Are travelers more satisfied with more options offered? A choice set paradox

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1. INTRODUCTION

Random utility models (RUMs) have been a standard tool for travel behavior analysis. RUMs assume that individuals seek to maximize their utility over their choice set, or a set of alternatives considered (McFadden, 1974). This assumption leads to the assertion that the welfare experienced by individuals increases with the size of the choice set; in other words, the more options individuals are offered, the greater satisfaction they receive. Nonetheless, this assertion has been challenged by an abundance of psychological evidence indicating that an excess of options can undermine individuals' welfare (Iyengar and Lepper, 2000; Schwartz, 2004; Chadd et al., 2021).

It has been extensively examined in economics that too many options will overwhelm individuals (also known as choice overload). This occurs because gathering and processing information can impose non-negligible cognitive costs. Fudenberg and Strzalecki (2015) introduced the concept of "choice aversion" stating that individuals sometimes are less motivated to choose from a larger choice set. Lleras (2017) suggested filtering rules to model that the elimination of an alternative from a large choice set might improve individuals' welfare under limited attention (i.e., less is more). Filiz-Ozbay and Masatlioglu (2023) proposed a random probabilistic choice model to accommodate heterogeneity and bounded rationality, which provides a characterization of "less is more".

Although this "less is more" (or more is less) phenomenon is well-recognized in psychology and economics, it still seems mysterious to the transportation community and is yet to be established in the travel behavior analysis literature, which has been dominated by RUMs. Recently, Knies et al. (2022) incorporated choice aversion into the recursive logit model to describe travelers' myopic route choice behavior in transportation networks, showcasing that adding an edge to the network can worsen travelers' welfare. Their focus, nonetheless, is relatively limited, and there is still a lack of attempt to systematically investigate "more is less" in the context of travel behavior. We believe that such paradoxical behavior merits attention from transportation modelers, as a viable behavioral model needs to offer realistic descriptions of how travelers behave. Investigation of such behavior could also reveal the limitations of existing modeling tools and point out directions to advance them.

This study is dedicated to formalizing and exploring such paradoxical behavior, leveraging slightly modified RUMs to facilitate the understanding of this behavioral "anomaly". In particular, we introduce the notion "*choice set paradox*", which aims to account for "*more is not always better*" from the aspect of the choice set. A simple threshold choice model (TCM) is suggested to capture the choice set paradox. The TCM assumes that individuals fail to consider all alternatives offered, imposing a threshold to exclude alternatives with an exceedingly low utility. Within the set of alternatives possibly chosen by individuals, the TCM retains the utility maximization assumption. Meanwhile, the expected utility received by individuals is penalized by the choice set size, which takes into account travelers' cognitive costs for gathering and processing information. Through this model, we identify two types of choice set paradox: the paradox may arise from adding either an inferior alternative (with a relatively low utility) or a superior one (with a relatively high utility). When an inferior alternative is included, the cognitive cost paid for processing it may outweigh the potential benefit; for a superior one, the presence of the threshold might cause individuals to overlook some potentially promising alternatives, possibly lowering individuals' satisfaction. These results offer valuable insights that could guide future developments in travel behavior modeling and analysis.

2. RANDOM UTILITY MODELS

2.1 Mathematical formulation

For a choice set $N = \{1, \ldots, |N|\}$ with $|N|$ alternatives, consider that the random utility of an individual choosing alternative n takes an additive form, which is:

$$U_n = V_n + \xi_n,\ \forall n \in N, \tag{1}$$

where V_n and ξ_n denote the deterministic utility and random error, respectively. For notational ease, we omit the subscript associated with the individual. The random utility theory postulates that the individual strives for random utility maximization.

$$p_n = \Pr(U_n \geq U_l,\ \forall l \in N,\ l \neq n) = \Pr(\xi_l - \xi_n \leq V_n - V_l,\ \forall l \in N,\ l \neq n),\ \forall n \in N. \tag{2}$$

Eq. (2) implies that the choice probabilities are functionally dependent on the utilities, and the form of the probability function is determined by the distribution of random variables.

If ξ_n~Gumbel$_n(0, \mu)$, $\forall n \in N$ (with positive scale parameter μ), Eq. (2) leads to the multinomial logit (MNL) model, which can be expressed as:

$$p_n = \Pr(U_n \geq U_l,\ \forall l \in N,\ l \neq n) = \frac{\exp(\mu V_n)}{\sum_{l \in N} \exp(\mu V_l)},\ \forall n \in N. \tag{3}$$

2.2 Expected maximum utility

The expected maximum utility S_N captures the utility (or welfare) that individuals derive from the choice set N. Specifically, S_N can be calculated by:

$$S_N = \mathbf{E}_\xi[\max\{V_n + \xi_n,\ \forall n \in N\}], \tag{4}$$

where $\mathbf{E}_\xi[\cdot]$ is the expectation. Formally, for every RUM, we have:

Lemma 1. The expected maximum utility monotonically increases with the choice set size, i.e., $S_N \leq S_{N \cup \{n'\}}$, where n' can be any new alternative.

