid.

The questionnaire begins with a description of robotaxi. It tells the participant that a trial version of robotaxi service is available in a number of big cities in China and that calling for a robotaxi is as easy as calling for a traditional taxi. The questionnaire emphasizes that a robotaxi does not have a human driver, that it simply relies on self-driving algorithms to handle travel routes and vehicle control, and that removing the human driver creates a private space for the passenger. Afterward, the questionnaire asks the participants to answer four questions to ensure the participants carefully read and understood the description. If a participant failed to correctly answer all the questions, the feedback was regarded as invalid.

Having briefly introduced robotaxi, the questionnaire then asks the participants to assess to what extent a robotaxi will help them achieve gains in job performance and daily life (performance expectancy), the degree of ease associated with its use (effort expectancy), and the degree to which individuals perceive that important others believe they should use it (social influence). All three scales were directly borrowed from Venkatesh et al. [8] and were slightly adjusted to fit the robotaxi scenario.

The questionnaire now enters the trolley dilemma session with three parts. The first part introduces the concept of trolley dilemma and its robotaxi version. The second part lets the participants reflect on whether trolley dilemma is highly associated with robotaxi (trolley dilemma relevance). For this part, we developed four proprietary items to measure relevance. In the third part, the participants are randomly assigned to two groups, either group A or group B. Participants in group A are told that all robotaxis are programmed with a utilitarian algorithm (trolley dilemma algorithm), such that when facing trolley dilemma, the robotaxi will conditionally compromise the passenger(s) to save a significantly larger group of pedestrians. Meanwhile, participants in group B are informed that all robotaxis are programmed with an egocentric algorithm, such that when facing trolley dilemma, the robotaxi will always prioritize the safety of the passenger(s).

Finally, the questionnaire asks the participants to rate their intention of adopting robotaxi (behavioral intention). The questionnaire also collects participants' personal information, including gender, age, taxi usage, robotaxi usage, and robotaxi usage by friends and family. It is noted here that at the moment when we were collecting data for this study, the trial version of robotaxi in China included human driver, as was mandated by the regulators for safety concerns. Still, the driver served as a backup for the self-driving system in case of system break or emergency. This makes it significantly different from the final version of robotaxi, a genuine Level 4 self-driving machine with literally no driver, such that it is the algorithm, rather than the backup human driver, that fully handles trolley dilemma. All the information collected by the questionnaire was converted to the variables listed in Table 2.

Table 2. Variables and their values.

Variables	Information Collected by the Questionnaire	Value	Note
IV			
PE	Performance expectancy	$1 \leq PE \leq 7$	PE is calculated by averaging the points of the four questions
EE	Effort expectancy	$1 \leq EE \leq 7$	EE is calculated by averaging the points of the four questions
SI	Social influence	$1 \leq SI \leq 7$	SI is calculated by averaging the points of the four questions
TD_REL	Trolley dilemma relevance	$1 \leq TD\_REL \leq 7$	TD_REL is calculated by averaging the points of the four questions
TD_ALG	Trolley dilemma algorithm	0 or 1	0: utilitarian (Group A) 1: egocentric (Group B)
DV			
BI	Behavioral intention	$1 \leq BI \leq 7$	BI is calculated by averaging the points of the three questions
Control			
Female	Gender	0, 1	0: male 1: female
Age	Age	0, 1, 2, 3, 4	0: under 20 1: between 20 and 29 2: between 30 and 39 3: between 40 and 49 4: 50 and above

Table 2. *Cont.*

Variables	Information Collected by the Questionnaire	Value	Note
TaxiUsage	Taxi usage	0, 1, 2	0: less than once a week 1: at least once a week 2: almost daily
RoboTaxiUsage	Robotaxi usage	0, 1	0: the participant has not used robotaxi 1: the participant has used robotaxi
RoboTaxiUsageFF	Robotaxi usage by family and friends	0, 1	0: the participant's family or friend has not used robotaxi 1: the participant's family or friend has used robotaxi

The above variables were incorporated into the following multi-linear regression model:

$$BI = \beta_0 + \beta_1 \times PE + \beta_2 \times EE + \beta_3 \times SI + \beta_4 \times TD\_REL + \beta_5 \times TD\_ALG + \chi + \tau + \varepsilon \quad (1)$$

where χ denotes the cross terms, τ denotes the control variables, and ε denotes the errors.

