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Application of the extended value-belief-norm (VBN) theory to understand consumers' intention to use autonomous delivery vehicles (ADVs)

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A R T I C L E I N F O

A B S T R A C T

Emissions from transportation fuel vehicles are polluting the environment more than ever before. Currently, autonomous delivery vehicles (ADVs) are welcomed by logistics service providers and lots of consumers in general for their significant contribution in reducing environmental pollution and increasing delivery efficiency. However, there is a lack of in-depth research on consumers' willingness to adopt ADVs, despite the fact that ADVs are innovative delivery method in the field of last-mile delivery. The purpose of the study is to expand the existing knowledge of consumers' adoption behaviors by developing and testing the extended Value-Belief-Norm (VBN) theory in autonomous delivery literature. In particular, the study adds subjective norms and COVID-19 risk into the original VBN model as a theoretical framework to gain a comprehensive understanding of the consumer decision-making processes with respect to their intentions to use ADVs. Structural equation modeling is conducted using data from a web-based survey of 561 consumers through an online sample platform. The results of the study demonstrated that both subjective norms and COVID-19 risk are all related with consumers' intention to use ADVs. The casual chain hypotheses of the extend VBN theory mentioned in our study are all supported. The results of the study make significant theoretical and managerial contributions to the field of last-mile delivery and the adoption behaviors of emerging technologies.

1. Introduction

Environmental problems such as carbon dioxide emissions and air pollution caused by the large amount of emissions from traditional fuel vehicles for last-mile delivery have greatly increased more than before [1–5]. To alleviate these problems, innovative transportation and delivery technologies such as autonomous delivery tools have been developed and promoted [6–8]. The autonomous delivery vehicles (ADVs), as an innovative delivery solution, can be effective in generating remarkable environmental and social

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benefits, such as improving roadway efficiency and safety, reducing energy consumption and tailpipe emissions, and relieving the pressure of the last-mile delivery problems [9]. However, to date, few studies have explored what factors influence consumers' behavioral intention to use ADVs.

At the scale level, autonomous delivery services have gained an significant position in building modern express services and developing community e-commerce. According to McKinsey's prediction in 2017 that 80% of package deliveries will be delivered automatically in the next ten years [10,11]. According to the report "Identity and Road Safety of Autonomous Delivery Vehicles" jointly published by China Electric Vehicle Association and Meituan, the market space for autonomous delivery can reach 750 billion yuan based on the stock market [12]. With the further expansion of the takeout, new retail, and the last-mile delivery markets, the autonomous delivery market is expected to reach the trillion-dollar level by 2030.

On June 20, 2022, the Autonomous Delivery Joint Innovation Center (hereinafter referred to as the Innovation Center), led by the China Electric Vehicle Association, was established. The members of the Innovation Center include 18 enterprises, including Alibaba Dharma Academy, Baidu, Huawei, JD X Division, Meituan autonomous delivery, etc., which will work together to promote the solution of testing standards, access certification systems, and traffic management systems, etc., for autonomous delivery scenarios, and promote the standardized and orderly development of the autonomous delivery industry [12].

In the relevant policies jointly issued by the Ministry of Transportation and other departments, it is mentioned to promote the development of autonomous delivery vehicles (drones), which shows the central government 's support for its potential market and confidence in autonomous delivery. In January 2022, the "14th Five-Year Plan" for the construction of urban and rural community service systems was issued, which explicitly proposes to promote the development of autonomous delivery into the community and the construction of supporting facilities for couriers, which provides policy support for more cities to build autonomous delivery demonstration areas [13]. In February 2022, Shenzhen urban transportation planning clearly put to promote the establishment of infrastructure specification system suitable for autonomous delivery.

