Considering Indicators of External Costs in a Transportation Mode Choice Model

Filippos Adamidis*[1], Mohamed Abouelela[1], Constantinos Antoniou[2]

[1] M.Sc., Technical University of Munich, Germany

[2] Prof. Dr., Technical University of Munich, Germany

SHORT SUMMARY

Although transportation is vital to satisfying human needs and sustaining economic activity, it is linked with negative side effects, including emissions, noise, accidents and congestion. The negative costs resulting from them, also called external costs of transportation, are very often neglected in our everyday mobility decisions. This paper proposes a simple mode choice model incorporating external cost indicators based on recent estimates from Munich, Germany. The respondents of a stated preference survey were asked to choose between transportation modes in theoretical scenarios, where indicators of external costs, numerical or schematic, were shown as mode attributes. The results of a multinomial logit model show that indicators of external costs can influence travel behaviour, although other variables, such as the ownership of mobility tools and the sociodemographic background, also explain mode choices. Despite the limitations, this paper provides initial insights into modelling travel decisions under external cost pricing indicators.

Keywords: discrete choice modelling, external costs, mode choice, pricing, travel behaviour.

1. INTRODUCTION

The transportation of people and goods has been linked to negative impacts such as air and noise pollution, accidents, time loss, health effects and land consumption. Those impacts, also known as externalities, are not carried exclusively by transportation users but rather by the society as a whole, even by people who do not benefit from transportation. Nonetheless, those externalities are not reflected in the price the users have to pay for their transportation; thus, they may not influence travellers' decisions at all. Many researchers have argued that this injustice can be softened by achieving transparency regarding direct and external transportation costs (Molloy, Tchervenkov, & Axhausen, 2021).

The full transportation cost was extensively studied in the past, emphasising road modes. For example, Verhoef (1994) found that the benefits associated with road transport cannot compensate for the external costs, while Levinson and Gillen (1998) provided estimated costs for each externality (infrastructure, congestion, noise, pollution, etc.) as a result of road transport. Later, research increasingly acknowledged that different modes also come with different costs and benefits. Eriksen (2000) estimated the external costs of different passenger and freight modes in Norway, e.g. public transport, motorcycles and goods vehicles. Recently, Gössling et al. (2019) found motorised road transportation to have a negative economic footprint in the European Union, whereas active modes such as walking and cycling provided net benefits due to positive health effects.

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*Corresponding author: filippos.adamidis@tum.de

As a result, the impact could be reduced by shifting from road transport to alternative modes. Although influencing travel behaviour through external costs is challenging, the idea is to internalise external costs, i.e. pass the external costs to the user. To this aim, a solution proposed in the past is congestion charging, e.g. in London, Stockholm and Singapore, with positive effects on traffic, road safety and the environment (Green, Heywood, & Paniagua, 2020). Other researchers claimed that gamified mobile applications could impact travel behaviour and turn users to more sustainable modes (Axhausen et al., 2021).

As transportation results from a highly complex interaction between human behaviour, the built environment and policy, it is difficult to estimate external costs and their monetary value. Recently, Schröder et al. (2023) combined data from multiple sources to estimate the external costs of different modes in Munich. Based on the aforementioned study, we aim to investigate if indicators of external costs can influence the mode choices of individuals. The objective is to design and conduct a stated preference (SP) study, analyse the results through a suitable modelling framework and discuss the potential policy implications stemming from the model. More information about the methodology, the dataset, the modelling results and the main findings are presented in the next sections.

2. METHODOLOGY

Indicators of external costs

For each transportation mode, the intensity of external costs was simply calculated as the product of the travelled distance and the values shown in Table 1. It is important to mention that the value for gasoline-powered vehicles was assumed for car-based modes, although the differences between the various engine types were minor.

Table 1: Approximate external costs in Munich (Schröder et al., 2023)

Mode	**External cost** $€/km$
Walking	0.01
Private car	0.16
Private bike	0.07
Public transport	0.07
Car-sharing	0.16
Bike-sharing	0.07
E-scooter-sharing	0.19

The estimated external costs can be presented in two ways that convey the same information:

1. As a numerical indicator that shows the estimated value of the external costs.
2. Using a schematic indicator that presents the same information, although with fewer details.

