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Research Article

Modal Choice for the Driverless City: Scenario Simulation Based on a Stated Preference Survey

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The possible future introduction of Autonomous Vehicles (AVs) and Shared Autonomous Vehicles (SAVs) raises questions about how they might affect the demand for transport and especially modal choice. In this research, a stated preference (SP) survey and a modelling process using Mixed Logit are proposed to simulate the future market share of AVs/SAVs and how their introduction into the system could change the modal choice, especially in relation to active and public transport modes. An efficient SP survey design has been developed based on the state-of-the-art information and carried out in 2020 among citizens of two medium-sized Southern European cities within a car-intensive region. The design considered different trip purposes (compulsory, leisure), different trip distances, and attributes not taken into account before, such as comfort and the physical characteristics of the terrain for the active modes. The model results suggest that AVs and SAVs were the preferred transport modes for most respondents, accounting for more than 58% of the market share in the scenarios presented. Also, we detected some socioeconomic differences in the propensity to use this mode of transport showing that men living in high-income households and car users were more prone to use autonomous alternatives. The models allowed us to simulate different scenarios, such as experiencing higher costs for using the AV alternative. Policies imposing a higher cost for the AV alternative but lower costs and waiting times for the SAV and public transport alternatives could decrease the AV's market share favouring more sustainable modes. The above scenario showed that achieving a more sustainable future mobility system considering AVs requires an in-depth transport demand knowledge and adequate transport policies.

1. Introduction

The number of studies on Autonomous Vehicles (AVs) and Shared Autonomous Vehicles (SAVs) continues to increase, given the great impacts that this type of new modes of transport could have on mobility and the city [1–4]. However, their possible effects on the transport system, especially on the market share of various transport modes, remain largely an unsolved question on which few investigations have been concentrated.

Previous studies have shown a considerable higher intention to use AV/SAV alternatives than current transport modes. Krueger et al. [5] predict that 28% of their sample will use AV/SAV alternatives using Stated Preference (SP) scenarios while Becker and Axhausen [1] suggest that the use intention among the general public may be around 40%. Therefore, AVs and SAVs can imply a significant change in the equilibrium of the current transport market in many cities. Given the ability of SAVs to operate as a taxi system, at much lower costs than the current ones, and of private AVs to provide fully autonomous mobility without the driver having to pay attention to the environment, many travellers could be willing to replace their usual transport mode with an AVs or SAVs. However, AVs and SAVs' level of service

will largely depend on the cost and waiting times that users have to incur to use the services. Then, factors such as regulations and fleet size may be crucial for the final demand for these new modes of transport [6].

Therefore, it is necessary to continue exploring the willingness of different classes of users to choose this type of vehicles over other modes, especially in the face of scenarios that involve different levels of service and the application of various policies. In this paper, an SP survey is issued to estimate Mixed Logit models for establishing which variables can be more relevant in the modal choice, considering different modes of transport and trip purposes but also different trip distances and attributes that have not yet been studied. The models allow simulating various planning policies in the light of sustainability objectives; for example, economic measures aimed to ensure that active modes (walking, cycling) and public transport do not lose their modal share, given that they are more sustainable than any other autonomous car especially if used privately. The scenarios proposed have considered a future smart city horizon in which non-autonomous vehicles are excluded of the streets in favour of autonomous alternatives and active modes.

The following section reviews SP studies applied to modal choice considering AVs and SAVs in the user choice set. Section 3 explains the research methodology, elaborating on the survey design and the models to capture user preferences. Section 4 describes the study area, comprising the two main urban areas of the Cantabria region in Northern Spain, the SP data collection, and the results obtained. This section includes a scenario analysis to simulate the influence of implementing several policies on AVs and SAVs demand. Finally, the last section discusses the results and presents the main conclusions reached.

2. Autonomous Vehicles and Stated Preference Surveys

The recent investigations that have approached the potential use of AVs and SAVs have focused on two main issues: first, the type of users that might be the most willing to shift to these new transport modes; second, which variables would mostly affect their choices and the market shares of transport modes currently in service.

2.1. Potential AV/SAV Users.
Several studies have explored which types of users might be most willing to change their current modes of transport to AVs or SAVs. Some of them have highlighted that since AVs do not require a driving license, they could be used by people without access to car, such as minors, the elderly, or individuals with some type of disability or mobility difficulties [7]. Harper et al. [8] considered that the mobility of these nondrivers in the United States could increase up to 14% in the total miles travelled, which is a very significant growth that shows the relevance of analysing the modal choice of these groups.

A review of the results obtained so far by multiple general public surveys also shows that specific socioeconomic characteristics are more related to a greater

willingness to use AVs [1]. Thus, men are more open to adopting AVs than women, both in terms of use and willingness to pay. Concerning age, older people generally present a lower disposition to use AVs and great interest and concern for their potential adverse effects [9]. Finally, wealthier people appear to be more willing to pay for an AV [10, 11], including high-income millennials [12]. These results have been corroborated by Krueger et al. [5], who conducted an SP survey and estimated a Mixed Logit model that allowed them to infer that young individuals are more likely to use AVs. Furthermore, model results showed that the probability of using an AV was higher in persons with multimodality-based travel patterns, a phenomenon also detected by Winter et al. [13]. In contrast, users who based their mobility almost exclusively on the private vehicle were much more reluctant to change, unlike the results of the study by Winter et al. [13] where public transport users showed less preference for change than private vehicle users, considering SAVs on a sequential basis (i.e., without sharing the same trip with other unknown users). Ashkrof et al. [14] also found that market penetration could be higher among middle-aged men who make more long trips for leisure purposes.