Delivery costs remain a persistent problem in the e-commerce and express delivery industries [1,12,14]. This situation is further exacerbated by labor shortages compared to the pre-epidemic period. Manpower delivery is also affected by weather and other factors, making it difficult to achieve 7/24-h services, and packages are easily lost when delivery personnel pick up or deliver items [15]. Some users have questioned home delivery services due to privacy issues [4]. Various factors such as the impact of the epidemics on some closed areas and the fact that couriers are not allowed to enter limit the efficiency of last-mile delivery [2,9]. Unmanned delivery is a better solution as it avoids the above problems and improves the user experience [8]. As the costs of technologies costs such as LiDAR and AI chips decreases, mass production solutions mature, the costs of autonomous delivery will be significantly reduced.

On December 27, 2021, China's first driverless logistics vehicle "Pioneer" was tested at the internal site of ZTO Express for post parking, crosswalk courtesy and avoiding obstacles. It is reported that this vehicle is China's first driverless logistics vehicle, completely free of staffs and safety officers, and equipped with Huawei MDC intelligent driving computing platform, with a speed of more than 70 km per hour, and can achieve the goal of more than 3000 parcels per day delivery. The vehicle carries 20 kWh of power and has a range of up to 240 km.

As an emerging smart product, ADVs are receiving a lot of attention from different city administrators. Some governments and regions offer incentives for the production and scale of ADVs. However, in the current context, autonomous delivery cars still face challenges in terms of technology, business models, standards, policies, and infrastructure development. These factors contribute to the lack of awareness and acceptance of ADVs among users, which in turn leads to the continued use of traditional pickup methods. This study addresses the shortcomings of previous research by exploring consumers' willingness to accept ADVs from recipient's perspective.

The remaining sections of this paper are as follows. Section 2 introduces the literature review and theoretical hypothesis. Section 3 reviews the research methodology. Then the analysis results are presented in section 4. Section 5 puts forward conclusions and contributions, and the limitation and future research direction of this paper are provided.

2. Literature review

2.1. Value-belief-norm (VBN) theory

The value-belief-norm (VBN) theory was established by Ref. [16] on the basis of Norm Activation Theory (NAM) by integrating values theory and New Environmental Paradigm theory. The VBN theory emphasized negative consequences and ascription of responsibility, and intervenes in the psychological motivation of individuals through a series of moral and emotional mediators, thus promoting individual environmental behaviors [16–18]. The modeling framework can be divided into three dimensions: values, beliefs, and personnel norms. These three dimensions can be explained through values orientation, New Environmental Paradigm (NEP), awareness of consequences (AC), ascription of responsibility (AR), and personnel norms (PN). The effect of the variables are transmitted in the forms of chains, forming an interrelated logical causal chain [19–22].

Values are usually divided into three categories. (1). Egoistic values: Based on self-interest values, social actors give priority to the maximization of personal interests, especially economic interests, and individuals are typically characterized as "economic beings". (2). Altruistic values: Individuals tend to focus on the interests of other human groups and strive to maximize the interests of the community when they adopt certain behaviors, but altruistic values tend to ignore the interests of non-human species. (3). Biosphere values: These values refer to the need for individuals to consider not only the interests of the human group, but also the interests of non-human species when engaging in certain behaviors. These three values can promote individuals to pay attention to environmental issues or implement pro-environmental behaviors [20].

Values are important factors in predicting and explaining pre-environmental behaviors [20,21,23,24]. Sometimes, based on certain values, individuals may be willing to make temporary sacrifices for long-term benefits [18,20,25]. Numerous studies have shown that altruistic and biosphere values are positively correlated with pro-environmental behavior, while egoistic values produce the opposite results [26,27]. Compared with altruistic values, biosphere values, which are mainly concerned non-human interests such as the environment and ecology, have a stronger impact on consumers' pro-environmental behaviors [18]. Meanwhile, related studies have also found that those with biosphere values have a deeper understanding of the overall ecological environment and are more willing to adopt green or pro-environmental behaviors [17,19,28,29]. In addition [18], confirmed that the biosphere values can guide attitudes and behaviors of consumers, and that ADVs have tremendous environmental and ecological benefits over traditional delivery methods, such as low emissions and low energy consumption and can be considered as environmental-friendly services for consumers. Therefore, based on previous studies, this study focused only on the effect of biosphere values on consumer adoption of ADVs.

