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Kyushu University

June 2021

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Abstract

We seek to understand whether environmental concerns, fears of potential accidents, and merits regarding fully autonomous vehicles (FAVs) are motivators of willingness to buy (WTB) and willingness to pay (WTP) of FAVs. To do so, a large-scale survey on FAVs of more than 180,000 respondents was collected in Japan, and structural equation modeling (SEM) validated our findings. Interestingly, this study implicates a form of WTB-WTP disparity: those interested in natural environment conservation would purchase FAVs because they show high interest in overall social problems, and new technologies such as FAVs can resolve such problems, according to previous works. However, our result implies that they would not show high WTP because adopting FAVs does not `directly' contribute to natural environment conservation. Additionally, our results indicate that those who appreciate potential merits would have higher WTB and WTP, while those who fear FAV technology would not purchase FAVs and would have lower WTP. The results bear crucial policy implications for planners by showing the complexity between the factors of FAV WTB and WTP.

Keywords: Fully autonomous vehicle; WTP; structural equation model; environmental concerns.

1. Introduction

The rapid advance of autonomous vehicles (AVs) and fully autonomous vehicles (FAVs) implies the arrival of the era of completely driverless cars. Starting from Google's self-driving car project in 2009, famous companies such as Uber, Apple, and Tesla have been challenging the development of autonomous vehicles. This is because shifting to FAVs from vehicles without any automation function would have numerous benefits if properly used, including the prevention of accidents due to human errors (C. Zhao et al. 2020; Hagl and Kouabenan 2020), alleviation of congestion (Tscharaktschiew and Evangelinos 2019; Simoni et al. 2019), and reduction of emissions from traffic (Figliozzi 2020; Hong, Le Hong, and Zimmerman 2021; Jones and Leibowicz 2019).

Due to these benefits, the Japanese government has also challenged the development of these companies' autonomous driving technology's technical development. As one of the efforts, the Japanese government officially tested driverless taxis in Tokyo from August 27, 2018, to September 8, 2018. The Japanese government expects the introduction of complete automated vehicles, or fully autonomous vehicles, by 2025, which currently stays in partial automation until 2021.[1] Nonetheless, AV's actual acceptance in Japan is only approximately 2-5 percent in the new car market in 2020 (Ministry of Land, Transport, and Infrastructure, 2020)[2], while market experts predict the market share of FAV technology worldwide to reach 15-20% by 2025[3]. Thus, despite the advantages FAV/AV has and the global trend that pursues vehicle automations, the relatively small market share of AV in Japan indicates the need for policies and future blueprints for the gradual shift to FAV. Drafting such standards would

[1] There are five levels (types) of vehicle automation technology. Currently, Japanese government initiated level 3. Level 5 automation technology indicates a full automation, which does not need a driver to drive. We discuss this issue in Section 2.

[2] We refer to the Report by Ministry of Land, Transport, and Infrastructure of Japan. https://www.mlit.go.jp/policy/shingikai/content/001330176.pdf (In Japanese)

[3] We refer to the article by Junko Yoshida, from EE times (https://www.eetimes.com/autonomous-cars-breaking-down-market-forecasts/)

require understanding which factors would encourage or discourage potential consumers from adopting autonomous vehicles and, at the same time, how they evaluate them in monetary terms, which remains unanswered. To better design measures that enable the gradual substitution to FAVs, policymakers must tackle this question, and thus, we empirically study the problem by examining potential consumers.

This study investigates both the willingness to buy (henceforth, WTB) and the willingness to pay (WTP) of FAVs. This is because their implications are different; for example, while purchasing decisions would imply whether one is willing to buy something without a specific consideration of the price range (or a given price), willingness to pay shows how one evaluates the product in monetary terms (Krueger, Rashidi, and Rose 2016; Lu and Hsee 2019; Wertenbroch and Skiera 2002). Regardless of the differences between WTB and WTP, most of the previous works deemed the two to be positively correlated and thus looked into the two together without separately identifying them. Nonetheless, some of the previous works in the field of economics and marketing find that there is a disparity between WTB and WTP (Jiang et al., 2020 and Liu et al., 2021). This shows that a high level of WTB does not guarantee that s/he would have high WTP and vice versa. Such a trend is notable when environmentally conscious consumers purchase green products. (Barber et al., 2012), mainly because individual benefits are highly correlated with the WTB of green products, not with WTP (Follows and Jobber, 2000). Given that F/AVs have potential environmental benefits, we expect that people choosing F/AVs can also have WTB-WTP disparities.

Including people's intentions and behaviors, determined by attitude and perceptions, requires constructing latent factors (Ben-Akiva et al., 2002). Furthermore, people can have multiple attitudes simultaneously; for example, people can fear F/AVs but at the same time appreciate the merits of F/AVs. Thus, given that people simultaneously perceive benefits and fears from F/AVs, s/he may express high levels of WTB and WTP because s/he appreciates the benefits more than s/he fears F/AVs. Nonetheless, if s/he becomes to fear F/AVs more, the implications on WTB and WTP may change. Furthermore, such different attitudes might be correlated. Therefore, we construct four categories of latents, considering their correlations, that express the attitudes and behaviors of people through an extensive literature review and estimate their relationship to WTB and WTP. We also consider socioeconomic factors, such as income, gender, household size, and car-related factors, such as car ownership and car type. We choose structural equation modeling (SEM), a widely known methodology to scrutinize people's psychometric intentions, which allows the identification of latent factors and simultaneous estimations of latents with exogenous variables. Figure 1 shows our study structure. We first identify attitudes, which are expressed in latents, according to the behaviors, and estimate the relationship between intentions and decisions.

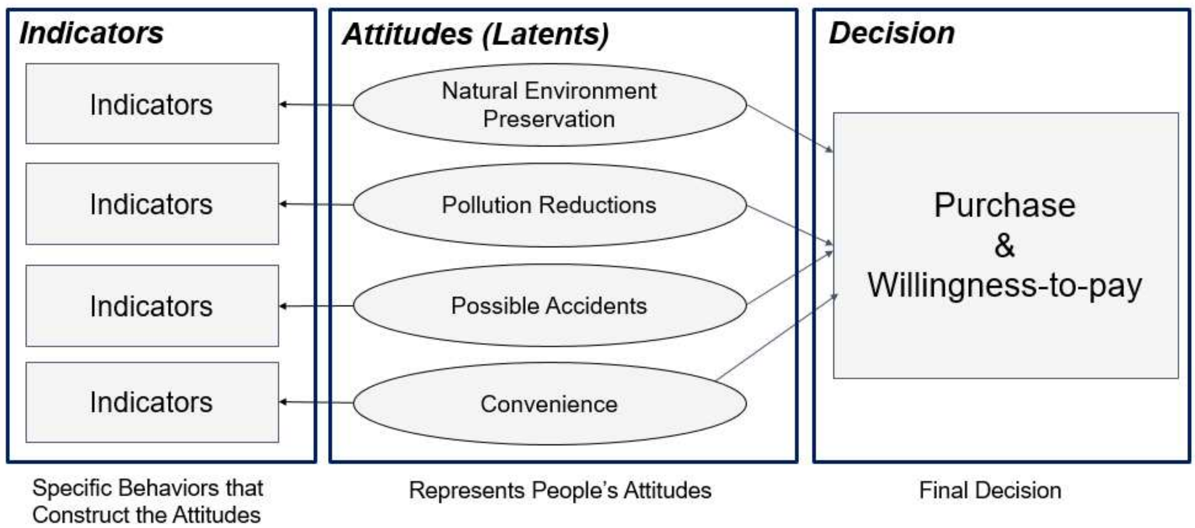

Figure 1: Study Structure.

This study mainly contributes to the existing literature that investigates the demands of FAVs (Xu and Fan 2019; Hidaka and Shiga 2018; Hatzenbühler et al. 2020; Asmussen et al. 2020; Kröger et al. 2019; Adnan et al. 2018). We mainly, answer the following questions:

Research Question 1: What are the factors that are correlated to the WTB and WTP of FAVs? We particularly look at environmental concerns, the merits and advantages of using FAVs, and fears of FAVs.

Research Question 2: Is there a disparity between WTB and WTP?

Research Question 3. Does a high level of environmental concern indicate a higher WTB and WTP? Hence, the term 'environmental concern’ is a broad concept that needs to be categorized for policy implications (Whitmarsh and O’Neill 2010). In this study, therefore, we divide environmental concerns into two concepts: those who support natural environment conservation and those who are concerned about air pollution, wastes, and water pollution according to the statistical analysis. We expect the two groups' implications to be different, as FAVs' environmental benefits are mostly focused on reducing pollution rather than natural environment conservation. Thus, while those who advocate conservation might have higher WTPs, whether they agree that FAVs have environmental benefits while implications on WTB remain ambiguous.