3. Results

3.1. Basic Statistics

We used the software STATA V17 to explore statistics, correlation, and multi-linear regression. The descriptive statistics are summarized in Table 3. The participants have a typical age between 20 and 40 and a typical taxi usage frequency of once a week. Moreover, 16% of them have once taken a robotaxi, while 34% of them have at least one family member or friend who had a robotaxi experience. The participants generally regard robotaxis as useful (PE averages 5.51), easy to use (EE averages 5.90), and socially influential (SI averages 5.19), with the standard deviations being of moderate size (0.91, 0.75, 1.09). Meanwhile, the participants believe there is a strong connection between the trolley dilemma and robotaxis (TD_REL averages 4.96). Half of the participants are in group A (utilitarian algorithm), whereas the other half are in group B (egocentric algorithm). Overall, the participants intend to take robotaxi in the future (BI averages 4.73). For reliability and validity analyses, see Appendix B.

Table 3. Descriptive statistics.

Variables	Min.	Max.	Average	Standard Deviation	N.
IV					
PE	1.00	7.00	5.51	0.91	299
EE	2.75	7.00	5.90	0.75	299
SI	1.00	7.00	5.19	1.09	299
TD_REL	1.25	7.00	4.96	1.23	299
TD_ALG	0.00	1.00	0.50	0.50	299
DV					
BI	1.00	7.00	4.73	1.55	299
Control					
Female	0.00	1.00	0.55	0.50	299
Age	0.00	4.00	1.39	0.86	299
TaxiUsage	0.00	2.00	0.62	0.53	299
RoboTaxiUsage	0.00	1.00	0.16	0.37	299
RoboTaxiUsageFF	0.00	1.00	0.34	0.48	299

The correlation matrix is reported in Table 4. PE, EE, SI, and TD_ALG are all positively correlated with BI, but TD_REL is not correlated with BI. Later, multi-linear regression presented similar results. Table 4 also suggests that TD_ALG is hardly correlated with any variable except for BI, validating the randomness of assigning the participants to two groups. Moreover, Age, RoboTaxiUsage, and RoboTaxiUsageFF are all positively correlated with BI, confirming the necessity of controlling them in multi-linear regression.

Table 4. Correlation matrix.

	PE	EE	SI	TD_REL	TD_ALG	BI	Female	Age	TaxiUsage	RoboTaxiUsage	RoboTaxiUsageFF
PE	1										
EE	0.277 ***	1									
SI	0.620 ***	0.357 ***	1								
TD_REL	0.017	−0.030	−0.086	1							
TD_ALG	0.048	0.064	0.027	0.004	1						
BI	0.446 ***	0.253 ***	0.370 ***	−0.052	0.488 ***	1					
Female	−0.116 *	−0.097	−0.067	−0.017	0.070	−0.021	1				
Age	0.069	0.043	0.104	0.058	0.128 *	0.158 **	−0.211 ***	1			
TaxiUsage	0.244 ***	0.189 **	0.212 ***	−0.048	−0.067	0.033	−0.220 ***	0.149 **	1		
RoboTaxiUsage	0.211 ***	0.118 *	0.258 ***	0.046	0.081	0.200 ***	−0.104	0.060	0.117 *	1	
RoboTaxiUsageFF	0.197 ***	−0.021	0.251 ***	−0.080	0.082	0.142 *	−0.094	0.001	0.114 *	0.484 ***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.2. Multi-Linear Regression Results

Table 5 summarizes the multi-linear regression results. PE is positively correlated with BI ($\beta_1 = 0.572$, $p < 0.001$), supporting H1. EE is also positively correlated with BI ($\beta_2 = 0.197$, $p < 0.05$), supporting H2. Neither SI nor TD_REL is correlated with BI, rejecting both H3 and H10. TD_ALG is strongly correlated with BI ($\beta_5 = 1.368$, $p < 0.001$), supporting H11. Because none of the cross terms has a coefficient significantly different from zero, all the following hypotheses are rejected, namely H4, H5, H6, H7, H8, H9, H12, H13, H14, H15. The above results were summarized as follows:

$$\begin{array}{c} BI = -0.766 + 0.572 \times PE + 0.197 \times EE + 1.368 \times TD\_ALG + \tau + \varepsilon \\ (0.700) \quad (0.096) \quad (0.099) \quad (0.138) \end{array} \tag{2}$$

where τ denotes the control variables, and ε denotes the errors.