The VBN theory has been widely validated in explaining pro-environmental behaviors [16–18,29]. For example, in studies of willingness to accept energy policies [30], intention to stay in green hotels [18], willingness to classify garbage [27], and willingness to engage in agricultural tourism behaviors [29], the VBN theory revealed a chain-like relationship between the variables of value orientation, awareness of consequence (AC), ascription of responsibility (AR), and personnel norms (PN), which is consistent with the results predicted by the original VBN theory [27,29,30].

In our study, ADVs offer significant advantages in terms of carbon emissions, energy savings, environmental friendliness, and higher efficiency compared to traditional delivery methods (trucks). Especially during pandemics, ADVs have won the favor of some consumers as a contactless delivery method that makes the last-mile delivery safer [6]. Therefore, in this study, we consider ADVs as an environmentally friendly services and apply the VBN model to explore consumers' willingness to adopt this emerging technology.

2.2. Extended VBN theory

Several studies have shown that the VBN theory can be appropriately adapted to enhance predictive and explanatory power [18, 29]. Therefore, the study designed subjective norms and COVID-19 risk variables to better reveal consumer's intention to use ADVs.

Subjective norms refer to the social pressure perceived by reference groups (e.g., family, friends, or relatives) when deciding to implement certain behaviors [31–33]. When an individual's behaviors are endorsed by the group of people involved, it enhances to implement those particular behaviors [33,34]. For example, people live in a society surrounded by others, which makes them more susceptible to certain social influences [35]. [36] found that subjective norms positively affected consumers' intention to use autonomous vehicles (AVs). Furthermore [7], found a positive correlation between social influence and consumer adoption of ADVs. As an innovative delivery service, the delivery services provided by ADVs are prone to attract consumers' attention with innovative and fresh ideas. Meanwhile, according to the innovation diffusion theory, consumers who are slower to enter the market are easily influenced by their friends or family members to implement ADVs adoption behaviors [7,37]. Although the VBN theory does not incorporate subjective norms into the model, there is growing evidence that a strong sense of community directly influences consumers' purchasing or adoption behaviors of environmental products or services [18,38]. Therefore, the study hypothesized that subjective norms are positively related to consumers' intention to use ADVs.

When consumers are exposed to the pandemic, they perceive the likelihood of infecting with COVID-19 and its associated consequences including physical and psychological behavioral change to be high. For example, scholars have studied the impact of risk perception on consumer adoption behavior from different perspectives [2,9,39]. During the COVID-19 epidemic, some consumers who often shopped offline switched to online shopping to minimize person-to-person contact [40,41]. The last-mile delivery process poses various risks to both consumers and carriers, such as contact risk, package delivery failure due to theft, damage, or other errors. Since ADVs is completely contactless, it reduces the perceived risk to the consumer. Consumers are more likely to use ADVs than traditional delivery methods [40]. states that the use of ADVs reduces the likelihood of consumers contracting viruses and reduces the associated health or mental consequences that people face. Additionally, a study by Ref. [39] suggests that when individuals are at higher risk, they have more positive attitudes and intentions toward new emerging technologies. A study of [42] reveals that consumers are more inclined to adopt alternative delivery solutions when they perceive higher risk. Therefore, we hypothesize that COVID-19 risk affects consumers' intention to adopt ADVs.

Based on previous studies, it is evident that consumers' decision-making may include their willingness to engage in green behaviors, which may affect their decision to select an environmental and efficient delivery solution. Thus, in this study, in addition to consumers' personal norms, subjective norm and COVID-19 risk also influence consumer's intention to use ADVs.

2.3. Intention to use ADVs

Behavioral intentions are considered the best way to predict and explain individual behavior [31,43]. For many logistics service providers (LSPs), it is particularly important to increase consumers' willingness to use the delivery services provided by ADVs, so it is crucial to examine consumers' decision-making processes with respect to use ADVs. Nowadays, people are aware that their behaviors directly or indirectly affect the ecological environment [18], and in our study, the intention to use ADVs due to their environmental attributes can be regarded as pro-environmental behaviors [16]. Lots of consumers are likely to accept and adopt environmentally-friendly services or behaviors over other alternatives. Therefore, it is important to understand what factors influence consumer's intention to adopt ADVs.

