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Conference Paper

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50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden

Provided in Cooperation with:

European Regional Science Association (ERSA)

A SEMI-COMPENSATORY RESIDENTIAL CHOICE MODEL WITH FLEXIBLE ERROR STRUCTURE

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ABSTRACT

This paper presents the development and estimation of a semi-compensatory residential choice model with a flexible error structure. The model assumes that apartment seekers engage in a two-stage process, consisting of a non-compensatory strategy to retain only alternatives that meet search-criteria thresholds, followed by a compensatory strategy to finalize the choice. The model can accommodate nested substitution patterns across the alternatives as well as random taste variation across the population. The proposed model is applied to off-campus rental apartment choices by university students. The model estimation is based on database search and choice outcomes retrieved from a synthetic real-estate website inspired by actual on-line real-estate portals. Results show the potential of the proposed semi-compensatory model to realistically represent residential choice and other spatial choices related to regional, urban and transport planning.
Keywords: residential choice, semi-compensatory, two-stage model, real-estate websites.

1. INTRODUCTION

Residential choice is typically represented by compensatory discrete choice models that are based on the principle of utility maximization. The application of compensatory models to residential choice bears important advantages: ease of estimation, ability to account for spatial correlation patterns and population heterogeneity, and possibility of estimation from standard data collected by municipal and government authorities.

Although widely applied, compensatory models have three main disadvantages with respect to residential choice. The first disadvantage is that the compensatory strategy is behaviorally realistic only for choice situations consisting of a fairly small number of up to five alternatives (Payne, 1976). The second disadvantage is that compensatory models are based on the assumption that individuals are fully informed regarding each alternative in their choice set. This assumption is unrealistic in choice situations entailing many alternatives due to the costly and time-consuming acquisition of complete information for large number of

multi-attribute alternatives (Shocker et al., 1991). Since many residential choice studies involve tens (e.g., Quigley, 1985; Borgers et al. 1986; Lapointe and Desrosiers, 1986; Rapaport, 1997; Chattopadhyay, 2000; Deng et al., 2003; Prashker et al., 2008), hundreds (e.g., Anas, 1981; Abraham and Hunt, 1997; Levine,1998; Duncombe et al., 2001; Bhat and Guo, 2004) or thousands of alternatives (e.g., Weisbrod et al., 1980; Anas and Chu, 1984), the incompatibility of the compensatory approach with behavioral theories and practice is a matter of concern. Hence, a considerable gap exists between the observed residential choice process and its mathematical representation in residential choice models.

Attempts to reduce this gap in the residential choice literature are characterized by different approaches to choice set formation, namely deterministic availability rules, aggregation methods and sampling techniques. Deterministic availability rules are mostly applied by confining the analysis to a designated area such as a specific county, city, community or metropolitan area (e.g., Weisbrod et al., 1980; Friedman, 1981; Gabriel and Rosenthal, 1989; Abraham and Hunt, 1997; Rapaport, 1997; Nechyba and Strauss, 1998; Bhat and Guo, 2004;), but also based on travel time and housing affordability constraints (Levine, 1998). Aggregation methods are implemented by considering building type, tenure, size, quality and proximity (e.g., Boehm, 1982; Lapointe and Desrosiers, 1986; Börsch-Supan, 1990; Tu and Goldfinch, 1996; Cho, 1997; Freedman and Kern, 1997; Skaburskis, 1999; Börsch-Supan et al., 2001; Deng et al., 2003; Tiwari and Hasegawa, 2004; Yates and Mackay, 2006; Barrios-Garcia and Rodriguez-Hernandez, 2007; Shiftan, 2008). Sampling techniques include random sampling (e.g., Anas, 1981; Anas and Chu, 1984; Quigley, 1985; Hunt et al., 1994; Waddell, 1996; Levine, 1998; Chattopadhyay, 2000; Duncombe, 200; Earnhart, 2002; Garasky, 2002; Bina et al., 2006; Prashker et al., 2008) and stratified random sampling (e.g., Ben-Akiva and Bowman, 1998). However, given the lack of information about the actual subsets considered by individuals, an obvious disadvantage of these methods is that the specified choice set may be incorrect and lead to inconsistent and biased estimates (Stopher, 1980; Williams and Ortúzar, 1982).