To this end, we conduct a survey of more than 180,000 respondents in Japan, which contains questions regarding WTB and WTP of FAVs, individual characteristics such as income, gender, commuting time and ages, environmental awareness, and opinions on advantages and concerns regarding FAVs. Then, we construct four empirical models that answer our research questions. While we are focusing on Japanese consumers, given that numerous countries are vigorously pursuing AVs and FAVs and there is also a need for these countries to examine how consumers make decisions in the market, and despite such efforts, given that the market share of AV/FAVs is still low, the implications from our study would therefore contribute to the policies and literature regarding the demands of AVs and FAV globally.

Our estimation result shows that those who support natural conservation are likely to buy FAVs but show lower WTP, which was statistically significant and robust. On the other hand, people who are interested in alleviating pollution and those who are interested in the conveniences/advantages of using FAVs show higher WTB and WTP. Those who fear FAVs are unlikely to purchase FAVs and have lower WTP. Our result implies the importance of understanding consumer awareness of WTB and WTP is crucial for promoting FAVs. We also briefly discuss using F/AVs without increasing emissions.

The remainder of this paper is structured as follows. Section 2 provides a background in terms of industry and policy. The data and model are presented in Section 3. Section 4 shows the empirical results. Section 5 discusses our findings and provides policy implications. Section 6 concludes.

2. Backgrounds and Literature Review

In this section, we first demonstrate the industry backgrounds in Section 2.1 and summarize previous works on F/AVs in diverse aspects in Section 2.2. Then, we emphasize our contribution on Section 2.3.

2.1. Autonomous Vehicle Policies and Japanese Industrial Backgrounds

The automatic operation of autonomous vehicles (AVs) has a level of operation automation, which is called system-automated operation. Table 1 explains the levels and explanations of each level. A system generally carries out all driving operations without conditions corresponding to level 5 (fully automated, or FAV) and has not yet been realized until 2021.

As mentioned in Section 1, due to the benefits and advantages of adopting FAV technology, Japan, which has self-driving technology, is also making rapid progress. However, the market share of AVs (level 3) in Japan remains at approximately 5.6%, which is still lower than that in other countries; for example, while Germany had approximately 20.2% (P&S Intelligence, 2019) in 2018, the USA had approximately 12.8% in 2018 (Mordor Intelligence, 2019). However, like other countries, Japan also aimed to increase AV's market shares by introducing various approaches, which can be broadly categorized into two types.

One approach is a governmental-level effort in which the government makes amendments to current legislation that allow the current traffic laws to include unmanned cars. Prior to Japan, many countries aimed to increase their market share with the introduction of various policies. For example, the USA, which enacted the Self-drive Act in 2017, aimed to ensure AV's safe and innovative development and deployments. Germany has also revised the Road Traffic Act to include AVs (level 3 to 4) to comply with state of the art regarding the tremendous and fast progress in research and development in various technologies. On the other hand, the Japanese government initiated amendments to the existing law on FAVs in April 2020, which was slightly late. In the case of Japan, the two types of laws were revised: the Vehicle Act and Traffic Act. The revisions were made in 2020 April. The revisions are designed to handle Level 3 and above and therefore include further advances in AV technologies, including FAVs, connected AVs (CAVs) and shared AVs (SAVs) (Imai, 2019).

The second approach addresses the supply sides through technological innovations. Japanese industries fiercely pursue F/AVs because if properly used, F/AVs can reduce traffic accidents, congestion, fuel consumption, and emissions and therefore become a primary transport mode that will accommodate Japan's aging population. The Japanese automotive industries, namely, Toyota, Honda and Nissan, are fiercely moving forward with plans to introduce autonomous driving vehicles and facilities that enable such systems. In particular, the Nissan-initiated ProPilot system, which is a semi-autonomous system that allows single-lane freeway automated driving, is installed in several models in Leaf, which is an electric vehicle. Nissan also provides New Propilot 2.0., which allows 3D mapping navigation and recognizes pedestrians' faces with cameras and sensors. Honda and Toyota are also pursuing AV technologies to be installed in their vehicles. The technology would allow drivers to take their hands off the wheel and, while in use, even look away from the road. However, when there is a problem, drivers have to have controls back — which is a reason why so many firms have skipped this level and switched straight to Level 4 or 5 automation and that's why Industry experts expect that AV technology would ultimately converge to FAV by 2025 (Mckinsey Center of Future mobility, 2019).

Despite the government and supply sides' efforts, investigating demand sectors is also necessary, as it would be the consumers who would finally decide whether to adopt AVs and FAVs. Hence, consumers may choose FAVs due to conveniences that FAVs would give, while at the same time, they would evaluate FAVs lower due to possible accidents. Thus, we examine the factors affecting consumers' purchases and WTPs on FAVs to improve the design of FAV technologies and policy mixes that can encourage consumers to choose FAVs.

Table 1. The Summarized Explanations on AV technology by Levels.

Level of Automation	Explanation	Subject of Driving
Level 0 (No automation)	Drivers perform all operations.	Driver
Level 1 (Driver Assistance)	Under certain conditions, System partially performs either brake, steering or acceleration/deceleration.	Driver

Level 2 (Partial Automation)	Under certain conditions, System performs brake, steering and acceleration.	Driver
Level 3 (Conditional Automation)	Under certain conditions, the system handles all operations, and the driver intervenes when the system cannot operate.	System + Driver
Level 4 (High Automation)	Under certain conditions, the system handles all operations.	System
Level 5 (Full Automation)	The system handles all operations unconditionally.	System

Source: SAE International (2014)

2.2. Existing Literature

2.2.1. Expected Benefits and Concerns on F/AVs

F/AV technologies are expected to change a transportation paradigm with minimized human interventions (Lee et al. 2019). While experts predict that F/AVs would bring benefits from diverse aspects, experts also express concerns in case F/AVs are not properly used.

Benefits from F/AVs include an increased/optimized traffic capacity (Chen et al. 2019; Noruzoliaee et al. 2018) and reduced vehicle emissions (Zhang et al. 2019; Jones and Leibowicz 2019). Due to these advantages, AV technology has experienced explosive growth, and substantial recent literature focuses on the potential changes after introducing FAVs and AVs. These works include changes in travel behavior (Childress et al. 2015; Dias et al. 2020; Kröger et al. 2019; Zhong et al. 2020; Zhao et al. 2020; Herrenkind et al. 2019), and some of the works focus on changes in work-home location (Zhao et al. 2021; Tian et al. 2019). Some works focus on travel time savings (Moore et al. 2020; Rey and Levin 2019; Allahviranloo and Chow 2019), while the other strands of works look at the time-saving effects and merits of using AVs with public transportation choices (i.e., shuttle bus) (Shen et al. 2018; Kassens-Noor et al. 2020; Abe 2019; Nazari et al. 2018). Some of the studies look at the environmental benefits of using FAVs (Hong et al. 2021; Stern et al. 2019; Saleh and Hatzopoulou 2020; Jones and Leibowicz 2019).

On the other hand, there are also several works highlighting the potential negative consequences of employing AVs; Greenwald and Kornhauser (2019) state that policies need to intervene to reduce emissions from AVs, and Liu and Song (2019) show that the fuel economy needs to be improved to reduce emissions from AVs. Pammer et al. (2021) emphasizes that accidents may increase due to overtrust in AVs. Wang et al. (2020) show that autonomous vehicles have trouble reacting to the complex pedestrian environment. Thus, F/AV drivers need to pay additional attention to protect pedestrian safety.

To summarize, the findings of the works above highlight the importance of looking into the people who are adopting FAVs by looking into the potential benefits and disadvantages of AV or FAV. Therefore, these benefits would be realized if people accept AVs and FAVs and use them properly without neglecting fuel economy improvement or increasing travel distance rapidly and overtrusting AVs, which again emphasizes the role of consumers. Such findings would necessitate the research of consumer behaviors (choices and WTP, representatively) on AV/FAVs.

2.2.2. Hindrances on F/AVs Choices

Then why has F/AV's market share been so low until now? Numerous studies show that the acceptability of autonomous vehicles is hindered because people are wary about various issues. First, previous works argue that people are reluctant to purchase FAVs because they fear potential traffic accidents. Fagnant and Kockelman (2015) mention that concerns regarding accountability/responsibility in traffic accidents can be an obstacle for potential FAV consumers. Li et al. (2019) and Raj et al. (2020) point out that resolving the problems regarding the responsibility of damages is crucial for promoting FAV usages. These problems eventually discourage people from choosing FAVs (Raj et al. 2020; Wang et al. 2020). Therefore, Morita and Managi (2020) mention that to promote usage, credibility should be guaranteed. Concerns about traffic accidents can also be extended to problems that might discourage technological improvements of FAV suppliers. Bansal and Kockelman (2017) mention that the appropriate regulations on safety norms can accelerate FAV technology innovations. Bansal and Kockelman (2017) and Shladover and Nowakowski (2019) show that the absence of clearly defined safety norms would be a challenge for consumers to accept FAVs.