2.4. Hypotheses

Based on the excessive research mentioned above, the study presents the theoretical model shown in Fig. 1. Table 1 lists each scale measure in the extended VBN theory. The study assumes that each variable in the causal chain is directly related to the next variable and possibly to variables downstream in the causal chain. The assumption are as follows.

H1. Biosphere value has a positive effect on awareness of consequences (AC).

H2. Awareness of consequences (AC) has a positive effect on the ascription of responsibility (AR).

H3. Ascription of responsibility (AR) has a positive effect on the personal norm (PN).

H4. Personal norm (PN) has a positive effect on the intention to use ADVs.

H5. Subjective norm (SN) has a positive effect on the intention to use ADVs.

H6. COVID-19 has a positive effect on the intention to use ADVs.

3. Methodology

3.1. Survey design

Quantitative questionnaire method and the convenience sampling technique were used for data collection. Everyone involved in the survey received informed consent and no personal data, such as name, email ID, and other private information were recorded. The survey data analyzed in the study come from the professional online survey platform (https://www.wjx.cn/), which was a professional survey company with a large sample database covering all age groups in China. Those who have completed the questionnaire will receive extra reward bonus. The survey is divided into three parts. Firstly, in order for respondents to better understand ADVs, the questionnaire begins with a brief introduction of ADVs' attributes and functions in words and figures. In the second part, the demographic profiles of the respondents, i.e., gender, age, education level, occupation, monthly income, usage experience were presented. In the third section, the participants were asked to fill in the scales of each construct. All measurements were taken from previous literature to ensure content validity. For example, biospheric values (BV) and awareness of Consequences (AC) referred from Refs. [27,30]. ascription of responsibility (AR) was adopted from Refs. [27,44]. Subjective norms come from Refs. [18,39], personnel norms adopted the basic concept from Ref. [44]; Perceived risk was taken from Ref. [7]; Behavioral intention was adapted from Refs. [7,45]. Measurement scales are detailed in Table 1. All constructs were measured on a Seven-Point Likert Scale ranging from 1(totally disagree) to 7(totally agree).

Sample collection started in November 2022 and ended in December 2022, and finally we received 615 responses, after deleting importer responses and then 561 samples are valid with an efficiency rate of 91.22%. The demographic characteristics of the respondents can be summarized in Table 2. 50.01% of the respondents in the survey were male, 94.92% were aged between 19 and 45 years old, and 87.88% of the participants had a bachelor's degree or higher. Monthly personal income was between 1000 and 3000 RMB (36.36%).

3.2. Structural equation modeling

Structural equation modelling (SEM) is a statistical method to analyze the relationship among latent variables from observed indicators, and it is an important tool for multivariate data analysis [46,47]. Prior studies have used this method to analyze consumer various environmentally-friendly behaviors [7,22,48,49]. Since ADVs have not been widely put on the market, many functions and attributes of ADVs have not been recognized by potential consumers directly, then the SEM is appropriate to reveal the relationship between antecedent variables and the outcome.
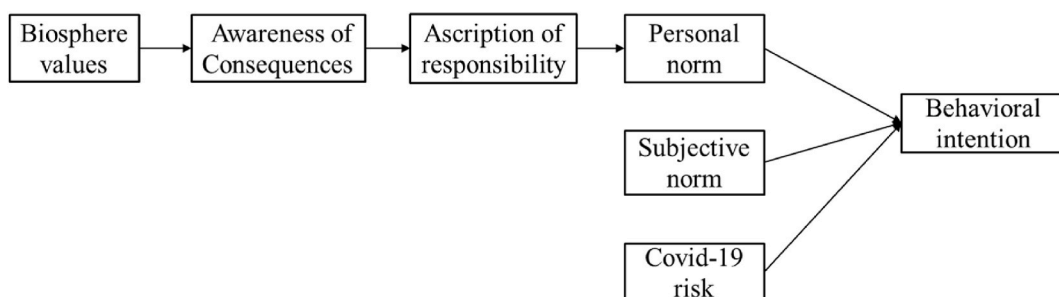

Fig. 1. Theoretical model.

