

## ABSTRACT

Nowadays, the need to jointly achieve an ecological and a digital transition in different sectors is recognised; however, both can only be pursued if there is a behavioural transition of the people involved. Consequently, this research project focuses on the study, interpretation and modelling of the mobility choice behaviour of transport users, in non-traditional choice contexts that cannot be easily interpreted within a 'utilitarian' paradigm.

Today, if the technological scenario in the transportation sector is complex and partially consolidated, the same cannot be said for the study of impacts on users' travel/mobility choices, which requires innovative tools consistent with the rapid social and cultural development that society is observing.

Up to now, users' choices have been studied by pursuing an economic approach, assuming, according to random utility theory, that users are fully rational, that they assign a utility to each choice alternative and that they choose the one to which they attach the maximum utility. The established models based on random utility theory have made it possible to interpret and model users' choices with a certain degree of reliability, using directly observable and measurable instrumental variables. In addition, the relatively recent development of hybrid choice models with latent variables has enabled a better interpretation of phenomena, with the possibility of considering variables that are not directly measurable (attitudes and perceptions), while still using a utilitarian approach.

However, the decision-making processes behind our choices are influenced by multiple determinants, which can only be taken into account through a psychological approach. The latter assumes that the decision-making process is local, adaptive, dependent on the choice context and the personal traits of the users; from this perspective, new cognitive paradigms should be explored, in conjunction with traditional approaches.

Furthermore, with respect to current mobility choices, which often require a real behavioural transition (e.g. switching from private cars to more sustainable mobility choices, switching from internal combustion vehicles to electric vehicles), it is deemed important not only to examine the users' choice at the moment it is made, but also to investigate the cognitive process that users go through before arriving at a given choice. Hence the intention to explore users' choices by focusing not only on a punctual analysis, but rather on an evolutionary process.

Two goals are pursued in this research, respectively of methodological and operational interest:

- 1) To identify and formalise innovative methodological approaches suitable for studying non-traditional choice contexts
- 2) To investigate the effectiveness of innovative methodological approaches on real case studies (e.g. market penetration of electric vehicles).

For the above reasons, the present research work investigates a new methodological approach involving the joint application of two psychological paradigms, namely the Theory of Planned Behaviour (TPB) and the Transtheoretical model (TTM) in order to test whether the stage of change can directly influence the users' behavioural intention.

This methodological approach is tested and applied to a choice context that lends itself to be understood as the result of quite a long evolutionary process, i.e. the purchase of an electric vehicle as opposed to the traditional solutions proposed in the Italian context (Petrol, Diesel, LPG and CNG).

The transition from an internal combustion engine vehicle to an electric vehicle involves a behavioural change. The question of the severity of the change in a person's level of mobility is not trivial, and the two objectives set in terms of research can be treated together. This work, explores:

- (i) **The joint applicability of two interpretative paradigms** → The idea of combining the theory of planned behaviour and transtheoretical model is the heart of the proposed methodological approach. Indeed, it can no longer be ignored that some choices are not punctual, but rather the result of an evolutionary process, representing a behavioural transition. This aspect must be explicitly taken into account when interpreting and simulating user mobility choices.

**[outcome (i)]** → Many of the postulated assumptions of this new methodological approach are confirmed through structural equation modelling. In particular, it emerges how the stage of change a user exhibits with respect to a certain behaviour directly influences his behavioural intention and thus his choices (actual behaviour).

- (ii) **Factors influencing the intention to purchase an alternative fuelled car** → Nowadays, the use of modelling tools to better interpret phenomena is common, as an essential aspect required to transport analysts is their ability to transfer to administrations, car manufacturers and different stakeholders the knowledge of the factors that, in each case, affect users' choices.

