Is the impact of transport modes on health an individual determinant of transport mode choice?

Hélène Bouscasse [*] Sandrine Mathy [†] Rim Rejeb [†] Carole Treibich [†]

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Abstract

High modal share of the private car has two important health consequences. First, air pollution, particularly fine particulate matter in urban areas, leads to increased mortality and morbidity (cardiovascular or pulmonary diseases, etc.). Second, the increase in sedentary lifestyles is partly due to the lack of physical activity in our mobility behaviour with the widespread use of the private car. This also leads to exacerbated morbidity (cardiovascular diseases, type 2 diabetes, cancer and mental illnesses). In this article, we try to evaluate the extent to which the impact of mode choice on public or individual health influences mode choice. in other words, does the fact that taking the car increase the risk of cardiovascular disease for the user, through physical activity, and for his co-citizens, through pollution, have an influence on the choice of alternative modes? We address this question using a Stated Preferences survey, considering car, public transport, walking and cycling modes.

Keywords

Health impact; mode choice; cardiovascular disease; risk

1 Introduction

Despite the many negative externalities of the private car (health and well-being impacts related to pollution, noise, increased sedentarity, contribution to climate change, accidents, etc.), public policies have most often failed to significantly change individual behaviour in the transport sector. It is therefore important to improve our understanding of the determinants of transport mode choices and how they can impact our choices in order to design more effective policies. There are many such determinants and they are not limited to cost, time, comfort, or infrastructure availability. Psychological factors such as perceptions of different modes

[*]CESAER, Agrosup Dijon, INRAE, University Bourgogne Franche-Comte, Dijon, France. helene.bouscasse@inrae.fr
[†]Grenoble Applied Economics Lab (GAEL), CNRS and Grenoble-Alpes Univ., Grenoble, France

of transport can also play a significant role. The perception we have of the impact of different modes of transport on our health and on public health could influence mode choices. Indeed, transportation choices impact our health through two distinct channels. One relates to public health, and the other to individual health.

First, private cars is one of the main source of atmospheric pollution which increases mortality risk, cardiovascular and respiratory morbidity, including through lung cancer incidence Hamra et al. (2014); Raaschou-Nielsen et al. (2013); Rückerl, Schneider, Breitner, Cyrys, and Peters (2011). Air pollution represents one of the biggest controllable environmental risk to health, and reducing air pollution could save millions of lives. In Europe, air pollution is causing around 467,000 premature deaths every year Guariso and Volta (2017) and in France, 48,000 deaths are attributed yearly to particulate matter exposure Aïchi (2015). Reducing the car's place then contributes to reducing the average exposure of the population to pollution and to improving the health of the population as a whole.

The other channel through which mobility impacts health relates to the physical activity associated with the choice of transport mode. Car use promotes physical inactivity and sedentary lifestyle which are associated with obesity, cardiovascular disease, diabetes, cancer, and other diseases. In general, researchers have agreed on the idea that switching to active and less polluting transportation choices has positive consequences on the physical and mental health Jaocob, Munford, Rice, and Roberts (2019). These consequences were quantified using several health indicators: decrease in the risk of obesity Flint and Cummins (2016), lower stress levels Wener and Evans (2011), cancer incidence Celis-Morales et al. (2017), risk of premature death Woodcock et al. (2018), etc. For example, a typical situation is to make a trip of about ten kilometres from a peri-urban area to the city centre. Given that the average risk of developing cardiovascular disease among the French population is 30% Inserm (2018), a person making this trip by bicycle every day, sees this risk reduced to about 24% Menai (2015); Rojas-Rueda, De Nazelle, Teixidó, and Nieuwenhuijsen (2013) compared to a person making this trip by car. The level of risk reduction depends on the intensity of the physical effort and the frequency at which this effort is made in a typical week.

It is therefore legitimate to question the influence of this health impact on mobility behaviour and in particular mode choice. Our health is at the heart of our daily concerns, whether through food, sport or the environment in which we live. These concerns may lead to important behavioural changes.