A different approach for reducing the aforementioned gap, as suggested by the study of Borgers et al. (1986), is to estimate semi-compensatory models, since they better comply with human decision making in choice situations entailing many alternatives (Simon, 1955; Payne, 1976). These models include a probabilistic two-stage choice process, consisting of an elimination-based choice set formation upon satisfying criteria thresholds, followed by a utility-maximization based choice. Alas, a major weakness of existing semi-compensatory

models is that their estimation relies solely on choice outcomes. Hence, they require the consideration of all the theoretically possible choice sets, and become intractable as the number of possible choice sets increases exponentially with the number of alternatives. As a result, existing semi-compensatory models are subject to three sets of simplifying assumptions that allow maintaining tractability, but impede their applicability to residential choice.

The first set of assumptions concerns the number of alternatives included in the universal realm and the number of considered choice sets. Most existing semi-compensatory models (e.g., Swait and Ben-Akiva 1987; Ben-Akiva and Boccara 1995; Swait 2001a; Başar and Bhat 2004; Cantillo and Ortúzar 2005; Cantillo et al. 2006) are estimated considering a narrow universal realm of three alternatives and hence only seven choice sets. Gensch (1987) and Swait (2001b) estimate a model with four alternatives in the universal realm, while imposing restrictions on the number of choice sets. Borgers et al. (1986) consider a universal realm of thirteen alternatives, although with a single choice set for each individual based on aggregate thresholds across the population. Morikawa (1995) deals with a universal realm of eighteen alternatives, but the data collection is cognitively demanding for respondents and thus impractical for a large number of alternatives. Zheng and Guo (2008) consider a universal realm of twenty-seven alternatives but restrict the number of choice sets to nine.

The second set of assumptions concerns the representation of the criteria thresholds that delimit the universal realm of alternatives to a viable choice set. The most frequent assumptions are independence of the thresholds from individual characteristics (e.g., Borgers et al. 1986; Gensch 1987; Morikawa 1995; Swait 2001a; Cantillo and Ortúzar 2005; Cantillo et al. 2006), normal distribution of threshold values across the population (e.g., Borgers et al. 1986; Swait and Ben-Akiva 1987; Swait 2001a; Cantillo and Ortúzar 2005; Cantillo et al. 2006) and independence across thresholds of different criteria (e.g., Borgers et al. 1986; Gensch 1987; Swait and Ben-Akiva 1987; Ben-Akiva and Boccara 1995; Swait 2001a; Başar and Bhat 2004; Cantillo and Ortúzar 2005; Cantillo et al. 2006).

The third set of assumptions concerns the error structure in the representation of the choice set formation stage and the utility-based choice stage. Existing semi-compensatory models are based on the assumption of independently and identically distributed (i.i.d) error terms across criteria thresholds and across alternatives. Hence, the choice set formation stage is represented by multiple threshold models with uncorrelated error terms and the choice stage is represented by the multinomial logit (MNL) model. As a result, current semi-compensatory

models accommodate neither correlation patterns across thresholds, nor correlation patterns among alternatives, nor population heterogeneity at the utility-based choice stage.

The current study proposes a semi-compensatory model that alleviates the aforementioned three sets of simplifying assumptions. The proposed model jointly represents a sequence of an elimination-based choice set formation governed by the conjunctive heuristic and a choice derived from the principle of utility maximization. The representation of the conjunctive heuristic accounts for multiple correlated ordered-response thresholds that result from intrinsic individual constraints, while the representation of the utility-based choice accommodates alternatively a nested correlation pattern across alternatives and random taste variation across the population. The mathematical formulation jointly represents the conjunctive heuristic with a mixed multi-dimensional ordered-response probit (MMOP) model and the utility-based choice with alternatively (i) a nested logit model (MMOP-NL) and (ii) a random coefficients logit model (MMOP-RCL).