Lemma 1 indicates that all RUMs conform to the principle of "*more must be better*".

3. CHOICE SET PARADOX

As discussed in Section 1, individuals do not necessarily perceive a monotonically increasing utility with the choice set size.

Formally, the *choice set paradox* is defined as follows:

Definition 1. The inclusion of a new alternative reduces the welfare experienced by individuals:

$$\exists M \text{ and } m,\ \text{s.t. } S_M < S_{M \cup \{m\}}, \tag{5}$$

where M is a choice set and $m \notin M$ is called a *paradoxical alternative*.

The choice set paradox may arise from various behavioral principles (e.g., bounded rationality; see Filiz-Ozbay and Masatlioglu, 2023), and many alternatives could be paradoxical. Next, we focus on the case in which individuals have limited cognitive capability and identify two types of choice set paradox: the paradoxical alternative could be either an acceptable but not very promising (i.e., inferior) or a very attractive (or superior) alternative.

4. THRESHOLD CHOICE MODEL

The choice set paradox will be showcased by the TCM, the derivation of which is detailed in this section. Specifically, the TCM makes several assumptions, as described below:

Assumption 1: Individuals have limited cognitive capability and may fail to consider all alternatives offered.

Assumption 2: Within individuals' cognitive capability, they still undertake a cognitive cost to process information of the considered alternatives.
Assumption 3: Individuals are fully rational and strive to maximize the *net utility* (i.e., the difference between the utility received from the choice set and the cognitive cost) in the decision-making process.

In Assumption 1, the limited cognitive capability can be interpreted as a physical limitation. Assumption 2 is based on the fact that information processing requires cognitive effort (see Ortoleva, 2013). Assumption 3 is standard. With these assumptions, we next derive the TCM step by step.

4.1. Acceptable threshold

Let $V_{max} = \max\{V_n, \forall n \in N\}$. The TCM imposes a threshold $\pi \geq 0$ on the utility to determine whether an alternative is considered by individuals (Assumption 1). An alternative n is acceptable and is possibly chosen if and only if $V_n \geq \pi$. Within the consideration set, individuals' choices follow the MNL probability (for convenience, the scale parameter is set to 1):

$$p_n = \begin{cases} 0 & ,\forall n \in N \setminus N', \\ \dfrac{\exp(V_n)}{\sum_{l \in N'} \exp(V_l)} & ,\forall n \in N' \end{cases}, \tag{6}$$

where $N' = \{n \in N | V_n \geq \pi\}$. The incorporation of a utility threshold is somewhat similar to the bounded choice model proposed by Watling et al. (2018), yet the TCM retains the MNL probability rather than takes a modified probability expression within the set N'.

4.2. Cognitive cost

From Assumption 2, a penalty term $\lambda \cdot \ln|N'|, \lambda \geq 0$ is embedded into the utility of each alternative to capture the cognitive cost. Accordingly, the TCM probability is:

$$p_n = \begin{cases} 0 & , \forall n \in N \setminus N', \\ \dfrac{\exp(V_n - \lambda \cdot \ln|N'|)}{\sum_{l \in N'} \exp(V_l - \lambda \cdot \ln|N'|)} & , \forall n \in N'. \end{cases} \tag{7}$$

The idea of penalized utility is similar to choice aversion (Fudenberg and Strzalecki, 2015), yet the TCM further considers physically limited cognitive capability (i.e., the threshold). In addition, the cognitive cost is functionally dependent on the size of N rather than the number of alternatives offered.

4.1.3. Expected maximum utility

The expected maximum utility of the TCM is:

$$p_n = \ln \sum_{l \in N'} \exp(V_l) - \lambda \cdot \ln|N'|, \tag{8}$$

which differs from the standard 'logsum' in two aspects: a threshold π is incorporated to constrain the choice set, and a cognitive cost is accommodated via penalty term $\lambda \cdot \ln|N'|$.

