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Heterogeneity in the solar-powered consumer electronics market: A discrete choice experiments study

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ABSTRACT

Solar-powered consumer electronics are a likely starting point for organic photovoltaic (OPV) market development. Therefore, a generic discrete choice experiments study can determine how Flemish consumers value solar-cell characteristics for solar-powered consumer electronics. Such characteristics include efficiency, lifetime, aesthetics, integratability, and price. We contribute to the literature by investigating preference heterogeneity in a solar-power niche market with an experimental design with a fixed reference alternative. The error components random parameter logit (ECRPL) with interactions provides a better fit than the latent class (LC) model for our choice data. The main effects had the expected signs. Consequently, aesthetics and integratability are OPV's assets. Nevertheless, heterogeneity puts the results that are valid for the average consumer into perspective. Based on our findings, OPV commercialization efforts should target the experienced, impatient user who highly values design and functionality.

1. Introduction

Several authors have identified solar-powered consumer electronics as a likely starting point for organic photovoltaic (OPV) solar-cells' market development [35,44]. OPVs are solar cells with an all-organic, solid-state active layer [13]. Among all alternatives to crystalline silicon-based solar-cells, OPVs are considered a strong solution to the problem of high cost and low throughput [36]. OPVs might also provide a better solution than crystalline silicon solar cells to global warming if consumers adopt this promising renewable energy technology (RET). Energy payback times (EPBTs) of only one day are predicted for OPVs under favorable circumstances, but taking lifetime issues into account. Crystalline silicon solar cells have EPBTs of one to two years [19].

Nevertheless, consumers' willingness to adopt a product depends on how they value it. Therefore, we performed a generic, discrete choice experiments (DCE) study to see how Flemish consumers value solar-cell characteristics for solar-powered consumer electronics. We assessed generic preferences for such solar cells by setting attribute levels to cover the range of possible levels different solar-cell types achieve. This allows for assessing the match with OPV's (future) profile. We respond to OPV material scientists' call for guidance on how to claim a significant market share of a predefined market [34]. We contribute to existing literature by incorporating unobserved heterogeneity into our modeling efforts. To this end, we investigated preferences using the error component random parameter logit (ECRPL) and the latent class (LC) logit models.

The remainder of this paper is divided into four sections. The methodology section reviews DCE use in RET literature, explains its intuition, and describes our approach. The results section provides the sample's descriptive statistics, after which we interpret the results obtained from the different models. The conclusion summarizes our main findings.

2. Methodology

2.1. DCEs covering renewable energy: a literature review

DCEs have frequently been applied to the topic of renewable energy, albeit from different angles. Table 1 presents the results of a literature review from 2006 to 2014. Contributions mainly examine the importance of the green electricity share in the electricity mix or the valuation of socioeconomic and environmental externalities of RETs. Solar power constitutes the exception to this rule. Photovoltaics and solar water heating have been investigated

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Table 1
Discrete choice experiments eliciting consumers' valuation of (the effects of) renewable energy.