The two indicators are similar with regard to their calculation basis, as they present the same information in a different way. The schematic indicator, here called the *MobiScore* (Figure 1), is a five-level indicator of external costs in urban transportation based on the Nutri-Score and has been developed within the project MCube SASIM[2]. Each transportation mode was labelled based

[2] Smart Advisor for Sustainable Integrated Mobility (https://www.mcube-cluster.de/en/projekt/sasim/)

on predefined and equidistant limits, starting from the least harmful (A) to the most harmful (E), also receiving the respective colour code from dark green to red.

Figure 1: The *MobiScore* – a visual indicator of external costs in transportation

The Nutri-Score is a front-of-pack nutritional rating system in Europe that indicates the overall nutritional value of products. It has been developed by the National Public Health Agency of France and is currently used in many European countries. Its main goal is to inform consumers without directly giving many nutritional details, thus easily capturing the attention of potential buyers. Similarly, the *MobiScore* was envisioned as a schematic indicator of the external costs for different modes. As of 2023, the Nutri-Score remains controversial in many countries, and only insufficient evidence supports a positive health effect (Peters & Verhagen, 2022). Its mobility-related equivalent, the *MobiScore*, will be deployed through a smartphone trip-planning application.

Survey design

The effectiveness of the aforementioned indicators in steering mode choices was tested in a three-part stated preference (SP) survey. The first part concerned the usual travel behaviour of the respondents, i.e. driver’s license and access to one or more private cars, use of car-sharing and shared micromobility, usual mode choices for everyday trips and home office habits. The second part sequentially presented sixteen SP mode choice questions to the respondents, including the main modes used in Munich and testing distances of 2 km and 7 km based on data from the MiD 2017 survey (infas et al., 2018). This part has been specified by considering a random selection of questions drawing from the full factorial design with up to three different attributes with three levels each. The attributes of the modes were defined as follows:

- Travel time is the total time needed for the trip.
- Direct cost is the total cost paid for the trip.
- External cost includes the cost society pays because of the choice of a certain mode.
- MobiScore is a rating of the external costs incurred by each mode.

At the beginning of part two, detailed explanations were given about application-based trip planners on smartphones and the external costs of transportation. The last part of the survey included questions that aimed to identify the sociodemographic characteristics of the respondents, including gender, age, physical disabilities, household size, occupation and income.

Data collection and analysis

The dataset was collected between November and December 2023 through an online panel (https://www.bilendi.de) consisting of respondents residing in Munich. The survey included four scenarios, each with four questions, that aimed to investigate the sensitivity of the respondents to different indicators:

1. The status quo scenario included only the travel time and the direct travel cost as mode attributes.

2. In addition to the previous, this scenario showed a numerical indicator of the external costs.
3. Showing the *MobiScore* indicator of the external costs in place of the numerical indicator.
4. Showing the travel time and the full cost of transportation modes (including direct and external costs).

The respondents were asked to select one mode based on the values of its attributes or to select 'None of the above', indicating dissatisfaction with the offered alternatives. For the subsequent analysis in this survey, data only from the second and third scenarios were utilised, i.e. eight observations per respondent.

The random utility theory was then employed to analyse the survey results. Multinomial logit (MNL) models estimate the probability of choosing one alternative among many based on the value of its utility. The average utility of each alternative i for an individual n is given by the random utility model:

$$U_{in} = V_{in} + \varepsilon_{in} \text{ with } V_{in} = \beta_i^T x_{in} \tag{1}$$

where β_i is a vector of the estimated parameters for alternative i. The probability of choosing alternative i from a choice set C_n of alternatives by individual n is given by:

$$P(i|C_n) = \frac{e^{V_{in}}}{\sum_j e^{V_{jn}}}, \quad \forall j \in C_n \tag{2}$$

The open-source package *Biogeme* (Bierlaire, 2023) was used to estimate the models and identify a vector of parameters β_i for each alternative.

