Traffic Calming Schemes: Monte Carlo Simulation to Evaluate Efficient Designs of Choice\(^{(1)}\)

Progetti di riduzione del traffico: una analisi Monte Carlo per valutare disegni di scelta efficienti

Rossella Berni, Silvia Ferrini
Dipartimento di Statistica “G.Parenti”, Università degli Studi di Firenze,
Viale Morgagni 59, 50134 Florence; E-mail: berni@ds.unifi.it; ferrini@ds.unifi.it

Riassunto: L’obiettivo del presente lavoro è la valutazione dell’effetto dei disegni di scelta sulla stima delle misure di benessere. In particolare, si valuta l’impatto dei disegni D-efficienti negli studi di choice experiments per la valutazione monetaria del danno ambientale. Si prendono in considerazione gli effetti negativi derivanti dal traffico urbano, così come percepiti dal cittadino, e si dimostra, attraverso un esperimento Monte Carlo, come i diversi disegni sperimentali influenzano la stima della disponibilità a pagare. Nel lavoro si descrivono alcuni disegni sperimentali per modelli non lineari (Multinomial Logit) e si dimostra la perdita di efficienza in presenza di scarsa informazione a priori. In relazione al modello si considera la presenza o meno della alternativa specifica costante; mentre per il disegno di scelta si valuta la presenza o meno dello status quo.

Keywords: Choice experiment, designs of choice (DOC), environmental economic valuation, willingness to pay (WTP).

1. Introduction

One way to protect the environment is for society to place a monetary value on it, and then charge any firm or individual that damages it. How can society measure the environmental damage in economic terms? The traditional tools of benefit assessment do not properly apply because of the non-market nature of the environment. To assess the values of non-marketed goods, i.e the external negative effects of road traffic, researchers apply experimental choice techniques to explore preference for real or hypothetical goods or services (Carson et al., 1994). Choice experiment is a powerful state preference method that allows, among other things, to estimate the willingness to pay for traffic calming schemes. In a choice experiment, consumers are presented with a set of scenarios that differ by the levels of attributes, including price, and are asked to choose their most preferred ones. Different scenarios are presented to respondents defined over a set of attributes and attribute levels characterizing traffic calming schemes, like Noise, Speed, pedestrian waiting Time. Researchers can use consumers’ responses to estimate a model of choice behavior of separate marginal rate of substitution (MRS) for each attribute. Given that price attribute is always included in environmental economic valuation, MRS represents the estimated marginal willingness to pay for the attributes. By designing traffic calming schemes, researchers have to combine attributes and attribute levels in a “clever way”, i.e.

\(^{(1)}\) The paper is a joint work of the authors. Nevertheless, Berni took care of sections no.: 1 and 3.1; Ferrini took care of sections no.: 2 and 3.2. Preface to section no.3 and section no.4 are in common.
to generate one or several questions such that one collects as much information as possible. We notice how experimental design techniques are important in choice experiments method. In this paper we present some design of choice used in experimental method to evaluate environmental damage. Our main aim is to compare statistical efficiency across experimental designs evaluated by means of Monte Carlo simulations.

2. **Motivation of study**

The first step of choice experiment (CE) method is the statistical design. It has an undoubtedly effect on the estimation of willingness to pay to avoid environmental damage.

Designs of choice (DOC) determine the degree of precision obtainable from estimates and welfare measure (Carlsson and Martisson, 2003). Despite that, these issues have yet to be satisfactorily addressed in the multiattribute stated preference literature for environmental valuation. Carlsson and Martisson (2003) use a set of Monte Carlo experiments to derive empirical performance of four DOC (orthogonal, cycling, D-optimal design with and without prior information) for pairwise CE in health economics. They find that, in general, the most efficient design is the D-optimal designs with good *a-priori* information. Ferrini (2004) extends the work of Carlsson and Martisson (2003) to environmental economics field. Comparing orthogonal designs, D-optimal design with priori information and D-optimal Bayesian designs with and without *a-priori* information, she demonstrates the powerful of Bayesian designs when the *a-priori* information is “of good quality” and the data generating process is consistent with the specification chosen. Nevertheless, she does not analyze the *a-priori* information effect on the bias of welfare measure estimate. To overcome this lack is our aim to: 1) evaluate the effect of *a-priori* information on derivation of DOC; 2) compare standardized procedures to derive DOC (SAS macros) and *ad-hoc* procedures to build Bayesian designs (i.e. Sandor and Wedel, 2001).

3. **Methods and results**

To perform the analysis previously suggested, we refer the case of study described in Garrod *et al.* (2002), where a choice experiment is used to evaluate different traffic calming schemes. The choice experiment considers two experimental design alternatives characterized by four attributes: Noise, Speed, Pedestrian time, Taxes – all described at different levels of intensity – and one Status Quo (SQ) option. To investigate the relative performance of D-optimal designs we derive DOC on different *a-priori* information and perform Monte Carlo simulations\(^{(2)}\).

### 3.1 Design of Monte Carlo experiment

Using the estimated values reported in Garrod *et al.* (2002), we hypothesize two experimental situations. The first one treats “good” *a-priori* information on model parameters\(^{(3)}\).