Second, the other strands of literature argue that people are not fully aware of FAVs' potential but substantial environmental benefits; therefore, substitution toward FAVs is hindered. On the one hand, Bansal and Kockelman (2017), Shladover and Nowakowski (2019), Acheampong and Cugurullo (2019) and Haboucha et al. (2017) mention that pro-environmental consumers accept technological innovations if they can reduce pollution. Similarly, Krueger et al. (2016) show that pro-environmental consumers are likely to choose FAVs. On the other hand, Gkartzonikas and Gkritza (2019) show that consumers' lack of understanding of FAV's environmental benefits can be a barrier to FAV acceptance.

2.2.3. F/AVs Choices and Demands

The relatively early literature in this area examined purchasing decisions (or a choice) by analyzing the relationship between sociodemographic variables (i.e., gender, income and age) and technology features to AV adoption. For example, some of the works look at the technological benefits (i.e., automatic braking and parking assistance) as the primary driver of AV purchases (Payre et al. 2014; Shin et al. 2015; Lavieri and Bhat 2019). More recent literature looks at psychological aspects such as fear of the new technology (Xu and Fan, 2019; Fagnant and Kockelman, 2015; Mordue et al. 2020; Raj et al. 2020). Some of the works also look at the factors correlated to the WTP of AVs (Daziano et al. 2017; Liu et al. 2019; Nyga et al. 2020), and most of them focused on the relationship between socioeconomic factors (i.e., income) and WTPs.

Earlier studies mostly find that higher environmental concerns, higher income, and technological benefits are indeed main drivers of AV and FAV adoption and higher WTP. We, however, find some research gaps from these works; that they primarily focus on either WTP and WTB, and less attention is given to the factors affecting both, leaving out a potential distortion in the results due the possibility that one might not have higher WTP but has higher WTB, and vice versa. Consequently, these studies tend to imply that factors with higher WTP on FAV would encourage FAV purchases. Such a conclusion may change, however, if the factors affecting WTB and WTP are different. In fact, some of the previous works have already shown that the WTB and WTP do not always align. Other than this research gap, we find some issues that our model can address, and we discuss all of them in Section 2.3.

2.3. Current Research Gaps and Our Contributions

This study aims to better understand the factors affecting the WTB and WTP of FAV choices. This study has several contributions. First and most importantly, to the best of our knowledge, our model is the first to account for the differences between WTB and WTP in the context of FAVs. Having a higher WTP does not necessarily indicate that someone will purchase a FAV. For example, as mentioned in Section 1, one might evaluate the autonomous vehicle higher than others because s/he is aware of FAV technology's benefits but would not purchase FAVs because s/he is afraid of potential accidents. Our work and results allow us to understand and distinguish the characteristics of individuals who belong to these groups (those who evaluate FAV higher but do not purchase, and vice versa), and those who do not belong to this group are crucial to policymakers who are willing to spread the use of FAVs and bring them into the mainstream.

Second, we account for technological advantages, fears toward new technology, environmental awareness, and sociodemographic factors (i.e., gender, age, income, and commuting time) together in the model. Each factor encompasses crucial issues (i.e., cybersecurity, regulations on accidents, responsibilities on accidents, safety, and malfunction) closely related to the WTB and WTP demands and carefully selected in the literature. One advantage of this approach is that we can separately analyze each factor's impact while fixing the other factor: for example, one might be afraid of FAV technology, but at the same time, s/he can support the conservation of the natural environment. Another example would be a person who fears FAV due to possible accidents or malfunction issues, but at the same time, s/he is fond of the advantages that FAV would give. In this case, there is a need to analyze these factors as independent factors separately. For example, our study allows us to look at the impact of fear toward accidents while fixing interests on natural environments, therefore focusing on the changes of one while leaving the other as it is, and vice versa. Such approaches would allow us to evaluate each factor's `independent' impact. Additionally, our model allows us to look at the impacts of each survey question on the factors. We discuss more on the factors in Section 3.2.

Third, we categorize environmental concerns into two categories and investigate their correlations to F/AVs' WTB and WTP. There are only a handful of studies on the impact of environmental awareness on FAV adoption and WTP (Wu et al., 2019). In a broader view, there are previous works on consumers' environmental concerns and their purchasing behaviors, and most of them agree that higher environmental concerns would lead to higher consumer preferences for pro-environmental products. (Jain et al., 2018; Oerlemans et al., 2016; Kowalska-Pyzalska 2018) Hence, one issue from these works is that they regard environmental awareness as a broad concept: public awareness of the importance of environmental protection. However, purchasing behavior might vary according to the type of environmental awareness. For example, the environmental benefits of adopting FAVs are mostly related to pollution and are not directly correlated to natural environment conservation (i.e., biodiversity preservation). In that sense, those who prioritize these issues more than reducing air pollutants might not show higher WTPs than those who regard resolving air pollution as important. Therefore, policy guidelines that do not consider differences between different environmental awareness types might result in misleading policy implications. To resolve this research gap, we categorize environmental awareness into 'Pollution,' which refers to the people who emphasize recycling, alleviating air/water pollution, and 'Nature,' which refers to the people who prioritize natural environments. Categorizing would also allow the identification of which types of environmental awareness would be positively/negatively correlated with WTB or WTP, respectively.

Hence, fourth, while our study looks at each factor's effects, we also allow the correlations between the different factors. Allowing such correlations is crucial because the WTB and WTP choices would be influenced by multiple combinations of different factors. To be more specific, our model allows us to look at the `independent' impacts of each factor. At the same time, our model would take into account the correlations of each factor in estimation. If we exclude one of each factors given that the factors may be correlated to each other, there will be potential omitted variable bias, and endogeneity can occur. From the perspective of econometrics, ignoring such endogeneity can lead to incorrect estimation and might result in misleading policy implications.

3. Methodology

3.1. Data

To answer our research question, we first carried out an online survey conducted in Japan from November 16 to December 14, 2015. The survey is conducted for all generations and consists of questionnaires related to lifestyle and environmental concerns, including topics about FAVs. The sampling procedure was designed to randomly select respondents while maintaining the gender and age distribution of the respondents similar to those of the Japanese population. We designed and employed the internet survey through Nikkei Research Inc., which is the largest research company in Japan. In the survey, several trap questions were included to detect the respondents who did not seriously answer the questions. Those who did not correctly answer such trap questions were excluded from the sample in the collection process by the survey company. As a result, we collected 246,642 respondents. We present the distribution of socioeconomic variables of the survey and Japanese Census data in Table A.5 to assess the sample representativeness of our survey. We find that there are slight differences between gender and education levels between our survey and Japanese Census data. Nonetheless, we do not find a difference across surveys and show that our data approximately range around the average levels of the two cities.

Topics in the survey include environmental benefits, merits and possible concerns of FAVs. Again, we are aware that in 2015, the respondents were less familiar with FAVs than those in 2021. Therefore, we excluded those who answered that they had 'no awareness' of FAVs, which accounted for 14.48% of the entire sample (35,715 observations). Thus, in our model, we only account for the people who were aware of FAV technologies in 2015. Therefore, given that FAVs were not introduced in the market back then and still not introduced in 2021, a substantial change in the result, for example, a change in sign or implications of the results, is less likely to happen. Therefore, more attention should be given to the signs and relative comparisons of coefficient magnitudes of the latent constructs.

Finally, we drop those who selected “don’t know/don’t want to answer” about their individual income (30,156 observations). As a result, we have 180,771 respondents in total. Before the large-scale survey started, a pre-survey was carried out to tune the questionnaires.

For the questions related to the purchasing intention of FAVs, respondents were asked the question: "Do you want to add a completely self-driving option that allows you to move around when you purchase a car in the future?". Then, the respondents answered the following questions: "(1) Purchase for sure, (2) Purchase under certain conditions, (3) Do not purchase, and (4) I don't know.". Given that FAVs are not yet fully introduced to the market in 2015 or 2021, we assume that people who show an affinity to FAVs can be potential consumers in the future. Therefore, we include those who answer (1) and (2) as a group of 'potential consumers' as they show affinity toward using FAVs. On the other hand, people who answer (3) and (4) are reluctant to purchase FAVs, and we did not consider them potential consumers. Therefore, we code WTB equal to 1 if a respondent belongs to a potential consumer group and code WTB as 0 if not. Therefore, our analysis would allow us to see what kinds of factors would shift consumers who belong to (3) and (4) to (1) and (2). We would like to note that we are making a clear distinction between “adding” a completely self-driving option and “purchasing” FAVs by asking "Do you want to add a completely self-driving option that allows you to move around when you purchase a car in the future?". Another note we would like to clarify is that we choose not to use the complete information from the survey; that is, we do not choose to treat survey answers of WTB as `ordinal’, rather we treat it as a categorical variable. For example, while it is possible to investigate the result of `ordinal’ responses of WTB by treating =1 a not purchasing, =2 if not sure, =3 as positively consider and =4 if s/he purchases, increase from 1 to 2 does not necessarily indicate the probability of s/he is purchasing F/AVs. Thus, we choose to analyze binary responses because we are interested in whether s/he is purchasing F/AVs.[4]

Next, we also asked WTP for FAVs. Respondents were asked to write down their WTPs freely regardless of the purchase decisions, ranging from 0 JPY to 3.25 Million JPY. We use a payment card method to measure WTP, and we provide detailed ranges of WTPs in Table 2. However, given that FAV is a newly introduced technology, people may not have a specific price range of WTP if we choose to leave WTP as an open question. In that sense, leaving WTP as an open question may increase the variances of responses for two reasons. First, because evaluating WTP is not a typical in-daily decision-making behavior, it may result in many nonresponses, and respondents would feel difficult to answer it with a concrete number without any examples given. Second, following the first reason, the number of outliers may increase, and the outliers may distort the representative values by abnormally large or small amounts. Third, the answers tend to be concentrated on round numbers (Ministry of Land, Transport, and Infrastructure[5]). Thus, we chose to use categorical but detailed WTP questions. We have respondents who chose a WTP of 0, indicating that they would choose to add it if it is free, and such an answer does not indicate that the respondents are not willing to purchase AVs.