**[outcome (ii)]** → By estimating different choice models, it was possible to highlight the directly measurable or latent factors influencing users' purchase choices. First of all, it emerged that the two tangible factors of greatest disutility with respect to the purchase of electrified vehicles are the total monthly cost and the charging location. The total monthly cost, measured as a function of monthly consumption (related to daily journeys of 30 km), maintenance costs and upfront costs, is a disutility for all the alternatives, but due to the high purchase cost it is most prevalent for electrified solutions. The charging location constitutes a non-negligible limitation in the purchase of an electrified solution; it emerges that the possibility of charging both on the street and at home/work determines a greater utility for users. However, it is not always possible for users to make use of both forms of

charging. Several additional factors are significant in defining the utilities associated with each choice alternative. These factors are typically users' socio-economic characteristics, characteristics of their commuting or features of their owned cars. Interestingly, these attributes may directly influence users' choices, but it appears that, more appropriately, they influence people's attitudes and perceptions. Then, it is these latent factors, and in particular attitudes towards the environment, perceptions of electric vehicles and perceived behavioural control (with respect to the use of an electric vehicle) that influence users' choices.

- (iii) **The use of structural equation modelling to study the proposed new framework** → The modelling approach generally used to study theories derived from the psychological approach consists of the adoption of structural equation models. There are two strands of study that take the form of PLS-SEM or CB-SEM. It is widely debated in the literature which of the two is the more appropriate to use. For the present study, the most suitable method seemed to be the PLS-SEM; however, the validated model was also studied using the CB-SEM. **[outcome (iii)]** → In part, it was possible to observe what is reported in the scientific literature regarding the concept of 'large-scale bias', according to which the relationships of the measurement model are overestimated with the PLS-SEM, while those of the structural model are underestimated. On the other hand, the strength relationships between the different indicators or between the different constructs assumed in the model remained unchanged. Hence the importance of subsequently testing a similar model on a larger sample.
- (iv) **The use of consolidated discrete choice models** → the aim is to identify which is the best choice set to be taken into account as well as the establishment of benchmark models against which to compare results from more advanced approaches. **[outcome (iv)]** → It emerges that the user does not actually perceive the proposed alternatives as single elements, but elaborates his own distinction into three alternatives: conventional (Petrol and Diesel), Bifuel (Methane and LPG) and electrified. This amalgamation is quite coherent if one takes into account certain factors such as: the need for special refuelling areas, which are generally located close to the centre for the CNG and LPG solutions, a reduction in consumption in terms of monthly expenditure, often associated with the bifuel and electrified solutions, a vision of superior performance for the two conventional alternatives, and so on.
- (v) **The use of hybrid choice models** → The purpose of this activity is to identify which latent factors may influence users' purchasing choices, their extent, and the improvement in interpretative and simulative terms that may be made by considering these factors. The latent factors referred to are those generally explored in the literature with reference to the examined choice context: attitude towards the environment, attitude towards technology, consumption perception, social norms, perception of the advantages of electric vehicles and perception of the disadvantages of electric vehicles. **[outcome (v)]** → It emerged that attitudes towards the environment and perceptions of the advantages of electric vehicles contribute to the utility associated with the purchase of electric vehicles. The models obtained strengthen the interpretation compared to the model without latent factors.
- (vi) **The use of hybrid choice models with latent variables from psychological paradigms** → The constructs postulated by the theory of planned behaviour (and thus derived from psychological considerations) have been incorporated, in the form of latent variables, into the choice models. In this way, while still considering utilitarian modelling, the exploration has been extended towards constructs derived from psychological theory. **[outcome (vi)]** → It emerged that the attitude towards electric vehicles and perceived behavioural control contribute to the utility associated with the purchase of electric vehicles. This emphasises how a psychological approach is crucial for a perfect understanding of the decision-making process.
- (vii) **The use of advanced models, based on a utilitarian estimation approach (maximisation of the utility function), but defined trying to integrate all the relationships postulated by the theory of planned behaviour** → With this step, an attempt is made to fully bridge the gap between the interpretative and simulative approaches. This step consists in implementing hierarchical hybrid models in order to reproduce all the relationships between the constructs postulated by the TPB directly in the choice model; an attempt is made to take into account the relationships between the different constructs derived from psychological theories and not only the constructs themselves. **[outcome (vii)]** → Due to the analytical complexity of the problem, advances in this direction have been carried out by proceeding step by step. A hierarchical hybrid model reproducing the structure of the theory of planned behaviour has been calibrated. The estimation of the model has been carried out using a sequential procedure and has made it possible to identify in the hierarchical hybrid model a good solution for taking into account not only the constructs formulated by psychological theories but also the relationships between them in the definition of utility functions. Furthermore, an advancement has been proposed by simultaneously calibrating a hierarchical hybrid model that takes into account the relationships between attitude towards electric vehicles, behavioural intention and actual behaviour. Despite the computational complexity and high computation time, this model also proved to be sufficiently promising to move from purely interpretive to interpretive and simulative modelling.