2.2. AVs/SAVs and Modal Choice.
The modal choice process depends on multiple variables related to both user socioeconomic characteristics and the level of service provided by each alternative. Krueger et al. [5] specified, as key attributes to consider in the SP survey, the travel cost, trip time, and waiting time. Waiting time was considered a differentiated variable because of its potential relevance to SAV-based systems' operation. Travel and waiting times had greater relative weights with respect to the cost variable in the alternative with SAV; that is, according to Krueger et al. [5], the value of travel and waiting times could increase when AVs are shared. Therefore, this option could have competitiveness issues concerning the private vehicle.

Yap et al. [15] selected, for their SP study, a set of variables similar to those in the study by Krueger et al. [5] to model the AV use in the last mile of multimodal trips by train. These variables were waiting time, trip time, travel cost, and whether the trip was shared or not. The model results showed that, in contrary to other studies, both users' sensitivity to trip time and their willingness to pay to reduce travel times were higher in the case of AVs. The above led the authors to hypothesise that other attitudinal variables could also influence the modal choice. These other attitudinal variables, in addition to the difference between work and leisure travel, were considered by Correia et al. [16]. These authors estimated discrete choice models from data obtained from two SP surveys, finding that although the value of time was reduced in AV, as opposed to a conventional vehicle, in the case of trips for work purposes in vehicles prepared as an office, the same did not occur in trips for leisure purposes. In addition, the only attitudinal variable that showed to be significant was convenience of using automated driving.

The user's sensitivity to different AV attributes and purchase options in the Chicago metropolitan area (USA)

were evaluated by Shabanpour et al. [12], using an SP experiment based on a Best-Worst-type choice applied to 1253 respondents. Results showed that AV's selection was mainly influenced by the vehicle price, the possibility of using exclusive lanes, and the driver's responsibility in case of an accident. Haboucha et al. [17] also designed an SP survey considering diverse attributes and three alternatives: conventional private vehicle, AV, and SAV. The attributes were the vehicle acquisition cost for the conventional vehicle and AV alternatives, the cost of belonging to a car-sharing platform for the SAV alternative, and the trip and parking costs for nonautonomous vehicles and AVs. The authors found that 44% of the respondents chose the conventional vehicle, being the cost a very relevant variable in their choice. Moreover, even simulating a zero cost of the SAV service, only 75% of the respondents chose it, making it clear how important it is for many individuals to be able to privately use their vehicle.

Steck et al. [18] also conducted a pseudoexperiment in Germany considering five transport modes: walking, cycling, AV, SAV, and public transport. The selected attributes were trip time, access time, waiting time, cost, and whether the SAV trip would be made with other passengers. Using a Mixed Logit model, the authors estimated that the willingness to pay to reduce travel time for AV and SAV options could fall by 31 and 10%, respectively, compared to the conventional vehicle. Also, several respondents showed their reluctance to share a vehicle, which could limit the demand growth of SAVs. Finally, another study developed by Ashkrof et al. [14] considered, through an SP survey, the modal choice between conventional vehicle, public transport, and AV. In this case, the authors distinguished trips according to their length (10 km and 40 km) and purpose and selected trip time onboard the vehicle, waiting time/search for parking, walking time, and cost as choice attributes. AVs were seen as a more favourable alternative for long-distance journeys and leisure purposes but less attractive for short journeys and mandatory purposes.

Therefore, there is a growing bibliography studying AVs/SAVs through SP surveys and discrete choice models. These results point out the importance of considering the classical level of service variables in the modal choice, accounting for the difference between private AVs and SAVs. The latter transport mode can have different values of time concerning private AVs, being also very dependent on the waiting times that users may have to endure to reach their destinations.

Within this body of literature, the novelty of this research lies in the fact that it analyses trip mode choices which include, in addition to autonomous technologies, active transport. Furthermore, the research will consider different trip purposes (compulsory and leisure trips), different distances (<2 km, 2–5 km, and > 5 km), as well as the relevance of some level of service attributes that have not been included in previous studies, such as comfort or certain physical characteristics like slopes. In addition, given that those studies have been done on large metropolitan areas in North America and Australia, or on Western European countries (Netherlands and Germany), this paper may provide a different perspective yet unexplored, focused on medium-sized cities within a car-intensive region of Southern Europe.

3. Methodology to Design the Stated Preference Survey

3.1. Survey Design. The SP survey design consisted of three sections. The first section involved questions about the socioeconomic characteristics of the respondents. Specifically, it included gender, age, household income level, possession of a driving license, car ownership, and whether the person had any type of personal mobility problems. The second section comprised a revealed preference questionnaire regarding data of their most recent usual trip. This section gathered information about origin, destination, trip purpose, transport mode, travel time, and walking access/egress times in public transport. The third section presented the SP questions for the five transport modes considered (AVs, SAVs, public transport, bike, and walk). The basic characteristics of AVs and how they differ from SAVs were presented, as respondents might not be familiar with them. SAV was highlighted as a sharing transport system similar to an autonomous taxi that could be shared with known or stranger passengers and that would be available through the use of an online booking and payment mobile application.