3. RESULTS AND DISCUSSION

Travel behaviour and sociodemographics

After collecting data, some responses had to be removed from the sample. The main reasons included speeding through the questionnaire, with a completion time lower than one-third of the average completion time, failing to respond correctly to the attention check question or because the given residence postcode was situated outside the study area. In retrospect, more respondents were removed because their sociodemographic segment was underrepresented in the sample, e.g. gender *non-binary / third gender* (n=3), resulting in a sample of 600 respondents. A comparison of the sample with the officially published census (Federal Statistical Office, 2011) can be seen in Table 2. Overall, the panel data achieved a satisfactory representation of the key characteristics of the city's population.

Table 2: Key characteristics of the sample

Variable	Answer	Sample (%) *N=600*	Census (%) *2011*
Gender	Female	53.5	51.7
	Male	46.5	48.3
Age	≤17	0	14.6
	18-29	14.7	17.2
	30-39	23.7	16.7
	40-49	18.8	16.2
	50-59	19.5	11.8
	60-69	16.2	10.7
	70-79	6.3	8.4
	≥80	0.2	4.4
Occupation	Full-time work	57.8	56.5
	Part-time work	14.0	
	Pupil, student or apprentice	5.3	4.5
	Retired	16.7	18.3
	Housewife/Househusband	2.5	2.9
	Other	1.2	17.8
Size of household (no. of people)	1	31.7	50.3
	2	38.5	28.8
	3	14.8	10.6
	≥4	15.0	10.3
Driving license	Yes	88.7	88.9*
	No	11.3	11.1*
Car ownership	0	24.6	44.0*
	1	55.6	49.0*
	≥2	19.7	7.0*

**Mobilität in Deutschland* (infas, DLR, IVT & infas 360, 2018)

Model estimation

This section includes the results of model estimation and some of the main findings. The MNL model (Table 3) was estimated after merging the alternatives bike-sharing and e-scooter-sharing, as their choice frequency in the sample was low (both less than 0.5%); those alternatives were included alternately in the choice set, thus enabling this simplification. Furthermore, it should be noted that each of the two indicators was considered in the estimation procedure only when available, thus avoiding collinearity, as the model drew on data from two different scenarios (based on the same assumptions).

As can be seen, the coefficients of mode attributes, i.e. travel time, direct cost, external cost and *MobiScore*, are reasonable in sign and magnitude. Regarding the variables of interest, we observe that external costs, modelled through a generic coefficient as usual with cost components, significantly impacted mode choices negatively (-0.342). However, an interesting finding, which requires further investigation, is the magnitude of the external costs compared to the direct costs of the modes (-0.144); it is apparent that the former was perceived as almost two times worse than the latter, even though external costs were only shown to the respondents, after stating in the hypothetical scenario description that the respondents would not have to pay for them. A similar effect has been observed in Vrtic et al. (2010), where an additional cost component related to the toll cost had a higher magnitude than the coefficient of the fuel cost. This demonstrates the importance of extraordinary costs on mode choice and also underlines the difficulty in explaining theoretical scenarios to survey participants. The *MobiScore* was found to be negatively significant in the choice probability of all modes except shared micromobility, with private car and public transport being less affected (-0.066) than private bike and car-sharing (-0.090) and walking (-0.179). These findings help answer our research question and confirm the initial hypothesis that the indicators of external costs can influence mode choices.

Regarding the established travel behaviour of individuals, we can see that car drivers tended to select alternative modes less often than the automobile (reference mode). As expected, respondents without access to a private car seemed to prefer alternative modes, especially car-sharing (2.010), whereas respondents with access to two or more vehicles showed a clear preference for private cars, as shown by the negative coefficients of all other modes compared to the reference mode (private car). Concerning trip purposes, respondents seemingly preferred walking (0.512) and avoided public transport (-0.178) for leisure, while active modes (walking, -0.619; private bike, -0.552) and public transport (-0.543) would also be avoided during shopping trips.

