Using artificial neural networks to investigate decision-rule heterogeneity

Sander van Cranenburgh[a], Ahmad Alwosheel[a]
[a]*Transport and Logistics Group, Delft University of Technology*

Introduction

Decision rules, i.e. the decision mechanisms humans use when making choices, have been studied in numerous branches of the social sciences e.g. psychology, behavioural economics, marketing and travel behaviour. Over the decades, several types of decision rules have been proposed and empirically tested, such as utility maximization (Debreu 1954), satisficing (Simon 1955), elimination by aspects (Tversky 1972), regret minimization (Loomes and Sugden 1982).

Recently, in the travel behaviour research community there is a growing interest in decision rule heterogeneity (Hess et al. 2012; Hess and Chorus 2015; Van Cranenburgh and Prato 2016). These studies aim to provide insights on what types of decision rules are adopted by what type of travellers (e.g. in terms of socio-demographic variables), and in what type of choice situations (e.g. mode choice, parking location choice, route choice, etc.) (Hess et al. 2012; Van Cranenburgh and Prato 2016). To the best of the authors' knowledge, studies investigating decision rule heterogeneity of travellers have exclusively been based on Latent Class (LC) discrete choice modelling approaches. In these studies the membership function of the LC model is employed to assign decision-makers (probabilistically) to decision-rules, which are represented by separate classes. However, although LC models provide an intuitive approach to investigate decision rule heterogeneity, they suffer from an important methodological limitation. In LC models taste heterogeneity, heteroscedasticity and decision rule heterogeneity are confounded. As a consequence, the extent to which LC models are capable to provide unequivocal evidence for, and insights on, decision rule heterogeneity is limited.

This study proposes a novel methodology to investigate decision rule heterogeneity in the context of choice data based on an Artificial Neural Network (ANN) modelling approach. Thereby, it aims to 1) provide new evidence for the presence of decision rule heterogeneity in the context of travel choice data and 2) to cross-validate the results of earlier studies based on LC modelling approaches. More specifically, in this study we employ pattern recognition ANNs to classify decision-makers (in terms of the underlying decision rule) based on the observed sequences of choices made the decision-makers. ANNs are well-known for being highly effective in solving complex classification problems (Zhang 2000) and are capable of modelling complex relationships, including in the context of discrete choice models (Alwosheel et al. 2017). Like other (supervised) machine learning methods, in order to detect patterns in the data pattern recognition ANNs need to be trained based on so-called training data, which includes the correct classification. Therefore, to train our ANNs, we created synthetic data sets based on two distinct decision rules: Random Utility Maximization (RUM) and Random Regret Minimization (RRM). During the training, the taste parameters associated with the RUM and RRM choice models were varied over large ranges. Thereby, we trained our ANNs to classify decision-makers in terms of their most likely employed decision rule in the presence of both taste heterogeneity and heteroscedasticity. Finally, to put our methodology to a test empirically, we apply our ANN to a Value-of-Time (VoT) data set, which is recently collected in the Netherlands.

Methodological contributions

The methodological contributions of this study are twofold. Firstly, we show how ANNs can be employed to investigate decision rule heterogeneity based on choice data. Specifically, we present a new methodology showing how to train pattern recognition ANNs such that they are able to detect patterns in sequences of choices that are more likely to be associated with certain decision rules than others. Secondly, we provide evidence that inferences on decision rule heterogeneity made using LC models are robust.

Preliminary results and next steps

First results are very promising. Firstly, we find that pattern recognition ANNs are well-capable to accurately classify decision-makers to decision rules based on an observed sequence of choices. In the context of our synthetic data, the ANN correctly classifies 96% of the RUM decision-makers to be RUM, and correctly classifies 85% of the RRM decision-makers to be RRM. Secondly, in the context of the empirical VoT data, we find a positive (but, not significant) correlation between the classification probabilities predicted by the ANN and the class membership probabilities predicted by a LC discrete choice model[1] estimated on the VoT data. Next, steps will involve 1) enhancement of the type and structure of our ANN models, and 2) extending our applications to multiple empirical data sets.

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[1] Note that in the LC models that we estimated the taste parameters are constrained across classes. Thereby, we aim to maximize the chance of capturing decision rule heterogeneity, rather than unwantedly capturing taste heterogeneity or heteroscedasticity.