The SP surveys are based on a pseudoexperimental exercise. In this research, the use of an SP survey was chosen since the autonomous and shared autonomous modes are not currently available. However, in order for the survey results and user choices to be credible, the survey design must be done carefully by selecting the most relevant attributes and realistic attribute levels in relation to the trips actually made in the study area. In addition, since it is possible to generate a large number of scenarios with the chosen attributes and levels, these must be selected based on justifiable criteria. In this research, an efficient type design was selected on the basis that it minimises the standard error of the parameters estimated in the choice models. Since the application of this technique requires the establishment of prior parameters, it is advisable to perform a pilot survey in order to establish them with the aim of obtaining the final design.

The final survey design was achieved after three steps: (1) selection of alternatives, (2) selection of attributes and their levels, and (3) generation of the D-efficient design. The following subsections contain details on these steps.

3.1.1. Selection of Alternatives. We selected five transport alternatives: AV, SAV, Public Autonomous Transport (PT), bike (BIKE), and walking (WALK). It is important to note that we decided to consider AV and SAV separately, as the literature review suggested that the two modes may have a different weighting in the parameters related to travel and waiting times. The other three alternatives represent other existing transport modes in the study area. Walking and cycling are also separate alternatives to consider speed and travel times differences. Nonautonomous vehicles have not been considered in the choice set because it is hypothesised

that a future smart city will not allow human intervention in the traffic flow.

3.1.2. Selection of Alternatives Attributes and Their Levels. We decided to segment travellers into three according to trip distances: short-distance (<2 kilometres), medium-distance (2–5 km), and long-distance (>5 km) trips. We selected these distances considering daily trips of small-medium-sized cities with a population between 50,000 and 500,000 inhabitants [19], as defined in the European context. The aim of segmenting the population was to present realistic choice scenarios based on their current trips.

The choice scenarios contained the following attributes: total cost of the trip (in euros), travel time (in minutes), waiting time (in minutes), the comfort of the mode, and the unevenness of the terrain in the case of active transport modes. We estimated travel times and costs by considering different average speeds and cost per kilometre for each transport mode (Table 1). We calculated average speeds based on available data from a mobility study in Spain [20]. We obtained travel costs from studies about a standard vehicle's fixed and variable operating costs [21]. This design also considered previous examples such as those of Steck et al. [18] and Ashkrof et al. [14]. Table 2 presents the attribute levels used in the survey design.

3.1.3. Generation of Choice Scenarios. We implemented a heterogeneous D-efficient SP survey design in the Ngene software [22]. Each of the three subdesigns, with eighteen choice scenarios, was subdivided into two blocks and received the same weight in the Fisher matrix. In this way, each respondent faced nine choice situations.

We decided to apply a pilot survey to test the survey design adequacy and obtain prior parameters, given the parameters' uncertainty. Table 3 shows the values corresponding to the final choice situations for medium-distance trips. This design was obtained using the parameters calculated with the data of the pilot survey. The respondents had to choose both the preferred mode to perform the mandatory (i.e., work, study) and leisure trips. In this way, the survey collected additional information on user preferences regarding two different trip purposes.

3.2. Modelling. The choice model in this research follows several assumptions. Each choice alternative i presents a utility to a user n equal to U_{in}. This utility is subdivided into two parts. Firstly, a systematic utility, linear in its parameters, is denoted as follows:

$$V_{in} = \beta X_{in}, \tag{1}$$

where X_{in} is a vector of explanatory variables related to both the socioeconomic characteristics of the users and the level of service provided by the alternatives and β' is a vector of parameters that represent the user preferences. A random utility ε_{in} is added to this systematic utility. The random term captures the nonobservable part of the utility (i.e., the one not contained in V_{in}). Assuming that the random utility

distributes Gumbel identically and independently among alternatives (IID), it is possible to derive the well-known Multinomial Logit (MNL) model [23].

In case it is considered that the parameters β' are not fixed across respondents (i.e., they present heterogeneity in the population), two more general models can be constructed: firstly, the Mixed Logit (ML) model, in which it is assumed that the parameters can present a continuous probability distribution to be specified. In this case, the expected probability for an individual $n E(P_n^*)$ takes the form [24]

$$E(P_n^*) = \int_\beta P_n^*(\beta) f(\beta|\Omega) d\beta, \tag{2}$$

where $f(\beta|\Omega)$ is the density function of β given some parameters of the distribution Ω.

This type of model can be estimated using both cross-sectional and panel data. The latter is the case present on SP surveys, in which the same individual usually responds to several choice situations, and there may be a correlation among observations.

It is also possible to add error components to an ML model to consider complex substitution patterns between alternatives. These error components allow considering the correlation between the alternatives, avoiding the problem of unrealistic substitution patterns in some choice contexts, derived from the IID hypothesis of the MNL model. Thus, the utility function of an error components model is specified as follows:

$$U_{in} = \beta_q' X_{in} + \varepsilon_{in} + \sum_{m=1}^M c_{im} W_{nm}, \tag{3}$$

where W_{nm} is the error m, with a normal distribution, for the individual n. If the alternative's utility function includes the error component, c_{im} will take the value 1 and 0 otherwise.