Moreover, many sociodemographic characteristics were found to be significant. For example, the model revealed the strong rejection of car-sharing by middle-aged (-1.260) and older (-5.800) respondents. Women were found to avoid car-sharing (-0.609), a prevalent finding in the literature. Students preferred private bikes (0.773) and public transport (0.563). Nonetheless, some counterintuitive findings were associated with car-sharing; for example, owners of a driving license highly disfavoured this mode (-1.460), while unemployed respondents tended to this mode (0.944), although car-sharing involves a high direct cost compared to public transport and private bikes.

Policy implications

The proposed methodology reveals that travellers perceived external costs negatively. Such costs can be communicated either directly as numbers or through a schematic indicator like the *MobiScore*. Thus, travel behaviour could potentially be influenced through the internalisation of external costs, i.e. the inclusion of an external cost component in the price of mobility (Saxena & Choudhury, 2022). Nevertheless, this presents an important challenge for policymakers because imposing an extra charge based on mode choice is almost impossible with the current transportation system. As mentioned at the beginning of this paper, congestion charging and tolls have been the prevalent ways of reducing transportation externalities until now. Nowadays, the widespread use of smartphones, which can detect mode usage, could be an alternative way to achieve full cost transparency for all modes while also enabling dynamic charging and wide network coverage.

Initially, policymakers should focus on increasing awareness about externalities and their associated costs. Information can be disseminated through many channels, including mobile trip planning applications, as they offer personalised information based on the modes or routes the user is willing to take. However, caution should be exercised about the findings stemming from this survey because the model was based on an SP experiment. This means that the participants considered the external costs and the *MobiScore* during the survey, although they may not consider them at all when faced with similar mobility decisions in reality. Therefore, finding an effective mechanism to influence mode choices through external costs is important if policymakers aim to reduce transportation externalities.