Table 2. The Range, Frequency and Respondents' Proportion of the Willingness-to-Pay(WTP) in our Survey

Please write down your Willingness-to-Pay for adding Fully-automated option to your newly-purchased vehicle.

Group	Range (10,000 JPY)	Frequency	Proportion (%)
1	0	40,093	22.18

[4] Similarly, we choose not to investigate the multinomial responses of WTBs as we believe each response is independent; therefore, looking into how 'not purchasing' decision interacts with 'no awareness,' for example, would not fit our research.
[5] We refer to https://www.mlit.go.jp/kowan/beneki/images/kaigan_hiyoubeneki_06.pdf

2	1 ~ 5	34,666	19.18
3	6 ~ 10	27,456	15.19
4	11 ~ 15	11,331	6.27
5	16 ~ 20	14,987	8.29
6	21 ~ 25	4,067	2.25
7	26 ~ 30	18,511	10.24
8	31 ~ 35	2,346	1.30
9	36 ~ 40	1,179	0.65
10	41 ~ 45	569	0.31
11	46 ~ 50	9,524	5.27
12	51 ~ 60	1,549	0.86
13	61 ~ 70	399	0.22
14	71 ~ 80	1,868	1.03
15	81 ~ 90	1,261	0.70
16	91 ~ 100	5,610	3.10
17	101 ~ 150	1,441	0.80
18	151 ~ 200	1,053	0.58
19	201 ~ 250	479	0.26
20	251 ~ 300	465	0.26
21	300~	1,917	1.06

We also include the respondents' car ownership and car types in our model for two reasons. First, we would like to increase the survey's internal validity; therefore, we would like to control for individuals who do not know the price and maintenance costs for cars. Thus, we included the `car ownership' variable to control for those who do not own a car and are less likely to be aware of the car price. Second, along with car ownership, we also include car types (gasoline, diesel, hybrid, plug-in-hybrids (PHEV), fuel-cell vehicle (FCV), and electric vehicles (EV)), and car prices differ according to the car types.

Then, we ask the concerns on environments in the form of ‘importance as a policy’. Based on previous studies, we classified the topics for environmental policy into eight factors referring to the House of Councillors, The National Diet of Japan, (2015); We have 13 questions in total, and the topics are about the renewable energies, air pollution, environmental conservation, water pollution, endangered species conservation (biodiversity), reuse and recycling, waste disposal, and CO_2 emissions with questions such as, "How important is the policy to you? 'The scale of responses is as follows: (0) for no awareness/interest at all--therefore, the difference between those who answer (0) and others would be whether that person at least has an interest in a certain policy/issue, (1) for very insignificant; (2) for insignificant; (3) for neither important nor insignificant; (4) for important; (5) for very important. Next, we survey the technological merits and concerns regarding FAVs. Respondents are asked to check multiple options among 17 options for merit and 12 options for concerns.

Among all options and questions, we use factor analysis to choose the options that are used in the estimation. We discuss more on factor analysis and how we choose the important factors in Section 3.2. Specific lists of questions are listed in Table 4, which shows notations for each option and explanations of them. `Sources’ in Table 4 refers to the previous works we referred to when designing survey questions. The proportions of consumers choosing each option are listed in Appendix Table A.1. and A.2.

We also included sociodemographic variables: income, gender, age, and commuting time. Table 3 shows descriptive statistics. Overall, we had approximately 180,771 respondents. We divided the sample into three groups: the overall group (Panel (A)), those who would not purchase FAV, (as in Panel (B)), and those who would purchase FAV (as in Panel (C)). Although we do not see significant differences across the groups for the sociodemographic variables, annual income, WTP for FAV, and EV dummy show higher mean value for those who belong to Panel (C) than in Panel (A) and (B).

Table 3. Descriptive Statistics

Variable	Mean	Std.dv	Min	Max
Panel (A) Overall (N=180,771)				
WTP for FAV (10,000 JPY)	22.519	44.275	0	325
Annual Income (10,000 JPY)	485.383	411.226	100	3500
Household Size	2.864	1.362	1	10
Age	48.701	11.933	18	100
Female Dummy (=1 if female)	0.369	0.482	0	1
Married Dummy (=1 if married)	0.695	0.461	0	1
Car Ownership (=1 if own car)	0.823	0.381	0	1
Gasoline (=1 if car type is gasoline vehicle)	0.676	0.468	0	1
Diesel (=1 if car type is diesel vehicle)	0.023	0.150	0	1
Hybrid (=1 if car type is hybrid vehicle)	0.116	0.321	0	1
Plug-in Hybrid (=1 if car type is plug-in hybrid vehicles)	0.004	0.065	0	1
EV (=1 if car type is electric vehicles)	0.002	0.049	0	1
FCV (=1 if car type is fuel cell vehicles)	0.0005	0.022	0	1
Panel (B) People who won't choose autonomous vehicles (N=77,371)				
WTP for FAV (10,000 JPY)	19.449	46.026	0	325
Annual Income (10,000 JPY)	446.782	391.013	100	3500
Household Size	2.833	1.351	1	10
Age	48.833	11.980	18	100
Female Dummy (=1 if female)	0.415	0.493	0	1

Married Dummy (=1 if married)	0.685	0.465	0	1
Car Ownership (=1 if own car)	0.821	0.383	0	1
Gasoline (=1 if car type is gasoline vehicle)	0.693	0.461	0	1
Diesel (=1 if car type is diesel vehicle)	0.022	0.145	0	1
Hybrid (=1 if car type is hybrid vehicle)	0.101	0.301	0	1
Plug-in Hybrid (=1 if car type is	0.003	0.056	0	1

plug-in hybrid vehicles)				
EV (=1 if car type is electric vehicles)	0.002	0.045	0	1
FCV (=1 if car type is fuel cell vehicles)	0.0006	0.024	0	1
Panel (C) People who would choose autonomous vehicles (N=103,400)				
WTP for FAV (10,000 JPY)	24.817	42.775	0	325
Annual Income (10,000 JPY)	514.266	423.430	100	3500
Household Size	2.887	1.370	1	10
Age	48.602	11.897	18	100
Female Dummy (=1 if female)	0.334	0.472	0	1
Married Dummy (=1 if married)	0.702	0.457	0	1
Car Ownership (=1 if own car)	0.825	0.380	0	1
Gasoline (=1 if car type is gasoline vehicle)	0.664	0.472	0	1
Diesel (=1 if car type is diesel vehicle)	0.024	0.153	0	1
Hybrid (=1 if car type is hybrid vehicle)	0.128	0.334	0	1
Plug-in Hybrid (=1 if car type is plug-in hybrid vehicles)	0.005	0.072	0	1
EV (=1 if car type is electric vehicles)	0.003	0.052	0	1
FCV (=1 if car type is fuel cell vehicles)	0.0004	0.020	0	1

3.2. Empirical Strategy

We use structural equation modeling (SEM) to assess the relationship between factors that are correlated with the WTB and WTP of FAVs. We choose SEM, which is a suitable methodology that allows us to examine the psychometric factors that are correlated with people's intentions to F/AVs. SEM can handle a substantial number of endogenous and exogenous variables and can include latent variables in the model. Thus, SEM enables the inclusion of the theory of planned behavior (TPB), which explains people's behavior based on psychometric intentions through latent variables determined by attitudes (Ajzen 1991). Thanks to such benefits, SEM has been employed in many research fields incorporating psychometric modeling, such as psychology, sociology, educational research, political science, and market research. Several SEM applications in transportation research have been conducted in the past (examples of previous works including SEM as the main method include Tardiff, (1976), Fernandez-Heredia et al. (2014), Maldonado-Hinajeros et al. (2014), and Motoaki and Daziano (2015)). Our model explains the WTB and WTP of automated vehicles based on the four latents of nature, pollution, merit, and accidents and thus focuses on the psychometric intentions of the potential consumers, and SEM allows such analysis.