Table 1
Measurement scales.

Construct	Item	Measurement	Adapted from
Biospheric values	BV1	Human beings should prevent pollution	[27,30]
	BV2	Human beings should respect the earth.	
	BV3	Human beings should unity with nature.	
	BV4	Human beings should protect the environment.	
Awareness of Consequences	AC1	Global warming is a social problem.	[27,30]
	AC2	Saving energy helps to reduce global warming.	
	AC3	Energy depletion is a global problem.	
Ascription of responsibility	AR1	I feel a shared responsibility for the energy problem	[27,44]
	AR2	I feel a shared responsibility for the depletion of resources	
	AR3	I feel jointly responsible for global warming	
subjective norm	SN1	Most of the people who are important to me think that I should use delivery services provided by ADVs to receive deliveries, rather than other delivery methods	[18,39]
	SN2	Most of the people who are important to me want me to use delivery services provided by ADVs to receive deliveries, rather than other delivery methods	
	SN3	Those people whose opinions I value would prefer me to use delivery services provided by ADVs to receive deliveries rather than any other methods	
	SN4	People who influence my behaviors think I should use delivery services provided by ADVs to receive deliveries	
Personnel norm	PN1	I think I should protect resources and environment to the best of my ability.	[18,44]
	PN2	To reduce energy wasting, I think it is my responsibility to use ADVs to receive deliveries.	
	PN3	No matter what others do, I would use ADVs in a green way to receive deliveries.	
	PN4	I would feel guilty when I don't use the energy-efficient and environmentally-friendly ADVs to receive deliveries.	
Perceived risk	DR1	It is risky to deliver goods using ADVs.	[7]
	DR 2	It is dangerous to deliver goods using ADVs.	
	DR 3	As a delivery method, the use of ADVs would expose me to overall risks.	
	DR 4	Packages may be damaged when ADVs are used for delivery.	
Behavioral intention	BI1	I will choose delivery services provided by ADVs to receive packages in the future.	[7,45]
	BI2	I would recommend my friends or relatives to use delivery services provided by ADVs to complete deliveries	
	BI3	In the near future, I plan to use delivery services provided by ADVs to complete deliveries.	

Table 2
Demographic profiles of the respondents(n = 561).

Demographic profile	Item	Frequency	Percentage
Gender	Male	281	50.01%
	Female	280	49.9%
Age	<18	2	0.36%
	19–22	253	45.01%
	23–35	177	31.55%
	36–45	103	18.36%
	46–60	17	3.03%
	>60	8	1.43%
Education	High school or below	11	1.96%
	Junior college	57	10.16%
	Bachelor	396	70.59%
	Master or above	97	17.29%
Occupation	Students	337	60.07%
	Civil servant	6	1.07%
	Staff of public institutions	57	10.16%
	Private employee	137	24.42%
	Freelancer	14	2.5%
	Others	10	1.78%
Monthly income (RMB)	<1000	132	23.53%
	1000–3000	204	36.36%
	3000–5000	85	15.15%
	5000–10000	97	17.29%
	>10,000	43	7.67%
Whether you have used delivery services provided by ADVs	Yes	224	39.93%
	No	337	60.07%

4. Analysis results

4.1. The measurement model

The confirmatory factor analysis (CFA) indicated that all factor loadings were greater than 0.60 and the measurement model showed an acceptable level. The results in Table 3 presented that Cronbach's alpha and the Composite Reliability (CR) values of each construct ranged from 0.780 to 0.908 and 0.782 to 0.907, respectively, which revealed that the reliability of the scales was suitable and acceptable. The average variance extracted (AVE) values changed from 0.522 to 0.711, all factoring loading values are significantly above 0.5, showing a good convergent validity [50]. Table 4 shows that the square root of AVE values on the diagonal was higher than its correlation coefficient with other factors, which revealing that the measurement model has good discriminative validity [51].