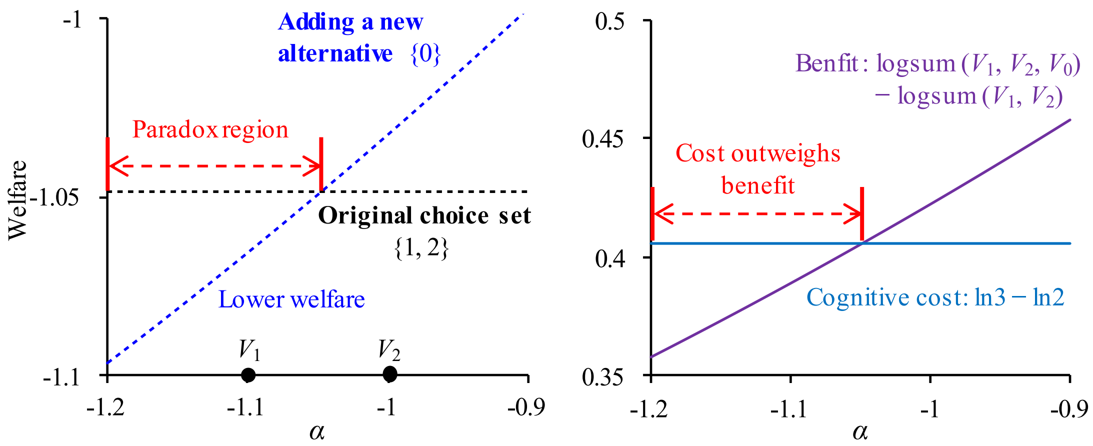
5. Paradoxical analysis

This section illustrates the choice set paradox with an example shown in Table 1. There are two alternatives 1 and 2 in the original choice set. Consider adding a new alternative 0 whose utility is a varied parameter α. The threshold π is 0.2. Fig. 1 shows the welfare varying with α.

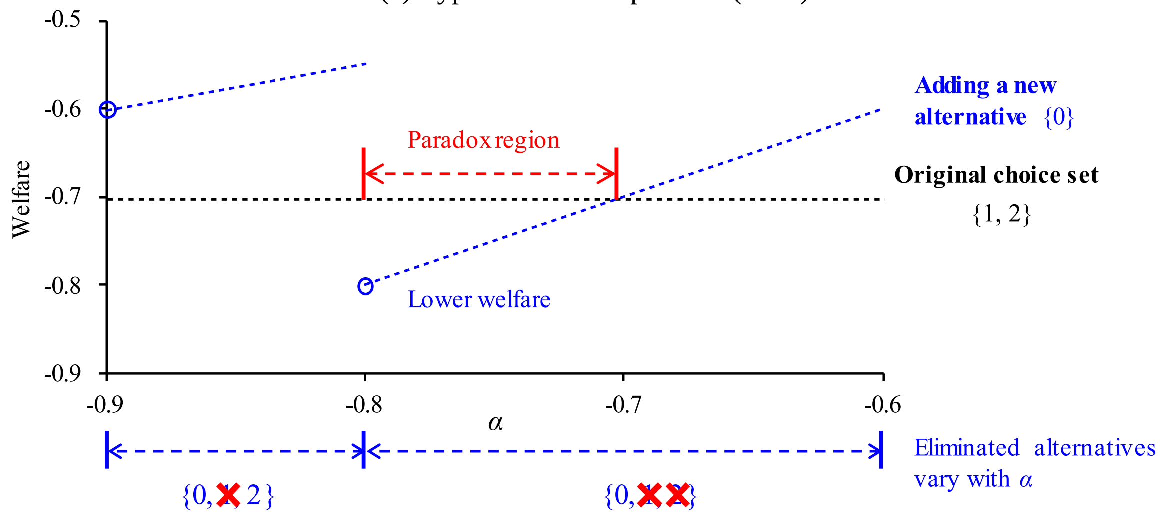
Table 1. An illustrative example

Alternative	1	2	0 (Newly added)
Utility	−1.1	−1.0	α

Fig. 1(a) depicts the type-I choice set paradox (with $\lambda = 1$), where the utility α ranges from −1.2 to −0.9. On the left, the welfare for the choice set {0, 1, 2} (marked in blue) is lower than that for {1, 2} (marked in black), when α is relatively low. This occurs because the cognitive cost of adding alternative 0 outweighs its benefit (as seen the right). As the utility α increases to a certain level, the inclusion of alternative 0 leads to an higher welfare. This demonstrates that individuals' welfare can be undermined by an inferior alternative. The type-II choice set paradox is illustrated in Fig. 1(b) (with $\lambda = 0.2$). Here, the utility $\alpha \in (-0.9, -0.6]$ is more promising than those of existing alternatives. However, due to the presence of threshold π, increasing the utility α will successively eliminate alternatives 1 and 2. This elimination may give rise to compromised welfare. Note that this type of paradox arises only if the newly added alternative is more attractive than all alternatives existed in the original choice set.



(a) Type-I choice set paradox (λ = 1)



(b) Type-II choice set paradox (λ = 0.2)

Figure 1. Illustration of two types of choice set paradox

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