Moreover, SEM offers *simultaneous* estimations of latent variables and exogenous variables and allows for correlations between latents. If the latents and exogenous variables are estimated sequentially, for example, one can conduct factor analysis to construct the latents in the first step and proceed to the estimation of latents and exogenous variables to the choice modeling, while this strategy is simple, it does not guarantee unbiased estimators for the parameters involved and tends to underestimate standard errors (see, for example, Walker and Ben-Akiva, 2002, Morikawa et al., 2002). Furthermore, a sequential estimation does not allow for the interaction of latent variables. As we assume that latents are correlated and people's choice behavior is not `sequential,' we choose SEM in this study and use STATA to estimate our model (see Raveau et al., 2010 for a discussion of sequential versus simultaneous estimation).

3.2.1. Identifying Latent Constructs

We first identify the latent variables that can be related to WTB and WTP for FAV based on the process used by previous studies (e.g., Fernández-Heredia et al., 2016), as shown in Table 4. We choose four categories: fear (fear of FAV technology), merits (advantages and benefits of FAV technology), pollution (concerns about pollution), and nature (concerns about conserving natural environments) as the latent variables.

We conduct an extensive literature review and factor analysis to sufficiently validate our latent variable construction process. To do so, we focus on the merits of FAVs and focus on the disadvantages that FAVs would possibly bring. First, the latent variables and statements (questions) for each survey were based, whenever possible, on statements previously used and found to be effective in the literature. Second, we construct the latent variables according to our research hypothesis, exploratory factor analysis (EFA) and previous works. First, using EFA, we explored the latent variables that represent the respondents' awareness and attitudes toward issues related to FAV and the natural environment. From the EFA, we obtained four latent variables: Fear, Merits, Pollutions, and Nature. These latent variables were derived from the indicator variables shown in Table 4. Cronbach's alpha values of Merit, Fear, Pollution, and Nature are 0.559, 0.734, 0.953, and 0.914, respectively. Cronbach’s alpha is regarded as a measure of scale reliability, whose acceptable range is >0.6. Only Merit does not satisfy this condition, but its Cronbach’s alpha value is not too far from 0.6 (e.g., Okada et al. 2019). The correlation between indicator variables is shown in Tables A3-1 to A3-4 in the Appendix.

Next, based on the EFA results, we include the same indicator variables and construct the four latent variables in our SEM model. These latent variables are used as the exploratory variables for purchasing decisions and WTP for FAV. In addition, we include gender, individual income, age, and commute time as the control variables for purchasing decisions and WTP for FAV because these individual characteristics may affect purchasing intention and WTP as well as latent awareness and attitudes.

The first latent construct, fear, represents an individual's concerns toward possible accidents, malfunctions, or responsibility issues (i.e., who would be responsible when there is an accident) toward FAVs. Numerous works and experts argue that FAVs will eliminate human errors, therefore creating safer traffic environments. Nevertheless, many members of the public are concerned about potential problems. These concerns were also mentioned in previous works; Petrovic et al. (2020) mention that rear-end collisions are likely to occur more often in AVs. Ahmed et al. (2020) argue that the public is still concerned about possible crashes due to malfunctions of AVs and cybersecurity issues. Other works also point out that people are concerned with safety issues (Ha et al., 2020). Due to these concerns, we expect those who are wary of possible accidents to be less willing to purchase FAVs and AVs than those who do not fear. On the other hand, resolving such issues would then encourage them to purchase FAVs and AVs (Hilgarter and Granig, 2020).

The second latent construct, 'merit,' shows an individual's interests in advantages that AVs/FAVs would bring. It ranges from simple benefits that allow people without licenses or people without long-term experiences in driving to drive (Upahita et al., 2018) to enable drivers to multitask (Malokin et al., 2019), drive more comfortably (Yuen et al., 2020), and usefulness (Panagiotopoulos and Dimitrakopoulos, 2018, Choi and Ji, 2015).

The third and fourth latent variables are related to the environmental awareness of individuals. The third latent construct, `pollution', represents attitudes about reducing environmental pollution and promoting reusing and recycling materials. The fourth is 'nature', which shows individuals' awareness about conserving biodiversity and the natural environment. Studies in the field of transportation show that an individual with high pro-environmental awareness has a higher intention to buy FAV (Wu et al., 2019; Yuen et al; 2020.) Although most of the previous studies have only focused on overall pro-environmental attitudes, we categorize environmental awareness into pollution-related and conservation-related because each of them might have varied effects on attitudes toward AV. The contribution from AV to the environment is associated with pollution (particularly those related to air pollution) reduction by easing traffic jams rather than conservation of natural environments such as animals and forests. Thus, to promote AV effectively, it is important to know whether both types of awareness, AV-related (pollution) and non-AV-related (nature), affect WTP and WTB for AV.

Table 4. The List of Latent Variables.

Notation	Explanation	Source
	Fear (FE)	(Acheampong and Cugurullo 2019) (Benleulmi and Blecker 2017) (Choi and Ji 2015; Anania et al. 2018) (Petrović, et al., 2020) (Amed et al.,2020) (Ha et al., 2020) (Hilgarter and Granig 2021)
FE1	There is a possibility that children will be able to move on their own.	
FE2	There is a possibility that the software is hacked. (Cyber security)	
FE3	The malfunction may cause accidents.	
FE4	It is unclear who is responsible for the accident due to FAV technology.	
FE5	Traffic volume and congestion might increase as those without a license can drive.	
FE6	The malfunction may lead to wrong destinations.	
	Merits (MR)	(Choi and Ji 2015) (Malokin et al., 2019) (Yuen et al., 2020) (Panagiotopoulos and Dimitrakopoulos, 2018) (Upahita et al, 2018)
MR1	People can drive without a license.	
MR2	Burdens on driving would be decreased.	
MR3	Children can move without a guardian.	
MR4	Able to do other works while driving. (Multitask)	
MR5	Able to avoid responsibilities of traffic accidents.	

	Pollutants (EP)	(Brown, Gonder, and Repac 2014) (Muller and Usher, 2014) (Wang et al., 2017) (Martin 2019) (Chen et al. 2019)
EP1	Recycling is important.	
EP2	Cycle utilization rate: the percentage of the total amount of reusable and recycled materials to be injected into society, is important for preventing pollution.	
EP3	I think water quality should be improved.	
EP4	Alleviating Particulate Matter (PM) 2.5. pollution is critical for our society.	
EP5	Resolving air pollution (particularly, photochemical smog) is important.	
	Nature (EN)	(Nordhoff et al. 2018) (Wu et al., 2019) (Yuen et al., 2020) (Nordlund and Garvill 2003) (Şimşekoğlu et al., 2015)
EN1	Preserving endangered species is important.	
EN2	Preserving living animals (overall) is important.	
EN3	The ratio of green area within 1,500 meters around a house is important.	
EN4	Green purchasing: When purchasing goods and services, consider the environmental impact before purchasing.	

3.2.2. Structural Equation Modelling

Using the latent constructs, we have created SEM models as in Figure 2 and Figure 3. We have three models in total. First, we investigate factors that are correlated to WTB (Model 1) and WTP (Model 2). Second, we assume that a higher WTP would be positively correlated with a higher WTB; therefore, we add such a relationship to Model (1) (Model 3). Finally, we include Model 4, which assumes that all types of latents and other exogenous variables are correlated to both WTB and WTP. Our preferred main Model is Model (4), and we take Models (1) to (3) to confirm our findings in Model (4). Such diverse specifications from Models (1) to (3) allow us to confirm the robustness of the results. To make a better fit of the model, we assume that some of the error terms associated with indicator variables are correlated. Hypothesizing a correlation between these error terms can improve our model's ability to explain the data.