However, our review of the literature did not allow us to find any reference making a direct link between the reduction of health risk due to a specific behaviour (diet, physical activity, smoking, etc.) and behavioural change, or quantify a willingness to pay for health risk reduction. At most, we found references that show that health considerations are an element of choice. For instance, Paul and Rana (2012) or Shepherd, Magnusson, and Sjödén (2005) show that health benefits are a major determinant of organic food consumption. Using a Stated Preferences survey, Asselin (2005) reports that willingness-to-pay for eggs with health value-added characteristics (omega-3, vitamins) increases with health consciousness and health behaviour. Herens, Wagemakers, Vaandrager, van Ophem, and Koelen (2017) demonstrate a willingness to pay for physical activity, related to perceived health. On the other hand, Johnson, Banzhaf, and Desvousges (2000) directly measure willingness to pay for improved respiratoy and cardiovascular health.

Concerning the difference between selfish (individual) and altruistic (public) motivation for a health related behavior, one of the few references in the literature is Umberger, Thilmany McFadden, and Smith

(2009) who show that consumer preferences for natural and regionally produced beef are motivated by a combination of perceptions of personal benefits and altruistic factors.

The purpose of this article is to contribute to this literature. To this end, we develop and implement a stated preference survey (i.e. a discrete choice experiment) whose objective is to assess the extent to which information provided to individuals on the positive individual and public health impacts induced by active and less polluting modes of transport modify their modal choice. This article presents the survey protocol and data, describes the model framework, and presents and analyses results.

2 Survey protocol and data

2.1 Discrete choice experiment design

We designed a stated preference survey (discrete choice experiment, DCE) to better understand the determinants of transport mode choice in the Grenoble conurbation and in particular the role that information on the health impacts of transport modes could play on daily transport mode choice decisions. The originality of the proposed design lies in the fact that we focus on the impact of health concerns and distinguish altruistic motivations related to public health (impact of the mode of transport on pollution) from selfish motivations related to individual health (impact of walking or cycling instead of driving on its own physical activity and its own health).

Each interviewee was asked to choose a trip he or she makes on a regular basis, this through a map of the Grenoble Metropolitan Area divided in 876 small zones. The individual was asked to consider this particular trip when answering to the DCE. Four modes of transport (car, public transport, cycling, walking) were presented in each choice exercice if the distance of the reference trip was smaller than three kilometers and three modes of transport (car, public transport, cycling) if not. Each mode was characterized by travel time, travel cost and sanitary risks expressed as risk of developing a cardiovascular disease (cf. Table 1).
Regarding the two health attributes, the probabilities presented in the DCE refer to Arterial Hypertension which is the most frequent chronic disease in France Inserm (2018). More precisely, 30% of adults will be affected by a cardiovascular disease during their lifetime. The attribute concerning physical activity of each mode corresponds to the absolute risk of developing a cardiovascular disease if the trip is made with a given mode on a regular basis, considering the distance done and the mode-specific intensity of effort required. As for the attribute concerning pollution for each mode, it corresponds to the average risk of the population of the urban area if 50%, 75% or 90% of the population uses this mode of transport on a regular basis.

For the first two choices, only two attributes (cost and time) were presented to the respondents. In the following seven choices the two attributes related to health were added.

Since the level of these attributes varied from one question to another, we are able, through discrete choice model, to estimate the weight of each attribute in the modal choice. These models allow us to evaluate demand elasticities, willingness to pay, time equivalents that can feed into operational evaluation and decision support tools.

The reference levels of the time and cost attributes use origin-destination matrices. Knowing the distance between the centres of two of the zones, it is possible to find the reference times for trips made by car, on foot or by bicycle, using the API of Google Map and Odomatrix Hilal (2010), and the reference times for trips by public transport with the outputs of the assignment stage of the multi-modal model of the Grenoble conurbation. For health-related attributes, benchmarks are defined as absolute risks of developing cardiovascular disease. We have set the absolute risk for the car at 30% Inserm (2018).

The levels for all attributes are set at the levels described in Table 1.

In order to build our experimental design, we used the software NGENE ChoiceMetrics (2012) and create an efficient design that can take into account the information we have on priors and the reference alternative. The efficiency of the design was evaluated thanks to the D-error. We obtained D-errors ranging between 0.02 and 0.1, which indicates a high statistical efficiency (covariances of the parameter estimates being low). Finally, no dominant alternatives were found in any of the choice situations generated by the designs after careful manual checks.

2.2 Data

The data was collected between June and September 2019. 1,000 participants were recruited for this survey. To be illegible, the respondent must live in one of the 49 municipalities of the Grenoble metropolitan area, must be 18 years old or more, must have a driving licence and at least one car in her household.