4. Case Study and Results

4.1. Case Study. The survey was issued to the main urban areas of Cantabria (Spain). Cantabria is a uniprovincial Autonomous Community located in the middle of the northern coast of Spain. Its capital city, Santander, is a medium-sized city with 172,539 inhabitants in 2019 in its municipality and more than 280,0000–300,000 inhabitants in its area of influence. The second city of Cantabria, Torrelavega, accounts 51,494 inhabitants in its municipality and more than 100,000 in its influence area. This region is the second province in Spain, after Vizcaya (Basque Country) with the highest percentage of intermunicipal commuting trips, 46.3% [25], which is reflected in extensive car use. Indeed, the modal split in the region, for daily compulsory trips and according to data for 2017, was 70.1% by private motorised vehicles and taxis, 16.5% by walking and cycling, and 13.4% by bus or train.

This modal split is similar to those of its main cities, especially to Torrelavega, with the private car being the most used mode for working purposes, 66%, since 40% of its working population daily commutes to other municipalities [26]. In the case of Santander, where most people work and

TABLE 1: Speeds and cost per kilometre for each transport mode.

Attribute	Trip distance	AV	SAV	PT	BIKE	WALK
	<2 km	25 km/h	22 km/h	15 km/h		
Average speed per mode	2–5 km	35 km/h	32 km/h	25 km/h	15 km/h	5 km/h
	>5 km	45 km/h	42 km/h	35 km/h		
Cost per kilometre per mode		0.32 €/km	0.2 €/km	—	—	—

TABLE 2: Selected attributes and their levels in the SP design.

Attribute	AV	SAV	PT	BIKE	WALK
Trip time (TT) (min)	Calculated −20%	Calculated −20%	Calculated −20%	Calculated −20%	Calculated −20%
	Calculated (1 km, 3.5 km, 8 km)	Calculated (1 km, 3.5 km, 8 km)	Calculated (1 km, 3.5 km, 8 km)	Calculated (1 km, 3.5 km, 8 km)	Calculated (1 km, 3.5 km, 8 km)
	Calculated +20%	Calculated +20%	Calculated +20%	Calculated +20%	Calculated +20%
Total cost (CT) (€)	Calculated −20%	Calculated −20%	0.5	—	—
	Calculated (1 km, 3.5 km, 8 km)	Calculated (1 km, 3.5 km, 8 km)	1		
	Calculated + 20%	Calculated + 20%	1.5		
Waiting time (WT) (min)	1	2	1	—	—
	2	4	3		
	3	6	5		
Comfort (CM)	High	High	High	—	—
	Low	Low	Low		
Unevenness terrain (UT)	—	—	—	With slopes	With slopes
				Flat ground	Flat ground

TABLE 3: Example of scenarios selected using the D-Error technique for a 2 to 5 km trip.

Scenario	AV				SAV				PT				BIKE		WALK	
	TT	CT	WT	CM	TT	CT	WT	CM	TT	CT	WT	CM	TT	UT	TT	UT
1	7.5	0.84	3	0	4.9	0.53	2	1	6.3	1.5	1	1	17.5	0	31.5	1
2	6	1.12	1	0	8.2	0.88	6	1	6.3	0.5	5	1	14	1	52.5	0
3	4.5	1.12	3	1	8.2	0.7	2	0	10.7	0.5	1	0	17.5	0	42	1
4	6	1.4	2	1	6.6	0.7	4	0	10.7	1	3	0	10.5	0	31.5	1
5	4.5	0.84	2	1	6.6	0.88	4	0	8.4	1	3	0	14	1	42	0
6	7.5	1.4	1	0	4.9	0.53	6	1	8.4	1.5	5	1	10.5	1	52.5	0

Note. TT: minutes; CT: euros; WT: minutes; CM: high (1)/low (0); and UT: with slopes (1)/flat ground (0).

study in the same municipality, car use declines to 46.4%, followed by walking with 37.8% of compulsory trips. In contrast, as regards total daily trips, walking becomes the primary transportation mode for both cities, enhanced by the traditional compactness and mix of land uses of these cities, with more than 46% and 47% of daily trips made on foot. However, this modal distribution could be significantly altered by the introduction of AVs.

4.2. Data Collection and Description. The survey was conducted between June and July 2020. A total of 296 observations were collected, of which at least one scenario was answered in 179 cases (60%) and the entire questionnaire in 123 cases (42%). The respondents were contacted via e-mail and social media (Twitter). We did not offer any special incentives to participate in the survey.

The responses of those who answered at least one scenario (Table 4) were compared with the sociodemographic data of the Cantabrian population [27] to ensure sample representativeness. While the distribution by gender was very similar (51.5% women and 48.5% men in the population), the distribution by age showed several deviations, mainly due to the overrepresentation of the group between 35 and 44 years old (41.3% of the sample versus 15.4% in the population) and the underrepresentation of the elderly, that is, >65 years old (5% of the sample versus 22.2% of the population). Also, we detected an underrepresentation of the households of lower incomes. In order to minimize this problem, we weighted observations according to the percentages present in the population to correct this effect.

Regarding the most common/usual trips of the respondents, data showed that 75% of the trips were destined to home, work, or study (i.e., compulsory purposes), while almost 20% of the trips were motivated by shopping or leisure activities. Less than 5% of the trips have health or other purposes. The relevance of shopping and leisure trips for the sample is very similar to those of Spanish average,

TABLE 4: Socioeconomic and usual trip characteristics of the respondents ($n = 179$).