4.2. The structure model

The structure model was used to test the previously mentioned hypotheses. The result showed appropriate fitting effect including $x^2/df = 2.74$, GFI = 0.908, NNFI = 0.928, NFI = 0.908, CFI = 0.939 and RMSEA = 0.056 [46]. It is clear that all coefficients are significant at the $p < 0.001$ level, and the structure model confirmed the theoretical pathways we hypothesized was acceptable (Table 5). BV was positively correlated with AC, confirming H1. The effect of AC on AR was significantly positive, validating H2. Meanwhile, AR also showed a positive influence on PN and the hypothesis 3 was supported. PN was positively related to intention to use ADVs (BI). confirming H4, subjective norm (SN) and COVID-19 risk (CR) were also correlated with intention to use ADVs, confirming H5 and H6, respectively.

5. Conclusions and discussions

Understanding consumers' intention to use energy-efficient and environmentally friendly autonomous vehicles is particularly important for the last-mile delivery sector, given the growing concern about the environmental problems associated with the large amount of emissions from fuel-efficient and other fuel-intensive vehicles [9]. Nonetheless, there is a limited number of studies on how to effectively shape consumers' behavioral intentions to accept of ADVs in the context of autonomous delivery.

The technology acceptance model (TAM), unified theory of acceptance and usage of technology (UTAUT), and task-technology fit (TTF) model have been used to study consumer acceptance of autonomous delivery robots (ADRs) [52–54] or ADVs [7,9,55]. However, to the best of the author's knowledge. Our study is the first to use an environmental psychology model, namely the value-belief-norm (VBN) theory to explore consumers' intention to adopt ADVs. All hypotheses (including H1 to H4) in our study have been tested and verified, i.e., biosphere values affect awareness of consequences, awareness of consequences affects ascription of responsibility, ascription of responsibility affects personal norm, personal norm affects behavioral intention.

The VBN theory explores the ways in which individual psychological variables influence behavior by linking the variables of value orientation, new environmental paradigm, awareness of consequence, ascription of responsibility, and personnel norms through a

Table 3
Factor loadings, reliability and the average variance extracted (AVE).

	Items	Mean	Standard deviation	Loading	CR	Cronbach's α alpha	AVE
Biosphere values (BV)	BV1	6.21	0.935	0.676	0.832	0.832	0.554
	BV2	6.324	0.919	0.762			
	BV3	6.282	0.948	0.782			
	BV4	6.437	0.849	0.756			
Awareness of Consequences (AC)	AC1	6.005	0.977	0.582	0.664	0.666	0.398
	AC2	6.007	0.951	0.654			
	AC3	5.936	1.002	0.655			
Ascription of responsibility (AR)	AR1	5.938	0.99	0.685	0.782	0.780	0.546
	AR2	5.865	1.033	0.744			
	AR3	5.848	1.054	0.78			
Subjective norm (SN)	SN1	4.766	1.318	0.853	0.907	0.908	0.711
	SN2	4.804	1.362	0.867			
	SN3	4.752	1.353	0.853			
	SN4	4.807	1.366	0.797			
Personal norm (PN)	PN1	5.169	1.153	0.796	0.812	0.813	0.522
	PN2	4.8	1.213	0.786			
	PN3	4.913	1.188	0.787			
	PN4	3.995	1.366	0.541			
COVID-19 risk (CR)	CR1	4.677	1.286	0.706	0.884	0.878	0.664
	CR2	4.46	1.401	0.777			
	CR3	4.273	1.776	0.867			
	CR4	3.841	1.727	0.839			
Behavioral intention (BI)	BI1	5.244	1.079	0.81	0.832	0.832	0.622
	BI2	5.216	1.196	0.786			
	BI3	5.344	1.155	0.774			

Table 4

Discriminant validity.