Table 5. Multi-linear regression results.

	BI				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
PE	0.578 *** (0.111)	0.607 *** (0.110)	0.620 *** (0.111)	0.572 *** (0.096)	0.402 (0.260)
EE	0.240 * (0.113)	0.281 * (0.114)	0.279 * (0.114)	0.197 * (0.099)	0.468 (0.266)
SI	0.166 (0.095)	0.120 (0.096)	0.106 (0.097)	0.148 (0.084)	0.176 (0.201)
TD_REL			−0.079 (0.064)	−0.075 (0.055)	−0.309 * (0.141)
TD_ALG				1.368 *** (0.138)	1.492 *** (0.342)
PE × Female					−0.134 (0.210)
EE × Female					−0.381 (0.201)
SI × Female					0.030 (0.170)
TD_REL × Female					0.152 (0.119)
TD_ALG × Female					−0.136 (0.287)

Table 5. *Cont.*

	BI				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
PE × Age					0.200 (0.129)
EE × Age					−0.046 (0.171)
SI × Age					0.034 (0.117)
TD_REL × Age					0.082 (0.065)
TD_ALG × Age					−0.059 (0.172)
Female		0.167 (0.164)	0.165 (0.164)	0.019 (0.142)	2.158 (1.367)
Age		0.259 ** (0.094)	0.266 ** (0.094)	0.136 (0.082)	−0.884 (1.017)
TaxiUsage		−0.352 * (0.156)	−0.363 * (0.156)	−0.232 (0.136)	−0.272 (0.140)
RoboTaxiUsage		0.349 (0.249)	0.381 (0.250)	0.295 (0.217)	0.246 (0.218)
RoboTaxiUsageFF		0.104 (0.192)	0.079 (0.193)	−0.045 (0.168)	−0.051 (0.167)
F-value	28.51	12.99	11.74	23.91	12.76
p-value	0.000	0.000	0.000	0.000	0.000
Adjusted R2	0.216	0.243	0.244	0.434	0.441
N	299	299	299	299	299

Standard error in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

4.1. The UTAUT Model

Our findings suggest the UTAUT model has an intermediate explanatory power regarding robotaxi adoption. As was expected, both performance expectancy and effort expectancy have a positive influence on robotaxi adoption intention, but statistically, performance expectancy is a stronger predictor than effort expectancy, which is consistent with the studies by Xu et al. [41] and Yang et al. [42]. It is, therefore, recommended that robotaxi companies allocate greater budgets to advertising the usefulness of robotaxi than its ease of use in marketing campaigns. Such benefits include reduced traffic jams, more efficient vehicle operation, lower energy consumption, reduced car accidents, enhanced passenger privacy, and lower fees.

While marketing about the above benefits seems an easy thing, actually achieving some of these targets is much harder. Just as we reminded the participants that robotaxis are safer than taxis driven by humans even though both taxis and robotaxis may encounter accidents, with the latter having a smaller probability, the real accident that occurred in San Francisco suggests there is still a long way to go before robotaxi can be as reliable as customers are expecting. Meanwhile, until now, not a single robotaxi company has broken even. Although, currently, passengers are paying reasonable or even no fees for riding robotaxis, it is actually the companies that are undertaking the majority of the huge operation costs. Only when a company can cover its skyrocketing R&D cost with an adequate amount of daily orders will robotaxis justify their business model.