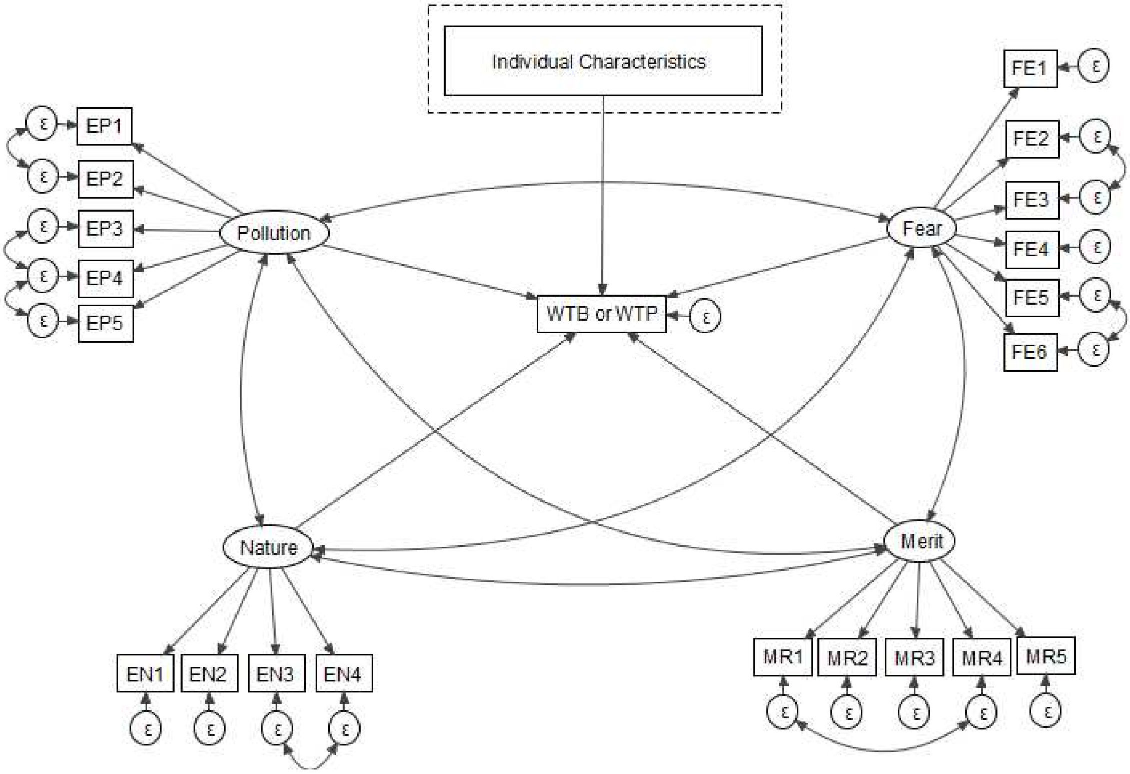

Figure 2: Conceptual Framework (1)

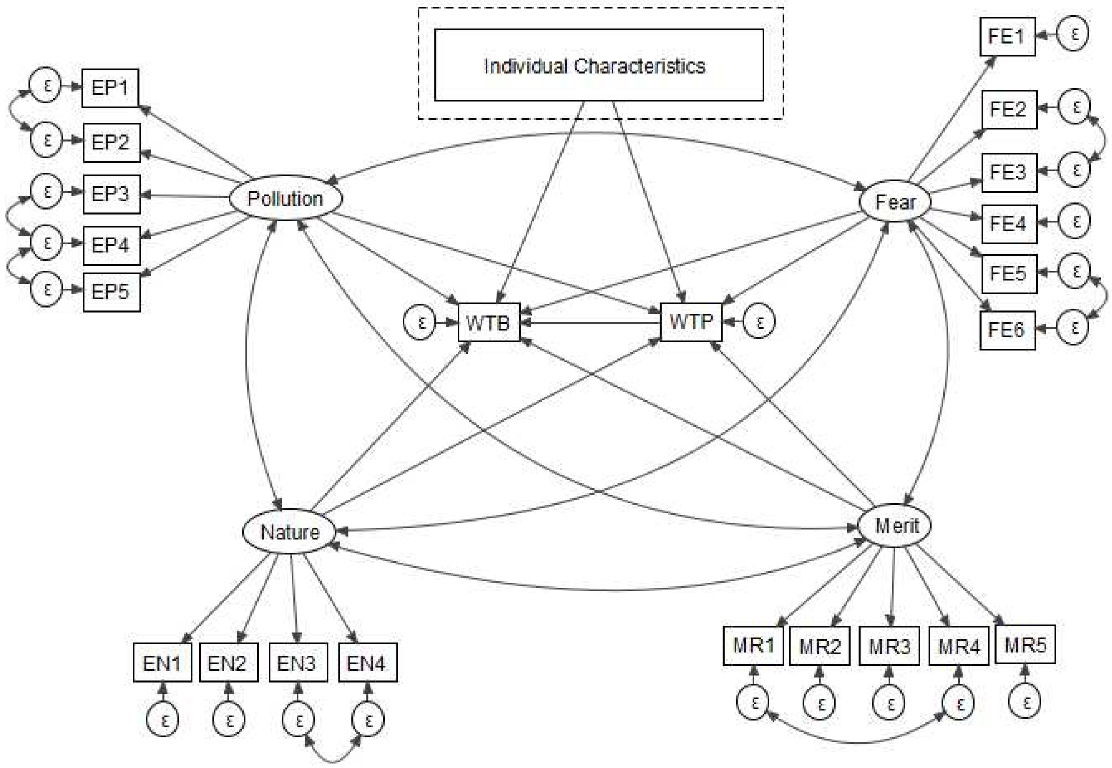

Figure 3: Conceptual Framework (2)

4. Result

The results of the structural equation are shown in Table 5. In Table 5, the upper column shows the estimation results of WTP, and the lower column shows the estimation results of WTB, of Models (1) to (4). Standardized coefficients are used to enable a comparison between the magnitudes of coefficients. This type of coefficient displays the change in a dependent variable when an explanatory variable increases by one standard deviation. Thus, standardized coefficients are frequently used in quantitative studies as the relative importance of explanatory variables within a model (e.g. You, 2017) While we have five models from Models (1) to (4), the estimated coefficients are similar across the models. Our models mainly show the WTB/WTP disparity in regard to environmental concerns. The results of the measurement equation are shown in Table A4 in the Appendix.

Notes for Interpretations. We would like to clarify that people can have different combinations of latents. For example, people can have high levels of both `Fear' and `Merit,' or lower levels of `Merit' and `Nature' and so on. Therefore, interpretations of our results should be made carefully. For example, it is concerns about accidents that are negatively correlated with WTP, and it does not indicate that a person with high levels of `Fear' does not appreciate benefits from FAVs. Appreciations to the benefits from FAVs would be expressed in the coefficients of `Merit'. Thus, it is possible to have both high levels of merit and fear. Our result shows the changes in WTB and WTP after one unit of standard deviation increases in a latent state, keeping other latents fixed.

WTB and WTP. Throughout Models (1) to (4), we find positive correlations between WTB and WTP of approximately 0.172, indicating the 'overall' trend that people with a high level of WTB are likely to have higher WTP and vice versa. Nevertheless, whether individuals' attitudes, expressed in latent factors, also show positive (or negative) trends in both WTB and WTP needs to be clarified. As mentioned in Section 2.3, if there is a disparity in WTB/WTP in the latents, then the changes in latents might divert the overall relationship between WTB and WTP. Furthermore, as people can have multiple latents, looking into how the individual latents are correlated would also implicate which aspects and how much people are attracted/not attracted to F/AVs. Implications from these results can also contribute to policies on motivating people to adopt F/AVs. In this study, we find such a trend in the latents that are related to environmental concerns.

Environmental Concerns. Although `Nature' and `Pollution' are positively correlated with WTB, `Nature' is negatively correlated with WTP, while 'pollution' is positively correlated with WTP. This result is interesting because it shows that environmental concerns can have different implications according to the types of concerns. Therefore, FAVs may be more attractive to people with higher levels of `Pollution' than those who have higher levels of `Nature'. We further discuss this result in Section 5.

Merits and Fear. As expected, Merit shows positive coefficients in both WTB (0.215 in Model 4) and WTP (0.172 in Model 4), while Fear presents negative coefficients in both WTB (-0.073 in Model 4) and WTP (-0.023 in Model 4). Such results are natural in the sense that people who appreciate the benefits of using FAVs would have higher WTB and WTP, and those who fear potential accidents would not be more likely to purchase FAVs and would not appreciate FAVs than those who do not fear FAVs.

Other Variables. Other socioeconomic variables, such as the income and `marry' dummy variables, show positive coefficients for both WTB and WTP, while household size, age, and gender show mixed conclusions, showing that factors affecting WTB and WTP are different according to socioeconomic group. Car ownership shows negative coefficients toward WTB and WTP, and this result implies that those who own and drive a car are unlikely to show high WTB and WTP compared to those who do not own a car. Taking gasoline cars as a baseline, hybrid car owners would show the highest WTB and WTP compared to other car types.

Model Fit. According to the goodness-of-fit indices shown at the bottom of Table, in general, the models fit the data modestly well. The acceptable range of RMSEA is < 0.08, and those of CFI, GFI, and AGFI are < 0.90 (Okada et al., 2019; Kumagai et al., 2020). In our model, the values of RMSEA, CFI, GFI, and AGFI are generally within or near each variable's acceptable range.

Table 6 shows the correlation among the predicted scores of the four latent variables. Pollution and Nature are strongly correlated, which implies that people who are concerned about a reduction in environmental pollution are also interested in conservation of the natural environment. Merit and Fear are also moderately correlated, meaning that people feeling merit from self-driving technology are also worried or scared about possible malfunction and the negative influence of FAV. Other combinations of latent variables are also correlated with each other, but the magnitudes are relatively smaller.

Table 5. Coefficient estimates of structural equation (N=180,771).