The descriptive statistics of the sample show a high representation of women in the sample of trips below 3 km. The two samples for distances have a very comparable age distribution of respondents. However, the reasons for travel in these two groups are very different. While more than two-thirds of the trips above 3 km are for commuting to work, this is the case for only 36% of the trips below 3 km. The modal choices for the status quo are also very different according to the distance travelled. For example, 58% of the status quo for trips longer than 3 km are made by car, 26% by public transport and 16% by bicycle, for trips shorter than 3 km only 39% are made by car and 16% by public transport, while 28% are made by bicycle and 17% by foot.

3 Model framework

The modeling framework fits into the standard Discrete Choice Modeling formulation McFadden (1974). We model the utility U_j associated with each transport mode j.

$$j \in \mathbf{C} = \{1, 2, 3, 4\} = \{\text{car, public transport PT, bicycle, walking}\}$$

This utility is derived from an alternative-specific constant (ASC_j), an alternative-specific travel time (T_j), travel cost (C_j), level of cardiovascular risk related to physical activity ($PHYS_j$), level of cardiovascular risk related to air pollution ($POLL_j$), as well as the percentage of the population adopting alternative modes to the car (A_j). These two last variables are crossed to control for a potential conformity effect. An individual's utility also depends on individual-specific variables which are age (AGE), gender ($GENDER$), and the transport mode ($STATUS$) used regularly (the status quo option). Hence, the status quo defines the type of user: car user, public transport user, cyclist or walker. The utility function is therefore $\forall j \in \{1,2,3,4\}$

$$\begin{aligned}U_j =& ASC_j + \beta_T j \times T_j + \beta_C \times C_j + \beta_{PHYS} \times PHYS_j + \beta_{POLL} \times POLL_j + \beta_A \times A_j + \beta_{POLL_A} \times A_j \times POLL_j \\ &+ \gamma_{AGE} \times AGE + \gamma_{GENDER} \times GENDER + \gamma_{STATUS_j} \times STATUS\end{aligned} \tag{1}$$

where $\boldsymbol{\beta}^T = (\beta_T j, \beta_C, \beta_{PHYS}, \beta_{POLL}, \beta_A, \beta_{POLL_A})$ and $\boldsymbol{\gamma}^T = (\gamma_{AGE}, \gamma_{GENDER}, \gamma_{STATUS})$ are two vectors of parameters to be estimated[1].

As mentioned previously in the description of our survey, the number of alternatives presented to the participants and the number of choice exercises depend, both, on the distance considered (more or less than 3km) and the step of the experiment (2 choice exercises for step 1 and 7 exercises for step 2).
Hence, we estimate four models which differ depending on 1) the alternative-specific variables introduced (depending on the step) and 2) the distance considered:

- S1B3: estimation on the data of the first step, for distances below 3 kilometers.

  In Equation (1), this corresponds to the constraint $\beta_{POLL} = \beta_{PHYS} = \beta_A = 0$, $\forall j \in \{1,2,3,4\}$

- S2B3: estimation on the data of the second step, for distances below 3 kilometers.

  Equation (1) holds no restriction on the β coefficients, $\forall j \in \{1,2,3,4\}$.

- S1A3: estimation on the data of the first step, for distances above 3 kilometers.

  In Equation (1), this corresponds to the constraint $\beta_{POLL} = \beta_{PHYS} = \beta_A = 0$, $\forall j \in \{1,2,3\}$ if we consider that 4 stands for the walking option.

- S2A3: estimation on the data of the second step, for distances above 3 kilometers.

  Equation (1) holds with no restriction on the β coefficients, $\forall j \in \{1,2,3\}$.

As outputs of these models, we define the willingness-to-pay for travel time (i.e. Value of Time, VoT), willingness-to-pay to gain 10% of risk reduction[2] in individual health risk related to physical activity (WTP_{PHYS}) and willingness-to-pay to gain 10% of risk reduction in health risk of the population related to air pollution (WTP_{POLL}).
We recall that WTP is the variation of the cost attribute (β_C) that an individual would accept to maintain the same level of utility when there is a variation in another attribute (e.g. Time attribute in the case of

[1] For simplicity purposes, the individual indices are omitted.
[2] e.g. reduction from 30% to 20%

calculating the VOT). In our case, these WTP are calculated as follow:

$$
\begin{aligned}
VOT &= -\frac{\beta_{Tj} \times 60}{\beta_C} \\
WTP_{PHYS} &= -\frac{\beta_{PHYS} \times 10}{\beta_C} \\
WTP_{POLL} &= -\frac{\beta_{POLL} \times 10}{\beta_C}
\end{aligned}
\tag{2}
$$

4 Results and discussion

4.1 Estimation results

Table 3 presents the results[3] of the regressions. For the interpretations of the four models, we choose the car as a reference mode which means that we normalize the ASC of the car to zero.