Table 3: Multinomial logit model

Modes	Walking		Private Car		Public Transport		Private Bike		Car-sharing		Shared Micromobility		None	
Parameters (β_i)	Value	Rob. *t-stat*	Value	Rob. *t-stat*	Value	Rob. *t-stat*	Value	Rob. *t-stat*	Value	Rob. *t-stat*	Value	Rob. *t-stat*	Value	Rob. *t-stat*
ASC	1.510	4.61***	-	-	1.660	9.89***	0.959	3.96***	-2.460	-4.41***	-2.940	-13.9***	-3.360	-18.30***
Travel time (min.)	-0.036	-4.37***	-0.030	-4.97***	-0.036	-8.21***	-	-	-	-	-	-	-	-
Direct cost (€)	-	-	-0.144	-5.65***	-0.144	-5.65***	-0.144	-5.65***	-0.144	-5.65***	-0.144	-5.65***	-	-
External cost (€)	**-0.342**	**-2.63*****	**-0.342**	**-2.63*****	**-0.342**	**-2.63*****	**-0.342**	**-2.63*****	**-0.342**	**-2.63*****	**-0.342**	**-2.63*****	-	-
MobiScore	**-0.179**	**-1.48**	**-0.066**	**-2.30****	**-0.066**	**-2.30****	**-0.090**	**-2.19****	**-0.090**	**-2.19****	-	-	-	-
$\text{Purpose}_{\text{Leisure}}$	0.512	4.07***	-	-	-0.178	-2.14**	-	-	-	-	-	-	-	-
$\text{Purpose}_{\text{Shopping}}$	-0.619	-4.06***	-	-	-0.543	-6.16***	-0.552	-5.02***	-	-	-	-	-	-
Driving license	-0.648	-3.16***	-	-	-1.190	-8.84***	-0.455	-2.35**	-1.460	-3.60***	-	-	-	-
$\text{Car access}_{=0}$	1.360	8.22***	-	-	1.270	11.50***	1.370	9.16***	2.010	6.65***	-	-	-	-
$\text{Car access}_{\geq 2}$	-0.453	-2.52**	-	-	-0.532	-5.25***	-0.673	-4.70***	-	-	-	-	-	-
$\text{Gender}_{\text{Female}}$	-0.186	-1.76*	-	-	-	-	-	-	-0.609	-2.46**	-	-	-	-
$\text{Age}_{\leq 39}$	-	-	-	-	-	-	-0.410	-4.11***	0.803	2.63***	-	-	-	-
$\text{Age}_{50\text{-}69}$	-	-	-	-	-	-	-	-	-1.260	-2.60***	-	-	-	-
$\text{Age}_{\geq 70}$	-	-	-	-	-	-	-0.580	-2.86***	-5.800	-16.90***	-	-	-	-
$\text{Nationality}_{\text{German}}$	-	-	-	-	-	-	0.417	2.89***	-	-	-	-	-	-
Disability	-0.794	-4.17***	-	-	-	-	-0.784	-5.09***	1.120	3.78***	-	-	-	-
$\text{Household size}_{=1}$	0.296	2.19**	-	-	0.292	3.36***	-0.514	-4.07***	-	-	-	-	-	-
$\text{Household size}_{=3}$	-	-	-	-	-	-	-	-	0.712	2.30**	-	-	-	-
$\text{Household size}_{\geq 4}$	-	-	-	-	-	-	-	-	0.772	2.51**	-	-	-	-
$\text{Personal income}_{\leq 2500}$	-	-	-	-	0.142	1.74*	-	-	-	-	-	-	-	-
$\text{Personal income}_{\geq 3750}$	-0.408	-2.94***	-	-	-	-	-	-	1.030	4.20***	-	-	-	-
$\text{Education}_{\text{Low}}$	-	-	-	-	-	-	-0.665	-1.91*	-	-	-	-	-	-
$\text{Education}_{\text{University}}$	-0.253	-2.32**	-	-	-	-	-	-	-	-	-	-	-	-
$\text{Occupation}_{\text{Student}}$	-	-	-	-	0.563	3.50***	0.773	3.51***	-	-	-	-	-	-
$\text{Occupation}_{\text{Unemployed}}$	-	-	-	-	-	-	-	-	0.944	2.36**	-	-	-	-

Summary of statistics

No. of observations	4800
LL*(0)*	-7627.3
LL*(final)*	-5371.5
Adj. Rho-square	0.30
AIC	10850.9

Reference mode: Private Car, Value of Time: 12.63 €/h (Private Car), 15.08 €/h (Public Transport)
Significance levels (Rob. *p*-value): 0 '***' 0.01 '**' 0.05 '*' 0.1

4. CONCLUSIONS

The main objective of this research was to provide initial insights into the effectiveness of external cost indicators in influencing mode choices. To address this question, a stated preference survey was designed and disseminated in Munich, Germany, where two indicators were introduced: a numerical and a schematic called the *MobiScore*. The collected responses were analysed based on the random utility theory, resulting in a mode choice model explaining the factors that influence the utility of different modes under the pricing of transportation externalities.

The results highlighted that the two indicators affected the individuals' mode choices. Both were found to reduce the utility of the modes, with the *MobiScore* having a lower negative impact on private car and public transport, while no conclusions could be made about shared micromobility based on the *MobiScore*. Other factors, such as the sociodemographic characteristics of the respondents (age, gender, nationality, education, occupation, personal income and household size) and their travel behaviour (car access, ownership of mobility tools), were also found to significantly impact mode choices.

Although this work provides important indications about the relevance of external costs in travel behaviour, it comes with limitations. An important limitation is the use of imbalanced data regarding the frequency of each mode in the sample. Furthermore, acquainting the survey participants with information about external costs could have influenced the significance of the relevant attributes within this modelling context. In the future, analyses should focus on integrating the full cost of transportation into mode choice models while also accounting for interactions between the measured variables. Combining this model with a suitable traffic simulation platform is important to investigate if pricing the externalities can result in a shift towards modes with lower external costs. Overall, this work can be seen as a first attempt to integrate the external costs of transportation into a mode choice model.

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