Socioeconomic data	Gender	Male	48.6%
		Female	51.4%
	Age	24 or younger	16.2%
		25–34 years old	10.6%
		35–44 years old	41.3%
		45–54 years old	14.0%
		55–65 years old	12.9%
		>65 years old	5.0%
	Monthly household income	<900 €	0%
		900–1500 €	7.8%
		1500–2500 €	30.2%
		>2500 €	57.0%
		DK/NA *	5.0%
	Reduced mobility	Yes	2.4%
		No	97.6%
	Driving license	Yes	90.5%
		No	9.5%
	Available vehicle	Yes	86.0%
		No	14.0%
Usual trip data	Trip purpose (origin)	House	27.2%
		Work	48.6%
		Study	9.2%
		Health	1.2%
		Shopping	4.6%
		Leisure	8.1%
		Other	1.1%
	Trip purpose (destination)	House	7.4%
		Work	56.8%
		Study	10.8%
		Health	0.6%
		Shopping	9.1%
		Leisure	10.8%
		Other	4.5%
	Transport mode	Walk	8.9%
		Bicycle	0.9%
		Bus	5.3%
		Car	80.0%
		Motorbike	0.9%
		Other	4.0%
	Trip length	Less than 5 km	28.3%
		Between 5 and 10 km	28.3%
		Over 10 km	43.4%

*Do not know/no answer.

while daily trips motivated by working and studying purposes were higher than those of Spain, 67.6% versus 43% of daily trips [28]. This difference is mainly because our question referred only to the most frequent trip instead of all trips made in one day and the overrepresentation of people between 35 and 44 years old.

Concerning the transportation mode, the car was the most frequent alternative (80% of the respondents), followed by walking in 10% of the cases, while the bicycle was the least used. These results are very similar with the modal split of Cantabria, where 70% of daily commuting trips are made by car or motorcycle and 16% by walking or cycling [29]. Also, in Spain, 61.5% of commuting trips to work are made by car or motorcycle and 17% walking [28]. This high representation of car use is due to two main reasons. Firstly, the

average length declared by the respondents of the survey was 19 km, an intermunicipal distance for which the car is the most competitive mode. Secondly, the mentioned high presence of people between 35 and 44 years old is the group which drives the most on their daily commuting [29].

The overall results of the modal choice suggest that AV was the most preferred alternative in all the scenarios analysed and all the distances considered for compulsory trips. The preference is mostly notable for intermediate trips of 2–5 km, being selected in 44.4% of the cases. As expected, the walking mode was very relevant for short distances, the second-best option with a 29%. Concerning SAV, its relevance changes depending on the distance, as it is the second-best alternative for intermediate distances, chosen by 22.4% of the respondents. However, it is the third option after PT

for long distances (>5 km). In the bicycle case, its best value corresponds to the intermediate distance, as it was selected by 7% of the respondents.

4.3. Model Results and Elasticities.

We estimated two Mixed-Logit models considering the presence of random parameters (i.e., heterogeneity in preferences) (Table 5). The first model considered the preferred mode selected by users for a journey with a mandatory purpose. Only variables that presented significant or near-significant parameters, for a reference of a 95% confidence level, were selected in the specification of both models. Also, these models incorporated panel effects among the answers of the same respondent, and error components to take into account the possible correlation between autonomous modes on the one hand and the active modes on the other. We estimated the models using the simulated log-likelihood approach and a Halton sequence of 200 draws [30]. Both models showed good goodness of fit, better than that obtained by the only constants model, exceeding the critical value in the χ^2 test of comparison between models ($\chi^2 = 1359$ in the case of compulsory trips and $\chi^2 = 1299$ for leisure trips).

Trip cost (CT), trip time (TT), and waiting time (WT) were specified as random parameters. Specifically, we formulated these distributions as a truncated triangular type (T) to avoid the presence of individual parameters with counterintuitive (positive) signs. In both the compulsory and leisure models, the three parameters were significant at the 95% confidence level. The CT random parameter, present in the AV, SAV, and PT alternatives, showed the highest value, followed by WT, which was only significant in the SAV and PT alternatives. The above result points out that respondents did not consider waiting time as a relevant attribute when choosing a private mode such as the AV, even though the survey design specified WT for AV as well, since this type of vehicle could be parked far from the origin of a trip. This could be due to the fact that the population does not yet associate the private vehicle with the waiting time as drivers do not usually take into account access time to the vehicle. We found TT to be generic in the five alternatives; that is, the disutility generated by the TT is the same for all transport modes.

All three distributions also had significant deviations. Then, we interacted CT, TT, and WT with socioeconomic variables to further capture preference heterogeneity. Thus, women showed to have a lower cost disutility in trips for leisure purposes, as well as individuals with a higher purchasing power (household income over 2,500€ per month) and those who use the car for their most usual trip (CAR_USED), applicable also, in this case, for compulsory trips. In the case of TT, the only socioeconomic variables detected to explain the heterogeneity in preferences were the highest purchasing level (for compulsory trips) and the use of the car in the most usual trip (for both compulsory and leisure trips), showing in both cases a slight decrease in disutility. Finally, the model suggests less disutility associated with waiting time for the SAV and PT alternatives by women, high-income persons, and car users when performing compulsory trips.

The parameters associated with the dummy variables on comfort were only significant for the SAV and PT modes. High comfort was valued in SAV and PT alternatives for compulsory trips, while just in the PT alternative for leisure trips. In line with previous research on bicycle suitability [31], the unevenness of the terrain reduced the utility of using a BIKE, although it is not significant at the 95% confidence level. It can also be observed, through the dummy variables SCENARIO_M and SCENARIO_L, how the alternatives AV, SAV, and PT tend, as expected, to be more chosen in the medium- and long-distance scenarios.