It seems surprising that social influence is not playing a role in encouraging robotaxi adoption, which is against the finding of Liu et al. [12] in their robotaxi adoption study in China. The difference may result from two factors. One factor regards questionnaire design. In our study, we measure social influence by directly borrowing the items from Venkatesh et al. [8]. In comparison, Liu et al. included in their survey the item “I would be proud if people saw me using a robotaxi", which somewhat carries the feeling of conspicuous consumption as of being an innovator at the very early stage of the diffusion of robotaxis, a new technology. The other factor regards the timing of the studies. Liu et al. completed their study in the first half of 2020, which means they possibly collected data in late 2019 when robotaxi was almost nowhere to be found in China. This adds to the first factor such that the proud feeling of being an innovator became a strong motivator towards robotaxi adoption. Considering the time until now, when 16% of our participants have already once taken a robotaxi (though with a backup human driver), while 34% of them have at least one family member or friend who had robotaxi experience, it makes sense to accept the diminishing effect of social influence.

4.2. Trolley Dilemma Relevance

The relevance of trolley dilemma in a robotaxi scenario was explored in this study, with results showing that the participants tend to believe there is a strong connection between the trolley dilemma and robotaxis (TD_REL averages 4.96), regardless of the fact that we explained to the participants that robotaxis are safer than traditional taxis thanks to advanced self-driving technology and that the trolley dilemma rarely happens in real situations. Consequently, we argue that the trolley dilemma is perceived by potential customers as an important ethical issue for robotaxis. That means that in the marketing practice of robotaxi, companies should choose either not to mention it or to mention it with caution. The worst choice would be a company mentioning the trolley dilemma but saying it is of negligible importance. Interestingly, although some participants regard the trolley dilemma as of high relevance while others do not (the standard deviation of TD_REL is as large as 1.23), such a difference does not lead to significant changes in robotaxi adoption intention. Considering the fact that it is rarely heard that an individual refuses to ride a traditional taxi because of the trolley dilemma, it is reasonable to predict that robotaxi consumption will not be affected by customers' opinions on the relevance of the trolley dilemma.

Existing studies have different ideas about whether the trolley dilemma is relevant to AVs. As mentioned earlier, some researchers are against applying the trolley dilemma to AV, arguing that the trolley dilemma represents extremely rare situations, which should give way to more common cases, while some others consider the trolley dilemma as a critical ethical issue to be solved before AV implementation. Our study managed to reconcile the above points of view. On one hand, customers perceive that a robotaxi is as safe as a human-controlled taxi, according to their own experience or the information they receive from others. Therefore, they tend to equalize a robotaxi with a traditional taxi in terms of the trolley dilemma, a concept they hardly engage with when they ride a traditional taxi. On the other hand, when you seriously ask customers how they feel about the trolley dilemma, creating a situation that induces them to attach importance to the trolley dilemma, they start to consider it is necessary to discuss the trolley dilemma in a robotaxi scenario. Overall, we tend to believe the trolley dilemma is more a theoretical discussion than a practical issue.

4.3. Trolley Dilemma Algorithm

What really impacts robotaxi adoption is not the trolley dilemma itself but how the companies choose to handle it. Our findings reveal that under the egocentric algorithm, such that when facing a trolley dilemma, the robotaxi will always prioritize the safety of the passenger(s), then participants are significantly more willing to adopt robotaxi. This agrees with previous findings that people would prefer to buy AVs that are programmed to save their passengers (themselves) [30]. However, this does not mean we encourage robotaxi companies to pursue the egocentric algorithm or even disclose it to the public to achieve greater adoption. That is because robotaxis not only consider the protection of their passengers but also the external impact they have on traffic actors outside the vehicle, such as pedestrians. Moreover, once passengers get off robotaxis, they themselves become pedestrians. Therefore, our study recommends that the algorithm a robotaxi company adopts should not be disclosed to the public.

4.4. What Can Robotaxi Companies Do?

Currently, it seems robotaxi companies are at a loss as to how they should handle the trolley dilemma; the best strategy is not mentioning it or publicizing their algorithm. Fortunately, robotaxi companies may take the following three steps to better cope with the trolley dilemma. Firstly, they can transfer the imaginary concept of the trolley dilemma to specific real-world self-driving settings by enumerating the many possible situations. Secondly, they can use redundant sensors and predictive algorithms to further reduce the possibility of being involved in a trolley dilemma. Thirdly, they can match each setting with a customized solution so as to reach a compromise between passengers and pedestrians. After all, the ending of Foot's original version of the trolley dilemma is black or white; robotaxi may find a third and better solution.