Initial development of the hereby proposed model focused on relaxing the first two sets of assumptions by estimating it on the basis of two-stage choice protocols retrieved from real-estate internet portals (Kaplan et al., 2009a). The basic version, which is suitable for a large universal realm of two hundred alternatives, captures differences in threshold selection across the population and accommodates correlations among thresholds of different criteria. However, similarly to other semi-compensatory models, the model assumes an i.i.d error structure at both the choice set formation stage and the choice stage. Although correlations across thresholds are partially accounted for by considering a hierarchical correlation structure and embedding in each criterion dummy variables for selected combinations of preceding criteria, the error structure across thresholds remains independent and the choice set formation is represented by multiple independent ordered-response models. The utility-based choice stage is represented with the MNL model (MOP-MNL). The current study relaxes the third set of assumptions by replacing the i.i.d error structure with a flexible error structure in the representation of both the choice set formation and the utility-based choice.

Replacing the i.i.d error structure with a flexible error structure in semi-compensatory models is of the outmost importance for their application to residential choice due to two reasons. First, residential choice alternatives are spatially correlated because of geographical proximity and socio-economic similarity. In fact, many compensatory residential choice studies represent nested correlation structures (e.g., Anas, 1981; Anas and Chu, 1984; Quigley, 1985; Waddell, 1996; Abraham and Hunt, 1997; Ben-Akiva and Bowman, 1998;

Levine, 1998; Skarburskis, 1999; Chattopadhyay, 2000; Deng et al., 2003; Tiwari and Hasegawa, 2004; Yates and Mackay, 2006), or distance-based spatial correlation patterns (Bhat and Guo, 2004). Second, residential choice is naturally highly influenced by population heterogeneity as a result of its importance, long-term impact and high costs. Indeed, a large number of compensatory residential choice models accounts for population heterogeneity by either focusing on specific population groups (e.g., Gabriel and Rosenthal, 1989; Freedman and Kern, 1997; Levine, 1998; Duncombe et al. 2001; Garasky, 2002; Deng et al., 2003; Prashker et al., 2008) or applying the random coefficient logit (e.g., Bhat and Guo, 2004; Barrios-Garcia and Rodriguez-Hernandez, 2007). Hence, extending the semi-compensatory model of Kaplan et al. (2009a) by embedding flexible error structure in the model enhances its suitability to real-world applications involving residential choice as well as to other spatial choices related to regional, urban and transport planning.

The model formulated and presented in this paper is applied to the context of off-campus rental apartment choice of students in a metropolitan core. The remainder of the paper is organized as follows. Section 2 focuses on the formulation of the proposed semi-compensatory model. Section 3 provides details regarding the data collection, estimation sample and variable specification for model estimation. Section 4 presents the model estimation results. Last, in section 5, conclusions are drawn from the study and further research is recommended.

2. SEMI-COMPENSATORY MODEL FORMULATION

The framework of the proposed model is inspired by Manski's (1977) probabilistic two-stage model:

$$P_q(i \mid G) = \sum_{S \in G} P_q(i \mid S) P_q(S \mid G)$$

where $P_q(i|G)$ is the probability of individual q $(q=1,2,...,Q)$ to choose alternative i from the universal realm G of alternatives, $P_q(S|G)$ is the probability of individual q to form a viable choice set S from G at the first stage, and $P_q(i|S)$ is the probability of individual q to choose alternative i out of S at the second stage. The universal realm G is shared by all Q individuals, while the viable choice set S is unique to each individual q. The number of theoretically possible choice sets grows exponentially with the number of alternatives (i.e., for J alternatives there are 2^J-1 possible choice sets). Hence, estimating Manski's (1977) model by relying solely on choice outcomes, while the considered choice sets remain latent, requires

simplifying assumptions regarding the size of the universal realm of alternatives, the choice set formation and the utility-based choice.