The models provided results related to the choice of AV and SAV for different socioeconomic groups. Thus, in leisure trips, women were less likely than men to travel by AV or SAV, although this difference did not occur in compulsory trips. The most remarkable results considering age groups were the lower propensity of older individuals (>65 years) to use AV and active modes in compulsory trips. This trend was the opposite in leisure trips, excluding the SAV mode, which showed no significant differences according to age. Also, individuals with higher purchasing power were more likely to use an AV for compulsory trips while active modes for leisure ones. Finally, if an individual stated that they owned a car, the propensity to use an AV or SAV was lower, but if they actually used the car on their most frequent trip, the utility of AV and SAV alternatives was higher. The above suggests that the more accustomed to using the car, the more likely to choose an AV, either privately or shared.

We estimated direct and cross elasticities to understand how changes in the model attributes influenced mode choices. Elasticities show the percentage increase and decrease in the choice probability of an alternative after a 1% increase in a continuous attribute or a change of a dummy variable from value 0 to 1 (in the latter case, we estimated arc elasticities) (Table 6). Among the service variables, CT has the highest elasticity, except for TT in active transport modes, which affects the SAV alternative more than AV and PT. The analysis also suggests that individuals preferably shift to SAV when AV cost increases by 1%. In the case of SAV, the highest cost cross-elasticity corresponds to PT.

Furthermore, if the fare or TT of PT increases, individuals tend to shift to SAV or even to an active transport mode such as the bicycle. Finally, it is also noteworthy how the positive elasticities for car use in the mandatory trip are high for the AV and SAV alternatives. The above indicates the greater preference of regular car users to use autonomous vehicles rather than any other mode, *ceteris paribus*. Other variables, such as CM or UT, in the case of the bicycle, play a less relevant role in the mode choice given their lower elasticities, although SAV alternatively benefits from a higher comfort.

Using the Bayesian estimation approach, we derived users' willingness to pay (WTP) for changing any of the attributes (Table 7). In the case of mandatory trips, the average value of travel time was twice that of the waiting time, since, although the trip time presented a lower estimate in the Mixed Logit models, the latter had a preference distribution with a higher dispersion and only was significant in the case of the SAV and PT alternatives. The WTP for

TABLE 5: Error component Mixed Logit models (mandatory and leisure purposes).

Variable name (alternative)	Error component Mixed Logit with panel effect (ECML): mandatory trip		Error component Mixed Logit with panel effect (ECML): leisure trip	
	Estimate	z-test	Estimate	z-test
Random parameters in the utility function				
CT (AV, SAV, PT)	−3.273	−11.61	−2.104	−7.22
TT (AV, SAV, PT, BIKE, WALK)	−0.184	−6.90	−0.126	−7.10
WT (SAV, PT)	−0.697	−8.40	−0.539	−7.57
Nonrandom parameters in the utility function				
SAV *	−1.218	−4.22	2.399	7.18
PT *	−0.013	−0.02	2.567	4.50
BIKE *	−2.442	−2.94	1.292	2.24
WALK *	−0.289	−0.36	2.884	4.81
Gender (AV, SAV) (1 = female)	—	—	−1.421	−3.11
Age 25–65 (AV) (reference: <25 years)	−0.543	−1.96	2.084	6.02
Age >65 (AV)	−2.035	−5.68	2.204	6.66
Age >65 (BIKE)	−4.291	−3.70	—	—
Age >65 (WALK)	−4.423	−3.36	2.579	9.54
Income >2500 € (AV) (reference: <900 €)	1.341	3.38	—	—
Income >2500 € (BIKE, WALK)	—	—	2.096	3.49
CAR (AV, SAV) (1 = car available)	−2.423	−2.96	—	—
CAR_USED (AV, SAV) (1 = car used in the most frequent trip)	2.809	5.85	—	—
SCENARIO_M (AV, SAV) (1 = medium-distance scenario)	3.489	7.28	2.047	7.36
SCENARIO_L (AV, SAV) (1 = long-distance scenario)	5.807	7.40	2.536	5.62
SCENARIO_M (PT)	2.448	5.23	0.602	1.73
SCENARIO_L (PT)	4.163	5.56	1.802	4.10
COMFORT (SAV,PT) (1 = High comfort)	0.452	2.44	—	—
COMFORT (PT) (1 = high comfort)	—	—	0.383	1.58
UT (BIKE) (1 = terrain with slopes)	−0.639	−1.86	—	—
Interactions of random parameters with socioeconomic variables				
Interaction of CT and gender (AV, SAV, PT)	—	—	0.478	1.92
Interaction of CT and CAR_USED (AV, SAV, PT)	2.714	7.50	0.710	3.10
Interaction of CT and income>2500 € (AV, SAV, PT)	—	—	1.186	3.59
Interaction of TT and income>2500 € (AV, SAV, PT, BIKE, WALK)	0.054	3.39		
Interaction of TT and CAR_USED (AV, SAV, PT, BIKE, WALK)	0.074	3.64	0.034	2.79
Interaction of WT and gender (SAV, PT)	0.325	4.58	0.205	3.43
Interaction of WT and income >2500 € (SAV, PT)	0.208	4.08	0.165	2.50
Interaction of WT and CAR_USED (SAV, PT)	0.211	3.24	—	—
Deviation of the distributions of the random parameters				
Sigma CT (AV, SAV, PT) (T)	3.273	11.61	2.104	7.22
Sigma TT (AV, SAV, PT, BIKE, WALK) (T)	0.184	6.90	0.126	7.10
Sigma WT (SAV, PT) (T)	0.697	8.40	0.539	7.57
Deviation of the random latent effects				
Sigma (AV, SAV)	4.661	10.46	2.324	8.97
Sigma (BIKE, WALK)	2.234	10.23	2.143	7.95
Log-likelihood	−1375.89	−1569.20		
ρ^2	0.391	0.302		
ρ^2 (adj)	0.331	0.293		
Log-likelihood (constants only)	−2055.55	−2218.71		

*Alternative specific constant of the alternative.