*** p<0.1, ** p<0.05, *** p<0.01.**

WTP	Model (1)	Model (2)	Model (3)	Model (4)
Latents				
Nature		-0.029***	-0.025***	-0.030***
		(0.004)	(0.004)	(0.004)
Pollution		0.086***	0.093***	0.086***
		(0.004)	(0.004)	(0.004)
Merit		0.148***	0.154***	0.152***
		(0.003)	(0.003)	(0.003)
Fear		-0.021***	-0.032***	-0.023***
		(0.003)	(0.003)	(0.003)
Socio-Economics				
ln(Income)		0.069***		0.069***
		(0.003)		(0.003)
Household Size		-0.011***		-0.011***
		(0.003)		(0.003)
ln(age)		0.026***		0.026***
		(0.003)		(0.003)
Female		-0.001		-0.0008
		(0.003)		(0.003)
Marry		0.022***		0.022***
		(0.003)		(0.003)
Car-Related				
Car Ownership		-0.010***		-0.010***
		(0.025)		(0.002)
FCV		0.008***		0.008***

		(0.002)		(0.002)
Diesel		0.011***		0.011***
		(0.002)		(0.002)
Hybrid		0.045***		0.045***
		(0.002)		(0.002)
Plug-in Hybrid		0.024***		0.024***
		(0.002)		(0.002)
EV		0.016***		0.016***
		(0.002)		(0.002)
Constant		0.550***	1.435***	0.550***
		(0.045)	(0.003)	(0.045)
WTB				
WTP			0.172***	0.172***
			(0.002)	(0.002)
Latents				
Nature	0.072***		0.077***	0.077***
	(0.004)		(0.004)	(0.004)
Pollution	0.048***		0.034***	0.033***
	(0.004)		(0.004)	(0.004)
Merit	0.240***		0.216***	0.215***
	(0.003)		(0.003)	(0.003)
Fear	-0.076***		-0.074***	-0.073***
	(0.003)		(0.003)	(0.003)
Socio-Economics				
ln(Income)	0.076***		0.063***	0.064***
	(0.003)		(0.003)	(0.003)
Household Size	0.006**		0.008***	0.008***
	(0.003)		(0.003)	(0.003)
ln(age)	-0.067***		-0.072***	-0.071***

	(0.003)		(0.003)	(0.003)
Female	-0.049***		-0.049***	-0.049***
	(0.003)		(0.003)	(0.003)
Marry	0.013***		0.009***	0.009***
	(0.003)		(0.003)	(0.003)
Car-Related				
Car Ownership	-0.008***		-0.007***	-0.007***
	(0.002)		(0.002)	(0.002)
FCV	-0.006***		-0.007***	-0.007***
	(0.002)		(0.002)	(0.002)
Diesel	0.007***		0.005**	0.005**
	(0.002)		(0.002)	(0.002)
Hybrid	0.035***		0.027***	0.028***
	(0.002)		(0.002)	(0.002)
Plug-in Hybrid	0.011***		0.007***	0.007***
	(0.002)		(0.002)	(0.002)
EV	0.006***		0.003	0.004
	(0.002)		(0.002)	(0.002)
Constant	1.618***		1.537***	1.524***
	(0.044)		(0.043)	(0.043)
RMSEA	0.069	0.069	0.067	0.067
AIC	6.011e+06	6.414e+06	6.656e+06	6.654e+06
CFI	0.843	0.842	0.842	0.843
GFI	0.842	0.842	0.842	0.843
AGFI	0.802	0.802	0.802	0.810

Table 6. Correlation matrix among the predicted scores of latent variables.

	Pollution	Nature	Merit	Fear
Pollution	1			
Nature	0.7990	1		
Merit	0.2245	0.1823	1	
Fear	0.3413	0.2122	0.4514	1

5. Discussion

In this section, we provide implications for our results in Section 4, referring to previous works. We first provide a discussion of our results in Section 5.1 and policy implications for adopting FAVs in Section 5.2.

5.1. Overall Discussion

FAV technology is a newly introduced technology that needs broader public acceptance. Thus, it would face approval and disapproval from the public. People can respond to such technology by considering purchasing it as consumers (in the form of WTB) or show higher monetary appreciation (in the form of WTP). If factors correlated with WTB are not linked or offer different implications to WTP, then WTB and WTP on FAVs should be separately examined. To this end, this study validates it using structural equation models. Our findings allow us to answer the questions suggested in Section 1:

Our results indicate that environmental awareness, advantages of using FAVs, fears of potential accidents, and socioeconomic factors are correlated with the WTB and WTP of FAVs **(Research Question 1)**. We find a form of WTA-WTP disparity. Those who are highly interested in natural environment conservation may purchase FAVs but would show lower

WTP. On the other hand, those who are interested in pollution alleviations show high WTB and WTP **(Research Questions 2 and 3).**

Then why does WTB-WTP disparity occur? One may think it is natural to have higher WTP if a person has higher WTB and vice versa. However, previous works in marketing, finance and economics state that WTB is positively correlated with social externalities (Waterfield et al. 2020), particularly for environmentally conscious consumers. This is because they perceive their social roles in which they are acting (Loureiro and Lotade 2005). These people are usually interested in resolving overall social problems (Bamberg and Moser, 2007; Thogerson, 2006; Werff and Steg, 2015; Bergquist, 2019). Particularly in the field of transportation, environmentally cautious consumers would be early adopters of new technologies (such as autonomous vehicles and battery electric vehicles) that may improve society even if the new technology is not yet mature (Cherchi 2017; Dimatulac and Maoh 2016; Kumar and Alok 2020). Those who perceive themselves as environmentally conscious, therefore, may choose to purchase if they regard FAV technology as beneficial for the overall society by reducing emissions and congestion and providing convenient services. Thus, those who are interested in natural environment conservation may show higher WTB.

What kinds of factors are correlated with higher WTP? Previous works (Uchida et al., 2014; Keith and Khanna, 2012; Teisl et al., 2002; Cunningham et al., 2019) answer this question by showing that WTP is more closely correlated to `private (or financial) benefits' rather than `social benefits.' In other words, consumers may not show higher WTP if the benefits from FAVs are not directly correlated to their private interest regardless of the benefits that society would receive. In sum, WTB is positively correlated with the advantages that society overall acquires, and this relationship may be powerful to those who are environmentally cautious. On the other hand, WTP is correlated to the direct and private benefits that the individual would receive, as mentioned above.

In that sense, we can explain our results as follows: (i) Those who are highly interested in preserving the natural environment may not appreciate FAVs; they would show lower WTP. This is because FAVs do not have direct advantages that contribute to preserving the natural environment. For example, increasing the market share of FAVs would not conserve biodiversity or increase the size of green parks. Meanwhile, those interested in conserving the natural environment are interested in overall social issues and believe adopting FAVs would better society; these people would purchase FAVs and therefore would show higher WTB. (ii) Those who fear FAVs are fearful of the accidents; they would be reluctant to purchase them, and such concern would be negatively correlated with WTPs.

By recognizing the form of WTB-WTP disparity, our result suggests that governments and industries may take an additional look at consumers with such disparities. Doing so could continue to expand the market share of FAVs in the future.

5.2. Implications on Future Adoptions of Autonomous Vehicles

FAVs would provide numerous social benefits. To realize those benefits and to accelerate FAVs' market introduction, it would be necessary to increase consumer acceptance and evaluation. In that sense, our results suggest important implications for future adoptions of FAVs. First, people are still wary of potential accidents and malfunctions. Technological innovations can alleviate these concerns, and by doing so, WTB can increase. Next, for environmentally conscious consumers, conducting further assessments and appealing to the potential benefits of reducing energy use and pollution increase their WTP toward FAVs. Our results show that the correlation between the latent constructs "nature" and "pollution" is highly correlated (79.90%), which implies that people interested in alleviating pollution are also interested in natural environment conservation. Increasing WTP by appealing to the potential benefits of reducing energy use and pollution to people who belong to "pollution" would positively correlate with the overall rise of WTP of environmentally conscious consumers.[6]

One concern from previous works and industry reports was that FAVs might increase the total vehicle miles traveled (VMT), as it allows many people to travel freely (Center for American Progress, 2016). The impact of FAVs on energy use and emissions would largely depend on their effect on the total VMT and their fuel efficiency and fossil fuel consumption. For example, Stephens et al. (2016) estimate that with the largest total vehicle traveled increase and the smallest efficiency increase could result in as much as a 205 percent increase in US transportation energy use. On the other hand, the FAVs would have the smallest increase in total VMT with the largest efficiency increase, and FAVs can result in a 58 percent drop in energy use. Another way to reduce emissions and energy usage is to promote shared FAVs, which can add up to 10% more travel distances than conventional vehicles would with the same energy consumption (Fagnant and Kockelman, 2014). Adopting electric FAVs and managing road infrastructures can also reduce emissions and energy usages.

6. Conclusion

We investigate the WTP and WTB of FAVs and find that a higher WTP toward FAVs is not necessarily correlated with higher WTBs, and vice versa. For those who are environmentally conscious, WTB would be high mainly because they believe FAVs can resolve social problems such as air pollution and congestion. On the other hand, these people

[6] Of course, another way to increase WTP is to promote that FAVs can also 'directly' contribute to natural environment conservation, which needs a careful approach. In the long-term, the proliferations of FAVs may reduce travel distances and fuel usages through reducing congestions, therefore green parks might increase in the future. However, as such benefits are not yet well-examined until now, we decided not to include in our main policy implications.

would not have higher WTPs as if they regard FAVs as not granting direct benefits; those who prioritize natural environment conservation would not consider FAVs to increase, for example, biodiversity. Therefore, these people would not appreciate FAVs. Those who are afraid of possible accidents would not purchase FAVs and would present lower WTPs. Using SEM, our model suggests that factors affecting WTB and WTP are nonidentical.