	BV	AC	AR	SN	PN	CR	BI
BV	0.744						
AC	0.497	0.631					
AR	0.447	0.647	0.739				
SN	0.015	0.119	0.234	0.843			
PN	0.23	0.314	0.361	0.352	0.722		
CR	0.067	0.103	0.034	0.078	0.61	0.815	
BI	0.147	0.221	0.324	0.602	0.35	0.035	0.789

Notes: Biosphere values (BV), Awareness of Consequences (AC), Ascription of responsibility (AR), Subjective norm (SN), Personal norm (PN), Delivery risk (DR), COVID-19 risk (CR), Behavioral intention (BI). The diagonal number is the root value of the factor average variance extracted (AVE).

Table 5

Results of structural model.

Paths	Standardized coefficient	z	p	Results
H1:BV→AC	0.651	9.611	0.000***	Supported
H2:AC→AR	0.893	10.909	0.000***	Supported
H3:AR→PN	0.482	8.869	0.000***	Supported
H4:PN→BI	0.339	8.114	0.000***	Supported
H5:SN→BI	0.641	14.343	0.000***	Supported
H6:CR→BI	−0.217	−5.460	0.000***	Supported

Notes: Biosphere values (BV), Awareness of Consequences (AC), Ascription of responsibility (AR), Subjective norm (SN), Personal norm (PN), Delivery risk (DR), COVID-19 risk (CR), Behavioral intention (BI).

causal chain [16]. Our study validates the applicability and elasticity of the original VBN theory, with findings suggesting that each variable in the causal chain affects the next and ultimately intention [16,17,20].

In addition, subjective norms have a positive influence on consumers' adoption of ADVs (affirming H5), which is consistent with the study of [7] that consumers' emerging technology adoption behaviors can be greatly influenced by subjective norms. The studies by Refs. [35,36] have shown that the decision-making process of consumers can be affected by those around them, i.e., family numbers, relatives, colleagues, and so on. However, between other researchers have taken the opposite view that there was no significant positive relationship these two variables [56]. This may be due to the fact that norms are mainly generated from social production and activities, but the final decisions and formulation are made by individuals, and the results may vary greatly on the origin of the members in the sample. Previous studies have attempted to identify consumer groups that are most attracted to environmental and green factors. As noted in the findings of [57], the higher the level of education and income, the more likely people are to be environmentally friendly consumers. Thus, education level may influence personal norms more than subjective norms. A study by Ref. [54] showed that age has a negative impact on consumers' willingness to adopt autonomous delivery robots. This implies that older people are not keen on exploring smart emerging technologies.

The results shows that COVID-19 risk negatively affects behavioral intention to use ADVs (affirming H6), which is in line with the study of [58], where perceived COVID-19 risk has a negative effect on consumers' intention to use cruise services. This situation suggests that people in the midst of epidemic panic are more likely to choose a safer and contactless method of receiving their packages after online purchasing. Environmentally friendly and energy efficient ADVs provide an alternative solution for logistics services providers to complete the last mile delivery services.

6. Implications

6.1. Theoretical implications

The theoretical contributions of the study are as follows. Firstly, our study sheds light on consumers' adoption behaviors and examines the consumers' ADVs decision-making processes using extended VBN theory by adding subjective norms and COVID-19 risk. The results of the study affirmed the study of [16] that people with high biosphere values can generate awareness of consequence (AC) for certain behaviors, which in turn creates ascription of responsibility (AR), and that a consumer's sense of responsibility for a certain behavior promotes the formation of personal norms, which ultimately produces strong pre-consumer environmental behaviors. This conclusion can also be verified by more other literature and studies [17–19,27,28].

The findings suggest that consumers' behavioral intentions are positively influenced by subjective norms, which is consistent with previous studies [18,30,59,60] that consumers' decision-making process may be affected by surrounding reference groups. An interesting finding is that COVID-19 risk was negatively associated with consumers' behavioral intentions to use ADVs, which is violated with the research of [61] that COVID-19 had a positive influence on consumers' behavioral intention. Furthermore, the study of [40] revealed that during COVID-19 outbreaks, consumers prefer contactless robot service over manual services in hotels. Similarly, consumers with strong COVID-19 risk perceptions preferred to receive packages safely without touching others, and they would adopt

safer, more efficient and environmentally-friendly delivery and pick-up methods than traditional fuel transportation vehicles [54]. Our explanation for the opposite finding may be that consumers may only consider ADVs as emerging innovations with an experiential mindset, but they are convinced that the adoption behaviors of autonomous delivery services could not prevent the transmission of dreaded epidemic. Thus, the risks posed by the epidemic would reduce consumers' intention to use contactless delivery services (ADVs).