The current study proposes a probabilistic two-stage model framework, which relaxes the need for simplifying assumptions by relying on information regarding choice set formation in addition to choice outcomes. The additional information alleviates the complexity embedded in Manski's (1977) formula by reducing the number of possible choice sets to those actually chosen, hence avoiding the sum over all the theoretically possible choice sets for model estimation purposes. Accordingly, the choice probability within the proposed framework is expressed as:

$$P_q(i \mid G) = P_q(i \mid S) P_q(S \mid G)$$

The proposed mathematical framework accommodates a wide range of two-stage models, which derive from different assumptions regarding the cognitive processes underlying the choice set formation and subsequent choice. The current study assumes a two-stage cognitive process consisting of a sequence of conjunctive heuristic and utility maximization. The conjunctive heuristic is by far the most frequent attribute-based heuristic (Lussier and Olshavsky 1979; Olshavsky 1979), while utility maximization is the most prominent model of rational decision making. According to the above assumption, at the first stage of the two-stage process individuals overtly specify their tolerated criteria threshold values concerning acceptable price and quality to delimit the universal realm of alternatives to a viable choice set. The criteria thresholds are naturally ordered and correlation among thresholds of different criteria is assumed. At the second stage of the two-stage process individuals choose their preferred alternative from their retained choice set. Two alternative specifications characterize the choice stage: (i) representation of nested substitution patterns across the alternatives within the retained viable choice set and (ii) representation of random taste variation across the population. In the case that some individuals do not find their ideal alternative within their retained choice set, they may select their most preferred alternative among the available ones, update their criteria thresholds, or decide to avoid making a choice. Figure 1 illustrates this two-stage process.

The mathematical formulation of the proposed semi-compensatory model is detailed in the next sections. Section 2.1 describes the conjunctive heuristic leading to the choice set formation. Section 2.2 presents the utility-based choice under the assumption of nested substitution patterns across alternatives within the viable choice set. Section 2.3 details the

utility-based choice under the assumption of random taste variation across the population. Section 2.4 provides details regarding model estimation.