Obviously, the proposals were not without their complexities and therefore some aspects could be improved.

First, it is clear that one of the main limitations of the study carried out lies in its targeted sample. Given the need to pursue continuity between one phase and the next of the survey, the study was conducted on a pilot sample, consisting mostly of university students, which is therefore partially biased;

Clearly, several solutions can be pursued to extend the survey to a larger sample, while still maintaining a certain continuity between one phase and the next. The most effective one (based on literature studies aimed at investigating the behavioural changes of users towards more sustainable mobility solutions) could consist in the design of a dedicated app that would not only provide respondents with informative moments, but also make it possible to test the actual behavioural stage at different times, while also investigating possible changes in lifestyle. Such an app could also prove directly useful in pushing users towards specific behavioural changes.

Furthermore, the possibility to extend the study by means of collected information in a mixed survey on declared preferences (in order to be able to define the behavioural intention) and detected preferences (in order to be able to take the actual behaviour into account) would be desirable.

Finally, with a view to future research steps, some improvements could be made at the survey stage, to take into account the evolutionary nature of decision-making processes. For example, although in the literature studies taken as a reference for investigating the construct of the stage of change and behavioural intention only one indicator is usually considered, for the implementation of hierarchical hybrid models it would be more appropriate to have at least three indicators for each latent construct, so that, while increasing the complexity of the model, one does not run into identification problems. This thesis is divided into seven chapters. Chapter one is intended as a summary and overview.

In chapter two, the decision-making process is explored. In particular, the architecture of the decision-making process is examined and the differences between economic and psychological paradigms are discussed. Following this, the chapter focuses on the development of economic theory, retracing a historical excursus of the main stages of development and the main paradoxes that are blamed on it and from which certain theories descend (such as the regret theory and the prospect theory, recently also used in the transport sector). The chapter then focuses on the transition between economic theory and the choice models derived from it, distinguishing between established models and more advanced hybrid choice models. Associated with this chapter is Appendix A, which presents a more detailed overview of the established choice models, providing the structure and mathematical formalisation for each.

Chapter 3, in turn, is completely dedicated to the psychological approach. In this chapter, a state of the art is proposed in which all the psychological theories that have found application in the transport sector in recent years are discussed.

Chapter 4, is a chapter solely devoted to the modelling. It contains all the necessary theoretical references for an easy understanding of the steps carried out with reference to the proposed case study and for the interpretation of the results. In particular, in this chapter we refer to several preliminary analyses needed to study the available data, to structural equation modelling, both with PLS-SEM and CB-SEM approaches, and to the specification, calibration and validation of traditional, hybrid and advanced choice models.

Chapter 5 is dedicated to the investigated case study, through which the objectives and contributions of the research are established. In particular, attention is paid in this chapter to:

- Define the experimental context and the survey from which the data are extrapolated. Associated with this paragraph is Appendix B, containing some details extracted from the survey.
- Define the preliminary data analysis, on the basis of which it was possible to choose the approach to be taken from a modelling point of view, which data could be used and for what purpose.
- The study of the proposed new modelling approach, carried out by means of structural equation modelling. The main results obtained are presented and those relationships with statistical significance are determined.
- Reproduce urban usage choices of cars with alternative fuels
- Reproduce purchase choices of cars with alternative fuels by implementing modelling approaches with different difficulties. Attached to the paragraphs on choice models is Appendix C, which provides a description of the considered attributes.

Chapter 6 discusses the main results shown in Chapter 5, while Chapter 7 concludes the thesis, summarising the results obtained for all the research contributions. The same chapter also discusses the main limitations found in the performed study.