6.2. Practical implications

The study has also great practical implications for logistics service providers (LSPs), government departments, developers and marketing managers of ADVs. The COVID-19 will cause internal instability and fear in consumers, which further affects their attitudes and decision-making towards certain behaviors [40,62,63]. Epidemic risk here refers to the severity of COVID-19 on individual physical, mental and consumers' susceptibility to infection in individuals [41]. Consumers with a strong perception of COVID-19 risk prefer to pick up their items via contactless ways, i.e., they are more inclined to choose safer and environmentally-friendly delivery methods. Considering the influence of COVID-19, Logistics service providers (LSPs), especially those focusing on last-mile delivery services, should provide innovative solutions to address delivery efficiency and improve service quality and customer satisfaction. For LSPs, ADVs can especially help reduce transportation risk, improve delivery efficiency, and reduce environmental and noise pollution. Specifically, logistics service providers should establish suitable distribution and sorting centers near consumers and rely on ADVs to automatically plan driving paths in advance.

Governments play an important role in guiding consumers to form positive personal norms for adopting the contactless delivery services provided by ADVs. This will stimulate people to realize the awareness of adverse environmental consequence and ascription of responsibilities (AR), such as the threat posed by conventional engine-driven vehicles or other high energy consuming cars. Those consumers who feel responsible for protecting ecology environment will positively express their beliefs and attitudes and take the lead in adopting pre-environmental behaviors, and then people are easily affected by subjective norms to follow the footsteps of early innovators. Government agencies could still provide incentives to companies that developing ADVs or other electric vehicles. In addition, relevant laws and regulations and infrastructure constructions should also be formulated and improved by relevant departments as soon as possible. Moreover, charging stations are necessary to established to facilitate timely charging of ADVs.

ADVs developers and ADVs marketing department staff should repeatedly emphasize the special features and innovations of ADVs, such as perceived usefulness and perceived ease of use, in operational guidelines to increase consumer awareness and acceptance of these new technologies. ADVs marketing managers can promote the energy-efficient image of the contactless delivery service offered by ADVs to appeal to environmentally conscious and action-oriented consumers. In addition, if marketing managers wish to enhance consumers' behavioral intentions to use environmentally friendly ADVs, they should develop service offerings based on consumers' values, beliefs, and norms. Once consumers' normative motivations are activated, they will consciously fulfill their commitment to the environment and, in turn, engage in pro-environmental behaviors and practices.

6.3. Limitations and the future directions

The present study, despite its important contributions, has some limitations. First, this study ignored egoistic and altruistic values in the value construct, as well as the New Environmental Paradigm (NEP) in the belief construct, and the model noted in our study only examined a portion of the original VBN theory, and future research could explore the effects of all value orientations on behavioral intentions or actual behavior. Second, our study sample was based on cross-sectional data, which affected the accuracy of the results to some extent. In the future, we can expand the sample capacity of the study to other regions or countries to generalize the findings. Third, since ADVs is an emerging innovative technology in the transportation industry, many people do not have the experience of interacting with ADRs, and the application of ADVs is narrow. As a result, consumers who have experienced ADVs and those who have not will have different levels of perceptions, and consumer perceptions of the constructs mentioned in the study may change as ADVs become more popular and widespread in the current market. Therefore, future research could update the proposed model by adding unique features and attributes of ADVs to investigate consumers' intention to adopt ADVs.

Author contribution statements

Chunhua Ju: Conceived and designed the experiments; Analyzed and interpreted the data; Shuo Wang: Performed the experiments; Analyzed and interpreted the data; wrote the paper; Zhirong Hu: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Li-Wei Lin: Performed the experiments; and Analyzed and interpreted the data; Jing Yu: Analyzed and interpreted the data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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