Whatever the specification of the model, the coefficients for the cost attribute are significantly different from zero at a 95% confidence level for all modes. As expected, cost coefficients are negative meaning that a higher cost impacts negatively the utility of the participant and discourages the use of the mode.

Concerning the time attribute, alternative specific coefficients are considered. For travel distance below 3km, time is only significant for walking. A possible explanation of this result is the fact that for short trips, trip duration is always small and negligible effort is required for other modes than walking. More in depth analysis is intended to confirm this intuition. With distance above 3 km, the duration of the trip has a significant and negative effect on the utility. This effect appears to influence differently the choice of the proposed alternatives. In S1A3 and S2A3 the results show that people perceive less negatively the time spent in the car compared to the public transport, and even less negatively compared to the bicycle (see also next Section for an interpretation of the VoT).

The introduction of the information about individual cardiovascular risk induced by physical activity related to alternatives to the car has a significant effect only for distance greater than 3 km. This effect is negative, which means that the lower the risk for cardiovascular disease is, the greater the likelihood that an alternative mode of transport to the car will be chosen. The insignificance of this attribute for distances below 3 km could be explained by the fact that for such short trips, the physical activity done through the chosen mode is not intense enough to influence notably the impact of cardiovascular risk and thus the preferences.

The information about the public health impact generated by the pollution is significant only in two cases. First, for distance below 3 km (model S2B3), it is significant only when the information is framed with 50% of the population adopting the same alternative mode: a mode presenting a higher risk is less likely to be chosen when 50% of the population adopt the same mode. With larger shares of the population adopting the same alternative, this attribute does not have an effect on the preferences of the respondents. On the contrary, for distance above 3 km (model S2A3), the information about the public health risk is significant (at 10%) only when the information is framed with 90% share of the population adopting the mode of transport.

[3] These results were obtained using PythonBiogeme Bierlaire (2016).

The effect of such information remains negative on the probability of an alternative to the car to be chosen when the public health risk increases.

For all models, the reference mode of the participant (i.e. her status quo) has a significant effect on the choice. Given that coefficients for the status quo ($STATUS_{PT}$, $STATUS_{BICYCLE}$ and $STATUS_{WALK}$) are positive, participants who do not have the car as status quo prefer to choose an alternative mode to the car.

4.2 Economic outputs: Willingness to pay (WTP) and Value of time (VOT)

Table 4 shows the VOT and WTP that are derived from our choice models.

VOT for car, public transport and bicycle can only be calculated for distance above 3 km. VoT for car is comprised between 3.8 and 6 €/hour, which is in the low range of French guideline values (Quinet et al., 2014) and literature (Wardman, Chintakayala, de Jong, & Ferrer, 2012). The public transport VoT range between 5.8 and 8.5 €/hour, which is consistent with the French values of Wardman et al. (2012)'s meta-analysis. There are still very few studies on the value of time of active modes. If we use the walking multiplicator of Abrantes and Wardman (2011), then the walking VoT is rather high by comparison to the car VoT. For cycling, the VoT is in the range of the values provided in Börjesson and Eliasson (2012).

A higher VoT for the bicycle and public transport compared to the car may result from the fact that 58% of our sample are usual car users. So, asking car users to change their modal choice requires them a costly effort, which reflects in VoT. This intuition must be confirmed by analysing the heterogeneity of VoT by type of user.

For all values that could be calculated, we obtain higher VOT when the health attributes are introduced. The increase of VOT between step 1 and step 2, is larger for car (+57%), than for public transport (+47%) and bicycle (+33%). This may result from the framing effect of introducing both health attributes which may discourage the use of cars compared to all other modes that have positive health effects.

For distances above 3km, the WTP for decreasing by 10% the individual risk of developing a cardiovascular disease related to physical activity amounts to 0.75 euro.