5. Conclusions

In this study, we applied a modified UTAUT framework to explore the antecedents of robotaxi adoption, with a special focus on customers' understanding of the trolley dilemma. The results show that both performance expectancy and effort expectancy have a positive influence on robotaxi adoption intention. As for the trolley dilemma, customers regard it as of high relevance to robotaxis. Moreover, if the robotaxi is programmed with an egocentric algorithm, such that when facing a trolley dilemma, the robotaxi will always prioritize the safety of the passenger(s), the customers are significantly more willing to adopt the robotaxi.

5.1. Contributions

Our findings contribute to both adoption studies and ethics studies. As an adoption study, this paper adds to UTAUT two new constructs, namely trolley dilemma relevance and trolley dilemma algorithm. Although these two constructs are robotaxi-specific, they can be generalized to "relevance plus choice" to adapt to other new technologies involving ethical issues, including AIGC and humanoid robot. We also believe the methodology is applicable to understanding customer choices in countries and regions beyond China.

Meanwhile, as an ethics study, this paper directly asks customers to assess the relevance and algorithm of the trolley dilemma, which is a meaningful supplement to existing ethics studies that mostly debate from researchers' perspectives. Moreover, existing studies have different ideas about whether the trolley dilemma is relevant to AV, with some researchers against applying the trolley dilemma to AV while others consider the trolley dilemma as a critical ethical issue. Our study managed to reconcile the above points of view but tends to believe the trolley dilemma is more a theoretical discussion than a practical concern.

The managerial contribution of this study manifests as providing solid suggestions to robotaxi companies in their marketing campaigns. Apart from recommending that robotaxi companies allocate more budgets to advertising the usefulness of robotaxi, we argue that they shall neither announce that the trolley dilemma is of negligible importance nor disclose their self-driving algorithm to the public. Instead, they are encouraged to turn trolley dilemmas into specific real-world self-driving settings, use redundant sensors and predictive algorithms to reduce the possibility of being involved in a trolley dilemma, as well as develop customized solutions for each specific case to reach a compromise between passengers and pedestrians.

5.2. Limitations

This study has several limitations that can be improved in future studies. Although we limited our samples to residents in China to control national cultural differences, because China has more than thirty provinces that exhibit distinctive regional cultures, we were not able to study the resulting heterogeneity due to the relatively small sample size. Meanwhile, both robotaxis and the trolley dilemma are topics of global interest. Therefore, it is attractive to conduct cross-cultural comparisons to discover additional findings.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Questionnaire

A. *Participants read the following statements. [Robotaxi introduction]*

[Note: Information in the square brackets is for explaining the questionnaire to the readers of this paper. Information in the square brackets is not visible to the participants.]

Robotaxi is being tested in several big cities in China. Users are invited to take a ride on those taxis that are controlled by self-driving algorithms. Currently, there are human drivers on robotaxis for emergency backup. In the future, there will be no backup human drivers on robotaxis.

Riding a robotaxi is similar with riding a traditional taxi, which requires just several taps on an App to call for a robotaxi and is charged by mileage and time. Robotaxi has the advantage of optimizing travel route and vehicle control, and providing a more private riding environment for the passengers.

B. *Participants answer the following questions. [Validation questions]*

1. Is robotaxi being tested in several big cities in China?
   A. Yes.
   B. No.
2. Riding a robotaxi is ____ riding a traditional taxi,
   A. significantly different from
   B. similar with
3. In the future, there will be ____ on robotaxis.
   A. no backup human drivers
   B. backup human drivers
4. Robotaxis ____.
   A. cannot provide a more private riding environment for the passengers
   B. can optimize travel route and vehicle control

C. *Participants answer the following questions. [PE, EE, SI]*

[Performance expectancy, PE]

5. Robotaxi will be useful to me.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
6. Robotaxi will shorten my travel time.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
7. Robotaxi will make travelling more convenient.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
8. Robotaxi will make me life and work better.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree

[Effort expectancy, PE]