Our study has several limitations and avenues for future research. First, our research adopts SEM, which contains a possible concern of reverse causality. For example, a person who wishes to purchase FAVs from the beginning might overestimate the merits of FAVs and underestimate the risks of accidents. Such reverse causality might be addressed by using the instrumental variable (IV) approach. For example, IVs that control the traits of early adopters or those with fixed demands can be employed. Unfortunately, we do not have such variables that can differentiate them.

Another interesting future study is to employ discrete-choice methods. This study is interested in investigating the correlations of psychometric factors (which were expressed in latent variables) to WTB and WTP of F/AVs; thus, we chose SEM. This study does not substantially discuss vehicle attributes such as fuel economy, weights, and sizes. Nonetheless, consumers may have some trade-off between vehicle attributes and automation functions. Applying discrete choice methods may capture trade-offs between different vehicle options, but it would require a completely different type of survey. For example, while this study investigates people's WTB and WTP on 'adding' FAV options rather than purchasing an entirely new vehicle, discrete choice mostly requires buying data and information on the vehicle attribute. Most importantly, the discrete-choice model would require automobile price, and our survey does not have price information, as we are not asking whether s/he is purchasing a new vehicle. Thus, conducting discrete-choice is left for future research.

Appendix

Table A1 shows the proportion of respondents' evaluations of benefits and concerns regarding FAVs. We calculate the proportion as follows: The number of people who choose the option/sample size (N=180,771).

Table A1. Evaluations of Benefits (Latent construct: Merit) and Concern (Latent: Fear).

Latent Category 1: "Merit"	Evaluation (%)
People can drive without a license.	28.78%
Burdens on driving would be decreased.	66.27%
Children can move without a guardian.	6.32%
Able to do other work while driving. (Multitask)	45.12%
Able to avoid responsibilities of traffic accidents.	32.89%
Latent Category 2: "Fear"	
There is a possibility that children will be able to move on their own.	63.25%
There is a possibility that the software is hacked. (Cyber security)	65.13%
The malfunction may cause accidents.	80.23%
It is unclear who is responsible for the accident due to FAV technology.	76.63%
Traffic volume and congestion might increase as those without a license can drive.	52.98%
The malfunction may lead to wrong destinations.	51.2%

Table A2 shows the proportion of respondents' evaluations on environmental awareness.

Table A2. Environmental Awareness of Respondents.

Latent Category 3: "Pollution"	No Awareness	Very Important	Somewhat Important	Neither	Not very Important	Not at all impotant
Recycling is important.	13.06%	1.61%	2.99%	24.61%	42.74%	14.98%
Cycle utilization rate: the percentage of the total amount of reusable and recycled materials to be injected into society, is important for preventing pollution.	13.50%	1.83%	3.49%	27.30%	41.40%	12.48%
I think water quality should be improved.	14.05%	1.43%	2.98%	26.05%	40.55%	14.93%
Alleviating Particulate Matter (PM) 2.5. pollution is critical for our society.	13.16%	1.27%	2.81%	22.78%	40.26%	19.72%

Resolving air pollution (particularly, photochemical smog) is important.	13.43%	1.28%	2.80%	23.87%	40.49%	18.14%
Latent Category 4: "Nature"						
Preserving endangered species is important.	17.12%	3.02%	6.56%	37.55%	27.58%	8.17%
Preserving living animals (overall) is important.	16.22%	3.87%	9.64%	41.24%	23.05%	5.98%
The ratio of green area within 1,500 meters around a house is important.	15.09%	2.41%	6.09%	35.36%	32.96%	8.09%
Green purchasing: When purchasing goods and services, consider the environmental impact before purchasing.	15.40%	2.66%	5.60%	38.95%	29.51%	7.89%

Table A3-1 to A3-4 show the correlation matrix of indicator variables of latent constructs.

Table A3-1. Correlation Matrix of Indicator Variables of "Pollution".

	EP1	EP2	EP3	EP4	EP5
EP1	1				
EP2	0.862	1			
EP3	0.7957	0.8184	1		
EP4	0.7479	0.7503	0.8086	1	
EP5	0.7531	0.7588	0.816	0.9035	1

Table A3-2. Correlation Matrix of Indicator Variables of "Nature".

	EN1	EN2	EN3	EN4
EN1	1			
EN2	0.8205	1		
EN3	0.7408	0.7357	1	
EN4	0.6831	0.6766	0.6993	1

Table A3-3. Correlation Matrix of Indicator Variables of "Merit".

	MR1	MR2	MR3	MR4	MR5
MR1	1				
MR2	0.2352	1			
MR3	0.2954	0.1403	1		
MR4	0.0942	0.2794	0.131	1	
MR5	0.3296	0.26	0.2284	0.1658	1

Table A3-4. Correlation Matrix of Indicator Variables of "Fear".

	FE1	FE2	FE3	FE4	FE5	FE6
FE1	1					
FE2	0.3162	1				
FE3	0.2317	0.3865	1			
FE4	0.2362	0.3407	0.4249	1		
FE5	0.2944	0.3187	0.2771	0.3238	1	
FE6	0.229	0.3531	0.3407	0.3257	0.3391	1

Table A4 shows the results of the measurement equation, which describes the effects of latent constructs on each of indicator variables. Standardized coefficients are shown and all coefficients are positive and statistically significant at 0.001%. The value of coefficients are almost unchanged across three specifications.

Table A4. Coefficient estimates of measurement equation (n = 180,771)

Latent variables	(1)	(2)	(3)	(4)
Pollution				
EP1	0.855	0.856	0.856	0.856

EP2	0.872	0.873	0.873	0.873
EP3	0.934	0.934	0.934	0.934
EP4	0.867	0.867	0.867	0.867
EP5	0.874	0.874	0.874	0.874
Nature				
EG1	0.910	0.910	0.910	0.910
EG2	0.902	0.902	0.902	0.902
EG3	0.816	0.815	0.816	0.816
EG4	0.751	0.751	0.751	0.751
Merit				
BD1	0.590	0.600	0.583	0.583
BD2	0.483	0.476	0.491	0.490
BD3	0.403	0.407	0.401	0.400
BD4	0.433	0.428	0.437	0.437
BD5	0.513	0.512	0.512	0.512
Fear				
AC1	0.443	0.444	0.443	0.443
AC2	0.618	0.619	0.618	0.618
AC3	0.623	0.623	0.622	0.623
AC4	0.607	0.607	0.607	0.607
AC5	0.513	0.513	0.513	0.513
AC6	0.546	0.546	0.546	0.546

Note: All coefficients are significant at $p < 0.001$.

Table A.5 shows a distribution of the socio-economic variables of our sample and government statistics.

Table A.5. Socio-economic Distribution of the Respondents and Japanese Population

		Sample (%) (n =246,642)	Government Statistics (%)[a]
Gender	Female	41.0	51.3
	Male	59.0	48.7
Education level	Junior high school or less	2.1	9.5
	High school	26.9	42.3
	Some college	22.6	15.6
	Bachelor / Master / Doctor	45.9	23.9
	Other	1.9	8.6
Age	18–19	0.2	2.3
	20–29	5.4	11.7
	30–39	18.1	13.3
	40–49	31.9	17.2
	50–64	25.8	22.1
	Over 65	10.7	33.4
Household income	< 2 million JPY	7.8	18.3
	2–3 million JPY	8.9	17.2
	3–4 million JPY	11.9	15.3
	4–5 million JPY	12.3	12.2
	5–6 million JPY	11.9	9.0
	6–7 million JPY	9.6	6.9
	7–8 million JPY	9.1	5.8
	8–9 million JPY	6.9	4.1
	9–10 million JPY	6.7	3.4
	10–15 million JPY	10.5	6.0
	15–20 million JPY	2.7	1.1
	≥ 20 million JPY	1.7	0.7
	Don't know / don't want to answer	-	–
Region	Hokkaido	4.6	4.2
	Tohoku	5.9	6.9
	Kanto	38.2	34.4
	Chubu	16.6	16.8
	Kinki	20.1	17.7
	Chugoku	5.1	5.8
	Shikoku	2.5	2.9
	Kyushu/Okinawa	7.1	11.3
Household size	1	15.6	34.5
	2	30.1	27.9
	3	23.6	17.6
	4 and above	30.1	20.0

[a] Sources: MIC (2013, 2015, 2017, 2019a, 2019b).

Acknowledgement

The author would like to acknowledge the financial supports from Specially Promoted Research through a Grant-in-Aid (20H00648) from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Environment Research and

Technology Development Fund (JPMEERF20201001) from the Japanese Ministry of the Environment.

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