For distances below 3km and a framing of the information with a share of 50% of the population adopting the mode of transport, the participants are willing to pay 6.04 euros to lower the risk related to air pollution by 10%. But, for distances above 3km and a framing of the information with a share of 90% of the population adopting the mode of transport, this value decreases to 2.6 euros.

Lastly, we note that for distances below 3 km, participants are willing to pay more when the risk is related to the public health than when the risk is related to the individual's health. On the contrary, when trips are of a greater distance, the participants' WTP becomes lower for reducing the risk related to public health.

Our findings seem to confirm that information on health risks related to air pollution or lack of physical activity both have a significant effect on the preferences of the participants in regards to modal choice. There is a preference for modes that generate a lower risk which means that there is a preference for the alternatives to the car.

To the best of our knowledge, this is the first study that investigates the effect of these kind of information as attributes in a discrete choice experiment.

Attributes	Mode	Definition	Levels <3km	Levels >3km
Time	**Car**	Time to get the car, time spent in the car, searching for a parking spot and to reach the final destination	tempsvoit × [0.8/ **1**/ 1.3] + 3 min	
	Public Transport	Time to go to the station and waiting time, time in the public transport and to reach the final destination	tempsPT × [0.7/ **1**/ 1.2] min	
	Bicycle	Time spent on the bicycle to get from departure to the final destination	tempsbike × [0.7/ **1**/ 1.2] + 3 min	
	Walk	Walking time from departure to the final destination	tempswalk × [0.7/ **1**/ 1.2] min	
Cost	**Car**	Cost of fuel (one way)	[**0.50**/ 0.75/ 1] €	coutvoit × [**1**/ 1.5/ 2] €
	Public Transport	Cost of a public transport ticket	[0/ **0.50**/ 1.50] €	
Pollution (Public health)	**Car**	Average risk of developing a cardiovascular disease for a person in the Grenoble urban area considering that [50/75/90]% of the population adopt this mode of transport	30%	
	Public Transport		[27/ **28**/ 29]%	
	Bicycle		[25/ **26**/ 27]%	
	Walk		[25/ **26**/ 27]%	
Physical activity (Individual health)	**Car**	Individual risk of developing a cardiovascular disease	30%	
	Public Transport		[24/ **26**/ 28]%	
	Bicycle		[24/ **26**/ 28]%	[15/ **20**/ 25]%
	Walk		[20/ **24**/ 27]%	

Notes: In the level column, figures in bold refer to the "statu quo" levels.
coutvoit = (0,12*(km-3)) arrondi au 0.5 superieur. tempsmode: issue de google map ou odomatrix.

Table 1: Attributes and levels

Label	Variable definition	Distance of reference trip					
		All distances		Below 3 km		Above 3km	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Alternative specific variables		($n = 9,027$)		($n = 1,899$)		($n = 7,128$)	
$Cost_{Car}$	Travel cost by car (in euros)	1.18	0.69	0.65	0.20	1.18	0.69
$Time_{Car}$	Travel time by car (in minutes)	20.52	9.07	10.12	3.15	23.29	8.06
$Time_{PT}$	Travel time by public transport (in minutes)	29.39	14.51	13.66	6.27	33.54	13.15
$Time_{Bicycle}$	Travel time by bicycle (in minutes)	24.33	15.07	9.09	2.92	28.39	14.40
$Time_{Walk}$	Travel time by foot (in minutes)			18.40	9.54		
Framing of the pollution information		($n = 1,003$)		($n = 211$)		($n = 792$)	
75% of pop	75% of the population adopt the same mode (=1 if yes)	33.00		36.97		31.94	
90% of pop	90% of the population adopt the same mode (=1 if yes)	34.30		29.38		35.60	
Individual variables		($n = 1,003$)		($n = 211$)		($n = 792$)	
Male	Gender (1 if male)	48.06		44.55		48.99	
Age	Age (in years)	51.72	12.70	51.36	13.65	51.82	12.44
Commuting trip	% of reference trips which are commute to work						
$STATUS_{Car}$	Car is usually used for the reference trip (=1 if yes)	53.94		38.86		57.58	
$STATUS_{PT}$	PT is usually used for the reference trip (=1 if yes)	23.93		16.11		26.01	
$STATUS_{Bicycle}$	Bicycle is usually used for the reference trip (=1 if yes)	18.94		28.44		16.41	
$STATUS_{Walk}$	Reference trip is usually made by foot (=1 if yes)	3.49		16.59		-	