RES	Reference	Topic	Observed heterogeneity	Unobserved heterogeneity
Biomass	Jensen et al. [28]	Valuation of E85 fuel originating from different biomass types	X	RPL
Biomass	Soliño [48]	Valuation of a forest biomass promotion program	X	/
Biomass	Susaeta et al. [50]	Valuation of woody biomass' positive externalities	X	RPL
Hydro	Han et al. [22]	Valuation of environmental impacts of large dam construction	X	/
Hydro	Kataria [31]	Valuation of environmental improvements for hydropower regulated rivers	X	RPL
Solar	Islam and Meade [27]	Estimation of preferences for factors influencing solar panel adoption	/	GMXL
Solar	Islam [26]	Estimation of preferences for factors influencing solar panel adoption	/	LC
Solar	Lizin et al. [40]	Valuation of solar cell characteristics for powering consumer electronics	X	/
Solar	Yamaguchi et al. [57]	Estimation of preferences for factors influencing solar panel and solar hot water adoption	/	/
Tidal	Lee and Yoo [39]	Valuation of environmental damage caused by the construction of a tidal power plant	/	/
Tidal	Vazquez and Iglesias [54]	Valuation of environmental and socio-economic externalities of a tidal power plant	X	/
Wind	Drechsler et al. [16]	Optimal spatial allocation of wind turbines	/	/
Wind	Ek and Persson [17]	Optimal establishment of wind farms	X	RPL&LC
Wind	Meyerhoff et al. [43]	Valuation of landscape externalities of onshore wind turbines	X	LC
Wind	Strazzera et al. [49]	Social acceptability of wind turbines	X	LC
Mix	Amador et al. [1]	The influence on WTP of the renewable energy share in the electricity mix		
Mix	Bergmann et al. [8]	Preferences over environmental and employment impacts that may result from renewable energy projects	X	/
Mix	Bergmann et al. [7]	Valuation of environmental and employment impacts that may result from renewable energy projects	X	RPL
Mix	Borchers et al. [11]	The influence on WTP of the specific energy source of origin	X	NL
Mix	Cicia et al. [14]	The influence on WTP of the specific energy source of origin	X	LC
Mix	Gracia et al. [21]	The influence on WTP of the specific energy source of origin	X	RPL
Mix	Kaenzig et al. [30]	The influence on WTP of the renewable energy share in the electricity mix	/	HB
Mix	Kosenius and Ollikainen [33]	Valuation of environmental and societal trade-offs of renewable energy sources	X	NL
Mix	Ku and Yoo [37]	Valuation of environmental and employment impacts that may result from renewable energy projects	/	MNP
Mix	Longo et al. [41]	Valuation of short-term security of energy supply resulting from RES	X	RPL
Mix	Scarpa and Willis [46]	Preferences for various micro-generation technologies	/	RPL
Mix	Tabi et al. [51]	Preferences for green electricity	/	HB
Mix	Willis et al. [56]	In-sample heterogeneity for various micro-generation technologies	X	RPL
Mix	Yoo and Ready [58]	Preference heterogeneity for renewable energy share in the electricity mix	X	RPL&LC&LCRPL

RPL=random parameter logit model, LC=latent class model, LCRPL=latent class random parameter logit, NL=nested logit model, MNP=multinomial probit model, GMXL=generalized mixed logit, HB=hierarchical Bayes model, /=type of heterogeneity remained untreated, X=observed heterogeneity was treated.

with an eye on predicting the adoption time. Table 1 shows that solar-power niche markets have barely been investigated, with little attention toward heterogeneity. Nevertheless, Yoo and Ready [58] showed that preferences for solar power are the most heterogeneous of all types of renewable technologies.

2.2. DCEs modeling approach

The discrete choice-based elicitation format closely resembles an actual purchasing decision [55]. To formalize this decision process, DCE adopted the random utility theory (RUT), which Thurstone [52] originally developed. McFadden [42] translated RUT into the mathematical formulation of the conditional logit (CL) model.

The assumption of independently, identically distributed (IID) error terms allows for the convenient closed form of the CL model. The simplicity of the closed form comes at a cost, given that the CL model translates the IID assumption into substitution patterns that are restricted by the independence of irrelevant alternatives (IIA). Fully relaxing the IIA assumption without adopting different distributions for the error terms or different structures in decision-making, forces the use of mixed logit type models. Moreover, these types of models allow for unveiling unobserved heterogeneity. Mixed logit models have unconditional probabilities P_{ij} equal to the integral of standard logit conditional probabilities $L_{ij}(\beta)$ over a density of parameters $f(\beta)$ (see Eq. (1)). This density may be continuous or discrete [53].

An error component random parameter logit (ECRPL) model assumes a continuous distribution of attribute parameters and allows for calculating preferences at the individual level. Error components are often normally distributed as $N(0,\sigma^2)$. The variance captures the magnitude of the correlation between the nested alternatives. Formulating the model in this way has been shown to provide the best fit when dealing with a reference alternative [25].

A LC model assumes a discrete distribution of attribute parameters and assesses the average preferences for homogenous segments while using a class membership function [53].

$$P_{ij}=\int L_{ij}(\beta)*f(\beta)*d\beta \quad (1)$$

2.3. Performing a DCE study

2.3.1. Setting up DCEs

Relevant attributes and levels were identified using focus-