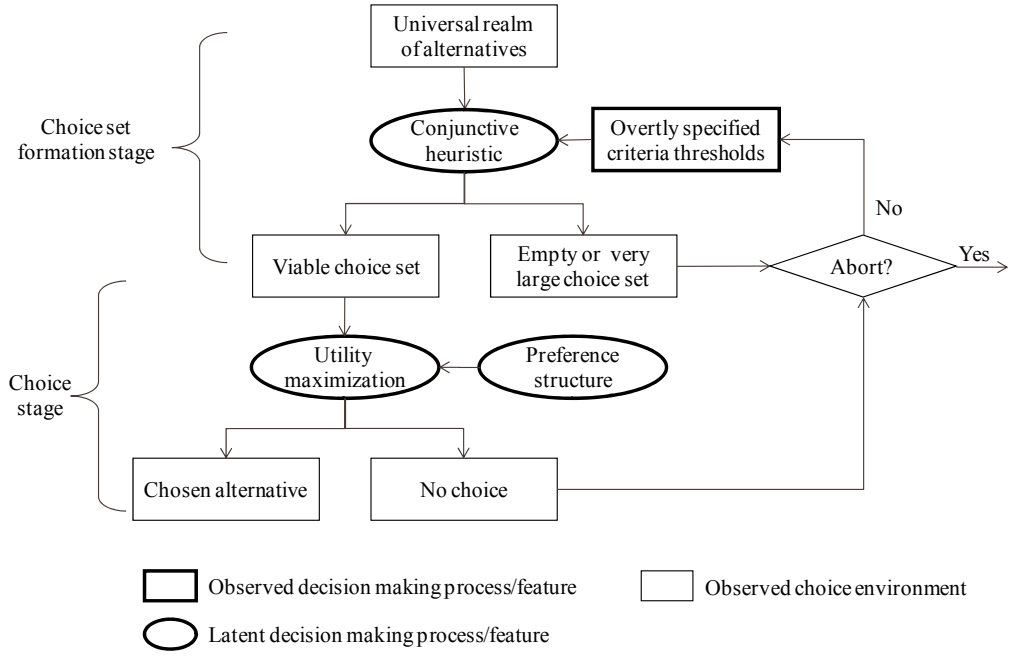

Figure 1 – Assumed two-stage decision process

2.1 Choice set formation: conjunctive heuristic with correlated error terms

Assuming that individuals apply a conjunctive heuristic to form their viable choice set, the probability of individual q to select choice set S derives from the probability of individual q to select a combination of criteria thresholds t^*_{kq}:

$$P_q(S \mid G) = P\left(t^*_{1q}\right) \cap P\left(t^*_{2q}\right) \cap \ldots P\left(t^*_{Kq}\right)$$

where $P_q(t^*_{kq})$ is the probability that individual q selects threshold t^* of criterion k *(k=1,2,...K)*.

The selection of criteria threshold values is driven by individual constraints. Hence, t^*_{kq} can be expressed as a function of a vector of individual characteristics Z_{kq}, a vector of coefficients to be estimated α_k, and an error term ε_{kq}. Assuming correlated error terms across different criteria thresholds for each individual, the error term ε_{kq} comprises an i.i.d. standard error term u_{kq} and a jointly multivariate distributed error term ζ_{qk} across criteria, which is also i.i.d. across individuals:

$$t^*_{kq} = \alpha'_k Z_{kq} + \varepsilon_{kq} = \alpha'_k Z_{kq} + \xi_{kq} + u_{kq}$$

Assuming the same correlation pattern among thresholds across individuals, the symmetrical correlation matrix Σ of the error terms can be written for K criteria, where the off-diagonal elements capture the correlation among different criteria thresholds:

$$\Sigma = \begin{bmatrix} 1 & a_{1,2} & \cdots & a_{1,K-1} & a_{1,K} \\ & 1 & a_{2,3} & \cdots & a_{2,K} \\ & & 1 & \ddots & \vdots \\ & & & \ddots & a_{K-1,K} \\ & & & & 1 \end{bmatrix}$$

The selection of a combination of correlated thresholds is represented by a multidimensional mixed ordered-response model according to the formulation developed by Bhat and Srinivasan (2005). Based on the assumption that the error terms u_{kq} and ξ_{qk} have a normal distribution, a multidimensional mixed ordered probit is utilized. The probability of individual q selecting threshold t^* of the criterion k is:

$$P\left(\theta_{(m-1)_k} < t^*_{kq} \le \theta_{m_k}\right) = \Phi\left(\theta_{(m-1)_k} - \left(\alpha_k^{'} Z_{kq} + \xi_{kq}\right)\right) - \Phi\left(\theta_{m_k} - \left(\alpha_k^{'} Z_{kq} + \xi_{kq}\right)\right)$$

where $\theta_{(m-1)k}$ and θ_{mk} are the lower and upper bounds of the threshold category m_k $(m_k=1,2,\ldots,M_k)$ that represents the threshold t^*_{kq}, and Φ represents the cumulative standard normal distribution. Relatively to each criterion k, the corresponding log-likelihood function for individual q is written as follows:

$$L_q\left(\alpha_k, \theta_k \mid \xi_{kq}\right) = \prod_{m_k=1}^{M_k} \left[\Phi\left(\theta_{(m-1)_k} - \left(\alpha_k' Z_{kq} + \xi_{kq}\right)\right) - \Phi\left(\theta_{m_k} - \left(\alpha_k' Z_{kq} + \xi_{kq}\right)\right)\right]^{d_{m_k q}}$$

where d_{mkq} is an indicator function that is equal to one if individual q selects the threshold category m of criterion k, and zero otherwise. The unconditional likelihood of individual q selecting a combination of K criteria thresholds yielding choice set S_q is expressed as:

$$L_q\left(S_q \mid G\right) =$$

$$= \int_{\xi_{1q}} \ldots \int_{\xi_{Kq}} \left(\prod_{m_k=1}^{M_k} \left[\Phi\left(\theta_{(m-1)_1} - \left(\alpha_1^{'} Z_{1q} + \xi_{1q}\right)\right) - \Phi\left(\theta_{m_1} - \left(\alpha_1^{'} Z_{1q} + \xi_{1q}\right)\right)\right]^{d_{m_1 q}} \right.$$

$$\left. \ldots \prod_{m_k=1}^{M_k} \left[\Phi\left(\theta_{(m-1)_K} - \left(\alpha_K^{'} Z_{Kq} + \xi_{Kq}\right)\right) - \Phi\left(\theta_{m_K} - \left(\alpha_K^{'} Z_{Kq} + \xi_{Kq}\right)\right)\right]^{d_{m_K q}} \right)$$

$$\ldots \varphi_K\left(\xi_{1q}, \ldots, \xi_{Kq}\right) d\xi_{1q} \ldots d\xi_{Kq}$$

where φ_K is a standard K-variate density function.

2.2 Choice stage: accounting for nested substitution patterns

Assuming the existence of similarities across alternatives within the viable choice sets, the choice stage is represented by the Nested Logit model (McFadden 1978).

Within the viable choice set S_q, for any two alternatives j and m in nest B_n ($n=1,...,N$), ε_{qj} is correlated with ε_{qm}. For any two alternatives in different nests B_{n1} and B_{n2}, the error terms are uncorrelated, and $Cov(\varepsilon_{qj}, \varepsilon_{qm}) = 0$ for any $j \in B_{n1}$, $m \in B_{n2}$ and $B_{n1} \neq B_{n2}$. Assuming that Q individuals share the same universal realm G, that the attribute values for any alternative j are identical across individuals and that the nesting structure is the same for all individuals, the likelihood of individual q to choose alternative i out of the viable choice set S_q is as follows:

$$L_q\left(i \mid S\right) = \prod_{i \in S_q} \left[\frac{e^{\left(\beta' X_i / \lambda_r\right)} \left(\sum_{j \in S_q, j \in B_r} e^{\left(\beta' X_j / \lambda_r\right)} \right)^{\lambda_r - 1}}{\sum_{l=1}^{N} \left(\sum_{j \in S_q, j \in B_s} e^{\left(\beta' X_j / \lambda_s\right)} \right)^{\lambda_s - 1}} \right]^{d_{qi}}$$

where X_i and X_j are vectors of attribute values of the alternatives i and j, respectively, B_r and B_s are nests, λ_r and λ_s are measures of the degree of independence in unobserved utility among the alternatives in nest B_r and B_s, and d_{qi} equals unity if individual q chooses alternative i, and zero otherwise. The vector β contains the coefficients to be estimated.

2.3 Choice stage: accounting for random taste heterogeneity

Assuming the existence of taste variation across the population, the choice stage is represented by the random coefficients logit (McFadden and Train 2000).

In order to capture taste differences across individuals, the random coefficients logit assumes that the coefficients in the utility function have a known continuous distribution across the population. Assuming that Q individuals share the same universal realm G, that the attribute values for any alternative j are identical across individuals, that the representative utility is linear in parameters and that the coefficients vary across individuals, the likelihood of individual q to choose alternative i out of the viable choice set S_q is as follows:

$$L_q\left(i \mid S\right) = \prod_{i \in S_q} \left[\int \frac{e^{\left(\beta' X_i\right)}}{\sum_{j \in S_q} e^{\left(\beta' X_j\right)}} f\left(\beta \mid \omega\right) d\beta \right]^{d_{qi}}$$

where X_i and X_j are vectors of attribute values of the alternatives i and j, respectively, and β is a vector of coefficients to be estimated. The vector β is distributed across the population with

a continuous density function $f(\beta|\omega)$ that is described by a vector of coefficients ω to be estimated. In the current study, a normal density function is assumed for several parameters, and hence the vector of coefficients ω contains the means and variances of their distributions.