Table 2: Descriptive statistics

Variable	S1B3	S2B3	S1A3	S2A3
$ASC_{Bicycle}$	-3.11 (2.09)	-5.03 (1.02)***	-0.03 (0.90)	1.02 (0.58)*
ASC_{PT}	-4.28 (2.14)**	-6.24 (1)***	-0.134 (0.90)	1.14 (0.55)**
ASC_{Walk}	-2.16 (2.09)	-3.87 (1.02)***		
ASC_{Car}				
Cost	-0.97 (0.28)***	-0.35 (0.16)**	-0.66 (0.10)***	-0.48 (0.056)***
$Time_{Bicycle}$	-0.06 (0.05)	-0.02 (0.03)	-0.08 (0.01)***	-0.07 (0.003)***
$Time_{PublicTransport}$	-0.011 (0.02)	0.01 (0.01)	-0.06 (0.01)***	-0.07 (0.004)***
$Time_{Car}$	-0.01 (0.06)	0.02 (0.04)	-0.04 (0.01)***	-0.05 (0.01)***
$Time_{Walk}$	-0.14 (0.02)***	-0.11 (0.01)***		
$CardioRisk_{Phys}$		-0.03 (0.02)		-0.04 (0.01)***
$CardioRisk_{Poll}$		-0.21 (0.07)***		-0.05 (0.04)
75% of pop		-2.2 (1.82)		1.61 (0.98)
90% of pop		-3 (2.04)		2.06 (0.98)***
$CardioRisk_{Poll}$ * 75% of pop		0.13 (0.07)*		-0.05 (0.04)
$CardioRisk_{Poll}$ * 90% of pop		0.13 (0.08)*		-0.07 (0.04)***
Male	0.34 (0.29)	0.37 (0.18)**	0.17 (0.12)	0.08 (0.07)
Age	0.14 (0.08)*	0.16 (0.04)***	0.01 (0.03)	-0.04 (0.02)***
Age^2	-0.002 (0.01)**	-0.002 (0.0003)***	-0.0002 (0.0003)	0.0003 (0.0002)
Distance (=1 if distance¡3km)				
$STATUS_{Car}$				
$STATUS_{PT}$	1.45 (0.46)***	1.3 (0.26)***	1.6 (0.18)***	1.93 (0.11)***
$STATUS_{Bicycle}$	2.18 (0.49)***	3.65 (0.52)***	2.33 (0.26)***	2.74 (0.18)***
$STATUS_{Walk}$	3.09 (1.05)***	3.6 (0.73)***		
L($\hat{\beta}$)	-444.37	-1563.22	-1443.05	-4858.39
$\bar{\rho}^2$	0.216	0.227	0.164	0.2
Observations	*422*	*1,47*	*1,584*	*5,544*

Notes: Standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$
S1B3: step 1 with distance below 3km; S1A3: step 1 with distance above 3km;
S2B3: step 2 with distance below 3km; S2A3: step 2 with distance above 3km.

Table 3: Estimation results

	S1B3	S2B3	S1A3	S2A3
VOT (€/hour)				
Car	-	-	3.8	5.96
Public Transport	-	-	5.8	8.54
Bicycle	-	-	6.82	9.08
Walk	8.85	18.8		
WTP$_{PHYS}$ (€/ 10% lower risk)				
All modes		-		0.75
WTP$_{POLL}$ (€/ 10% lower risk)				
All modes (50% of pop adopting the behavior)		6.04		-
All modes (75% of pop adopting the behavior)		-		-
All modes (90% of pop adopting the behavior)		-		2.6

notes: The WTP_{POLL} is calculated using a coefficient of $CardioRisk_{Poll}$ * 90% of pop that is significantly different from zero at a 90% confidence level.

A small line refers to the fact that the economic measure cannot be calculated because of the presence of one (or more) non-significant coefficient(s) (Hensher, Rose, & Greene, 2005, p. 359).

An example of interpretation: In S1A3, we have a VOT_{Car} = 3.8€/hour this means that, in average, our participants accept to pay 3.8€to minimize the duration of a trip with the car by 1 hour.

Table 4: Value of time (VOT) and Willingness to pay (WTP) for the attributes of the DCE

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