9. The user interface of the App for robotaxi will be clear and understandable.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
10. It will be easy for me to use the App for robotaxi.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
11. The user interface of the App for robotaxi will not be complicated.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
12. Learning to use the App for robotaxi will not be difficult.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree

[Social influence, SI]

13. My colleagues will use robotaxi.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
14. My family and friends will use robotaxi.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
15. My company will support me for using robotaxi.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
16. My family and friends will support me for using robotaxi.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree

D. Participants read the following statements. [Trolley dilemma]

Have you ever heard trolley dilemma? It is one the most famous thought experiments in the ethics field. Trolley dilemma refers to the hard decision of a driver on a runaway tram. The driver can only steer from one narrow track on to another; five men are working on one track and one man on the other; anyone on the track he enters is bound to be killed.

Theoretically, trolley dilemma can happen on robotaxi. For example, a robotaxi is driving with passengers on board and some pedestrians suddenly appear in its path with no time to brake and completely stop. The robotaxi has to decide between staying the course and running over the pedestrians or swerve to the side and hit a barrier that kills the passengers.

Although this sounds quite scary, but your experience might tell your that trolley dilemma rarely happens in real life. Meanwhile, research suggests that robotaxis are safer than taxis driven by human. However, please notice that both taxi and robotaxi may encounter accidents, with the latter having a smaller, yet not zero, probability.

E. Participants answer the following questions. [Validation questions]

17. Trolley dilemma is one the most famous thought experiments in the ____.
   A. ethics field
   B. legal field
18. Trolley dilemma ____ happens in real life.
   A. often
   B. rarely
19. Research suggests robotaxis are ____ than taxis driven by human.
   A. less safe
   B. safer
20. Robotaxi has ____ probability of encountering accidents.
   A. an extremely small
   B. zero

F. Participants answer the following questions. [Trolley dilemma relevance, TD_REL]

21. Regarding robotaxi, it is meaningful to consider trolley dilemma.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
22. There is a strong connection between robotaxi and trolley dilemma.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
23. Robotaxi will not go to the market before it resolves the trolley dilemma issue.
   1-totally disagree 2 3 4-neutral 5 6 7-totally agree
24. I would hesitate to use robotaxi before it resolves the trolley dilemma issue.

1-totally disagree 2 3 4-neutral 5 6 7-totally agree

G. *Participants read the following statements. [Trolley dilemma algorithm, TD_ALG]*

[Group A, utilitarian algorithm]

Many robotaxi companies have agreed that when facing trolley dilemma, their algorithm will follow the rule of thumb of "maximizing overall happiness, while minimizing overall suffering", such that in some cases, it will compromise the passenger(s) to save a significantly larger group of pedestrians.

[Group B, egocentric algorithm]

Many robotaxi companies have agreed that when facing trolley dilemma, their algorithm will follow the rule of thumb of "passenger first", such that in any case, it will always prioritize the safety of the passenger(s), albeit in some cases a larger group of pedestrians will be compromised.

H. *Participants answer the following questions. [Validation questions]*

25. Many robotaxi companies have agreed that when facing trolley dilemma, their algorithm will follow the rule of thumb of ____.
    A. minimizing overall suffering
    B. passenger first
26. That means ____.
    A. in any case, it will always prioritize the safety of the passenger(s)
    B. in some cases, it will compromise the passenger(s) to save a significantly larger group of pedestrians

I. *Participants answer the following questions. [Behavioral intention, BI]*

27. I will use robotaxi in the future.
    1-totally disagree 2 3 4-neutral 5 6 7-totally agree
28. Robotaxi is worth be used.
    1-totally disagree 2 3 4-neutral 5 6 7-totally agree
29. Once robotaxi is being officially deployed, I will download an App and call for a robotaxi.
    1-totally disagree 2 3 4-neutral 5 6 7-totally agree

Appendix B. Reliability and Validity

Table A1. Reliability.

Variables	Cronbach's α	Number of Items
PE	0.819	4
EE	0.834	4
SI	0.884	4
TD_REL	0.845	4
BI	0.940	3

Table A2. Validity.

KMO		**0.850**
Bartlett test	Approx. Chi-Square	3292.378
	DOF	171
	p-value	0.000

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