Table 6: Direct and cross point and arc elasticities for the ECML—mandatory trip model.

Attribute (alternative)	AV	SAV	PT	BIKE	WALK
CT (AV)	−0.3438	0.3459	0.2189	0.1590	0.0655
CT (SAV)	0.1075	−0.4396	0.1863	0.1028	0.0355
CT (PT)	0.0611	0.1657	−0.3933	0.1813	0.0488
TT (AV)	−0.1839	0.2004	0.1218	0.0675	0.0162
TT (SAV)	0.1075	−0.3155	0.0974	0.0480	0.0058
TT (PT)	0.0839	0.1149	−0.3381	0.1184	0.0152
TT (BIKE)	0.0241	0.0331	0.0727	−0.7299	0.0926
TT (WALK)	0.0299	0.0159	0.0390	0.7013	−0.4152
WT (SAV)	0.0794	−0.1666	0.0040	0.0318	0.0034
WT (PT)	0.0753	0.0059	−0.2063	0.0917	0.0256
AGE 25–65 * (AV)	−0.1457	0.1522	0.0826	0.0423	0.0429
AGE >65 * (AV)	−0.0346	0.0376	0.0240	0.0054	0.0048
AGE >65 * (BIKE)	0.0018	0.0035	0.0063	−0.0873	0.0173
AGE >65 * (WALK)	0.0042	0.0074	0.0110	0.0459	−0.0513
INCOME >2500 € * (AV)	0.2697	−0.3131	−0.1262	−0.0586	−0.0792
INCOME >2500 € * (SAV)	−0.1650	0.4600	−0.1062	−0.0380	−0.0447
CAR * (AV)	−0.7129	0.7429	0.4130	0.1974	0.2048
CAR * (SAV)	0.3914	−1.1118	0.2759	0.0985	0.0996
CAR_USED * (AV)	0.7558	−0.8274	−0.4109	−0.1716	−0.2134
CAR_USED * (SAV)	−0.4360	1.1820	−0.2654	−0.0761	−0.1028
CM * (SAV)	−0.0433	0.1230	−0.0294	−0.0123	−0.0118
CM * (PT)	−0.0199	−0.0289	0.0861	−0.0164	−0.0133
UT * (BIKE)	0.0044	0.0046	0.0074	−0.1403	0.0288

*Arc elasticities.

Table 7: Willingness to pay estimations for the mandatory and leisure models.

Model (alternative)	Mandatory trip	Leisure trip
TT-decrease of 1 minute (AV, SAV, PT, BIKE, WALK)	0.20 €	0.03 €
WT-decrease of 1 minute (SAV, PT)	0.10 €	0.39 €
CM-high comfort (SAV, PT)	0.46 €	0.12 €
UT-Flat (bike)	0.65 €	—

Table 8: Percentual demand changes in the scenarios (mandatory trips).

Scenario	AV	SAV	PT	BIKE	WALK
Baseline scenario	38.56%	20.32%	19.32%	6.11%	15.69%
(1) 50% increase in the CT of AV	−4.89%	+2.78%	+1.37%	+0.34%	+0.40%
(2) 100% increase in the CT of AV	−7.68%	+4.53%	+1.97%	+0.52%	+0.66%
(3) 50% decrease in the CT of SAV	−2.28%	+5.36%	−2.35%	+0.39%	+0.34%
(4) 50% decrease in the CT and WT of SAV	−4.92%	+9.09%	−3.03%	−0.63%	−0.51%
(5) 50% decrease in the CT of PT	−1.55%	−2.10%	+4.90%	−0.67%	−0.58%
(6) 50% decrease in the CT and WT of PT	−3.49%	−2.27%	+7.75%	−1.06%	−0.93%

travelling in a shared mode with high comfort or on flat ground in the bicycle alternative remained close to half a euro. In contrast, for leisure trips, the value of travel time was much lower than for mandatory trips. Users' WTP for waiting time was more prevalent in SAV and PT modes for this kind of trip.

4.4. Policy Simulation. We perform several simulations by changing the service level variables in the mandatory trip model (Table 8). The proposed scenarios aim to assess transport policies to promote active modes, PT, and SAV while reducing private AV use given their potential adverse effects from a sustainability perspective. These policies are in line with those evaluated as more effective by experts for mitigating the possible negative effects of AV implementation [32].

The baseline scenario consists of the answers to choice scenarios in the data. The modal split in this scenario has AV as the most chosen transport mode and, together with SAV, represent almost 59% of the market share.