\(^{(2)}\) The application is computed using Gauss 3.2.38 and the Statistical Analysis System (SAS) 8.2 software. 

\(^{(3)}\) We derive *a-priori* information performing a Monte Carlo simulation using a non dominate fractional factorial design with a sample of 52 respondents. We simulate a pre-test study.
The second case uses poor information based on economic expectations on parameter design. The \textit{a-priori} vector is \( \beta_{0p} = [-0.043, -0.0007, -0.553, -0.070] \) in the former case and \( \beta_0 = [-1, -1, -1, -1] \) in the latter. These values are used to derive two optimal designs (Kuhfeld, 2004) and three optimal Bayesian designs (Sandor and Wedel, 2001).

The applied efficiency criteria is the following: \( D - \text{optimal} = \left[ |\Omega|^{1/4} \right]^{-1} \) where \( \Omega \) is the covariance matrix of a Multinomial Logit (MNL). Following the standard Random Utility framework, the utility function is:

\[
U_{ni} = \beta' x_{ni} + \varepsilon_{ni} \quad (1)
\]

where \( x_{ni} \) is a vector of attributes for alternative \( i \) presented to respondent \( n \). Assuming \( \varepsilon \) distributed iid Gumbel, the choice probability is:

\[
P_{in}(\beta) = \frac{\exp(\beta' x_{in})}{\sum_{j=1}^{Jn} \exp(\beta' x_{jn})} \quad (2)
\]

The covariance matrix \( \Omega \) depends on the parameters in the utility function since the choice probability depends on them. To derive D-optimal designs we use \( \beta_{p} \) and \( \beta_0 \) through the modified Fedorov’s algorithm, coded by %choiceff macro in SAS. We obtain the labelled designs \( D_{SAS}, D_{SAS0} \). These designs do not express uncertainty about \textit{a-priori} vectors. On the contrary, considering the Bayesian D-optimal design, we assume uncertainty on \( \beta \). We assume \( \beta \sim N(\beta, \Omega) \) and through a RSC algorithm (Sandor and Wedel, 2001) we obtain two designs with \( \beta = \beta_{p} \) and \( \beta = \beta_0 \) parameters (labelled \( D_{BayNSq}, D_{Bay} \)). The third design \( (D_{Bay}) \) is based on \( \beta_{p} \) and it includes the SQ alternative. We note that the other designs do not consider any SQ. Generally SAS designs are easy to derive but SQ option cannot be included. On the contrary, Bayesian designs should be tailored according to different case study.

### 3.2 Monte Carlo experiments results

The experiment is designed to investigate the relative performance of the DOC when the data generating progress is MNL and MNL with SQ-specific constant. The latter specification is useful to capture the SQ effect examined in Ferrini (2004). Monte Carlo experiment allows us to obtain a choice process. We consider each DOC one-at-a-time and, given the true utility function parameters and the Gumbel error, we associate to each alternative the utility level. The alternative with the largest utility value corresponds to the preferred option and the index \( y_{ir} \) assumes value equal to one. Monte Carlo experiment considers a sample of 600 respondents and \( r = 1, \ldots, 1000 \) replications.

The sample obtained in each iteration are used to get maximum likelihood estimates of the two models. Table 1 illustrates the Noise attribute with the relative absolute error (RAE) and the measure of efficiency\(^{(4)}\) of MRS. We notice that all designs perform well when the DGP is MNL and estimates are MNL.

The bias is slightly higher when the model is MNL-ASC. In the latter case, \( D_{SAS0} \) is 1.2-2 times the RAE for the \( D_{SAS} \). The \( D_{BayNSq} \) performs higher bias than \( D_{Bay} \). Similar results are drawn for the MNL-Asc data generating process a part from the \( D_{SAS0} \) design. The \( D_{SAS0} \) presents a RAE very large.

\(^{(4)}\) We count the percent of MRS values falling within a 5% interval of the true value (\( \Gamma_{0.05} \)).
Table 1: Summary statistic.

<table>
<thead>
<tr>
<th></th>
<th>DGP:MNL</th>
<th>DGP:MNL+Asc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RAE</td>
<td>$\Gamma_{0.05}$</td>
</tr>
<tr>
<td>$D_{SAS}$</td>
<td>0.130</td>
<td>30</td>
</tr>
<tr>
<td>$D_{Bay}$</td>
<td>0.086</td>
<td>33</td>
</tr>
<tr>
<td>$D_{BayNSq}$</td>
<td>0.098</td>
<td>35</td>
</tr>
<tr>
<td>$D_{SASb}$</td>
<td>0.126</td>
<td>29</td>
</tr>
<tr>
<td>$D_{Bayb}$</td>
<td>0.080</td>
<td>37</td>
</tr>
</tbody>
</table>

4. Concluding remarks

The study shows the sensitivity of D-optimal designs to *a-priori* information and emphasize the robustness of Bayesian D-optimal designs for each experiment. The Bayesian designs is a promising tool in environmental economics and evaluation field. Yet, there is a trade off between its power and computation needs. Results show the relevance of experimental designs in welfare measures estimations and highlights the necessity to make an accurate pre-test survey. Our results contribute to the ongoing state of preference technique to evaluate environmental damage.

References