Thus, if the cost of using an AV is increased (scenarios 1 and 2), for example, by charging for parking or driving on high-demand roads, the other transport modes could be

promoted and especially SAV, an *a priori* more efficient alternative as the vehicles are continuously circulating, not parked most of the time, and move more passengers per vehicle. However, although when the cost increase in the scenarios is high, especially in scenario 2, the drop in demand for AV only reaches 7.7%; that is the AV is an attractive transport mode for users when making their journeys even at a high cost, presumably given its privacy and comfort. This also applies to the SAV alternative, where even a decrease in cost and waiting time of 50% only increases its demand by 9.1%. The demand change was mainly captured from the AV. In this sense, if the use of SAVs is to be promoted over AVs, it seems advisable to keep their costs at a moderate level, lower than those of AV. Furthermore, when PT is boosted, either by lowering cost derived from the fare (scenario 5) or by increasing the service, that is, reducing waiting times (scenario 6), increases of up to 7.8% in its demand could be achieved capturing up to 3.5% of the demand of AV.

5. Discussion and Conclusions

This article has examined how the modal choice might change in medium-sized cities with the arrival of future transport modes, such as AVs and SAVs. To this end, a SP survey on modal choice was carried out among citizens of two Southern European cities within the car-intensive region of Cantabria (Spain), considering five alternative modes, three scenarios on travel length, two trip purposes (mandatory and leisure trips), and five attributes. These attributes included the comfort of the autonomous and public transport alternatives as well as the physical characteristics of the terrain for the active modes. This type of attributes has not been included before in previous AV choice experiments although they are relevant for the competition with active modes in short travel distances. The survey has allowed estimating Mixed Logit models considering preference heterogeneity, panel effect, and the correlation between alternatives. All these contributions have helped to develop a more realistic experimental design and modelling framework in a hitherto underexplored context.

The results obtained can be classified into three main groups: (1) variation in the willingness to use AVs and SAVs according to socioeconomics; (2) differences in preferences for different levels of service associated with AVs and SAVs; and (3) WTP and modal choice of AVs and SAVs in different scenarios.

Considering the willingness to use AVs and SAVs by different groups of people, we found that men are more likely than women to use AVs and SAVs for leisure purposes. However, no significant differences were found in trips for compulsory purposes. This gender difference is similar to that pointed out by Becker and Axhausen [1], although previous research did not consider differences by trip purposes. Another difference was the lower utility for choosing AVs for compulsory trips in the case of the older individuals, which is a well-known result. However, in this case, the same outcome was not obtained for leisure trips, a

trip purpose in which citizens are usually more willing to choose an AV [14]. Finally, high-income individuals seem to be more willing to use AVs for compulsory trips, which is also in line with previous research that found a greater willingness of these users for buying an AV [10]. Likewise, the current transport behaviour can also influence the willingness to choose an AV or SAV. Thus, we detected that people who make their most frequent trip by car are more likely to use AVs and SAVs. In this sense, Winter et al. [13] argued that those types of respondents showed a preference towards SAVs only in the specific use of what they call free-floating car-sharing (FFCS) (i.e., using a car individually or sharing with known passengers which are parked in particular pick-up and drop-off spots). This result could not be corroborated in this study since the difference in using SAVs with known or unknown people was not considered.

Our results confirm the importance of preference heterogeneity in AV studies. We found several socioeconomic differences in the preferences of the service level attributes. Thus, regular car users and those living in high-income households showed, as expected, a lower disutility to the CT of the alternatives, an aspect that can explain their higher willingness to use AVs and SAVs even if their trip cost is higher than those of other transport alternatives. This heterogeneity in the preferences, showing a lower disutility, was also detected in the WT, present in the SAV and PT alternatives, for women, individuals in high-income households and regular car users. In this sense, these users can be less affected by the waiting time typical of public transport alternatives. The comfort was also significant in the nonprivate alternatives (SAV, PT), showing a higher elasticity in the case of SAVs. This result highlights the importance of considering the design of a future SAV mode to provide a high level of comfort that ensures the demand of the alternative.

The mode choice model for compulsory trips allowed us to simulate how the change in some attributes could influence the modal split in a future city with AVs and SAVs in competition with PT and active modes. AVs and SAVs were the most chosen alternatives among the people surveyed, accounting for more than 58% of the market share in the presented scenarios. This points to the potentially great popularity of these modes, especially of the private AV alternative, which could harm PT and nonmotorised alternatives [5]. It has been inferred that even with significant increases in AV cost, it is difficult to encourage modal shift to other alternatives with less expected negative impacts such as SAV, PT, or active modes. This relevant result has not been highlighted enough in previous research and should be taken into account by planners and policy makers in order to avoid that a mobility system based on private AVs present more problems than the current system in terms of sustainability. An effective strategy to promote sustainable mobility in urban areas could be achieved by combining cost increases in the AV alternative while improving PT and SAV alternatives to ensure their competitiveness against AVs. Cost combination may involve using higher parking fees, restricting free parking possibilities, or applying higher vehicle taxes. Also, the attractiveness of active modes should be improved by, for example, implementing cycle lanes and

pedestrian pathways that allow citizens to have a safer mobility.

As future lines of research, it is proposed to conduct new SP surveys as AVs become more present in the market and more familiar to users. These future surveys could also consider autonomous public transport with a higher level of service, more details on modal choice modelling for different trip purposes, and new simulations on the impacts that different policies could have on achieving more sustainable mobility with the presence of AVs. In addition, transport modelling should also take into account how AVs will affect induced trip generation as well as possible changes in the zonal distribution of trips.

Data Availability

The stated preference data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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