2.4 Model estimation

Choice set formation and choice from considered options are distinct mental processes (Bovy 2009). Hence, although the choice depends on the retained choice set, the error terms of the non-compensatory choice set formation and the compensatory choice are uncorrelated. Hence, the combined unconditional log-likelihood for a population of Q individuals who choose their most preferred alternative i from their viable choice set S_q can be written as:

$$LL = \sum_{q=1}^{Q} \ln\left[L_q\left(i \mid S_q\right) L_q\left(S_q \mid G\right)\right]$$

The coefficients of both the conjunctive stage and the utility maximization stage are estimated simultaneously. Since the model with a flexible error structure does not have a closed-form expression, it must be approximated numerically and hence is estimated by maximum simulated likelihood (MSL) with 500 standard Halton draws. The multi-dimensional integrals at the conjunctive stage are simulated in a similar manner to Bhat and Srinivasan (2005) with the true correlation pattern across different criteria thresholds serving as an input for the estimation. Further integral dimensions are added for representing random taste variations at the choice stage.

3. DATA

3.1 Population sample for model estimation

The sample for model estimation consists of a population of 631 students studying in the city of Haifa, in the north of Israel, who participated in a web-based experiment of rental apartment choice.

In the choice experiment, participants delimited the universal realm of alternatives to a viable choice set from which they chose their preferred alternative. Specifically, participants searched a synthetically generated apartment dataset by a list of pre-defined criteria threshold values, and from the resulting choice set the participants ranked their three most preferred apartments for completing a prospective rental transaction. The synthetically generated apartment dataset, which was constructed on the basis of a statistical analysis of local real-estate databases, consisted of rental apartments characterized by their location, monthly rent price, structural features, neighborhood amenities, roommate policy and electrical appliances.

The criteria for searching the dataset were apartment sharing, neighborhood, monthly rent price, rooms, walking time to campus, noise level and parking availability.

A questionnaire supplemented the experiment by collecting participants' socio-economic characteristics, attitudes and perceptions about relevant issues to rental apartment choice. Participants were also asked to rate several neighborhoods that are relevant to students' rental apartment choice according to their perceived location amenities.

The web-server automatically recorded the participants' answers to the questionnaire and typing actions during the two-stage choice experiment. The three most preferred apartments according to their priority ranking served for model estimation. Hence, the data sample for model estimation includes a pool of 1,893 observations of choice outcomes and their corresponding thresholds.

The survey design and its theoretical foundations are thoroughly discussed by Kaplan et al. (2009b). Further details regarding the construction of the synthetic apartment dataset and the design of the questionnaire are provided by Kaplan et al. (2009a).

3.2 Variable specification

The variable specification for the estimated model is based on the assumption that the conjunctive heuristic depends on individual characteristics, perceptions and preferences. Since in choice situations characterized by many alternatives individuals are not fully informed about the universal realm of alternatives (Shocker et al. 1991), individuals rely solely on their intrinsic constraints (either self-imposed or external), perceptions and preferences in specifying their criteria thresholds.

Individual characteristics specified in order to explain threshold selection at the conjunctive stage include socio-economic characteristics (e.g., age, marital status, monthly expenses), transportation related variables (e.g., car availability, trip frequency to the campus), residential experience, current residential location and living arrangements. Latent constructs specified in order to explain threshold selection at the conjunctive stage include price perceptions, travel preferences and place of study preferences. Price perceptions are price-quality ratio consciousness and price knowledge. Study place preferences include studying on-campus due to either study effectiveness or communication efficiency with faculty members. Travel preferences are the preference for non-motorized modes and the preference for travel minimization. The observed personal characteristics are directly used as explanatory variables, whereas perceptions and preferences are incorporated in the model after performing factor analysis.

Upon specifying their tolerated criteria thresholds, individuals are provided with detailed descriptions of the apartments that satisfy the criteria thresholds. Hence, the model specification is based on the assumption that the utility-based choice depends on the attributes of the apartments included within the choice set. According to Kaplan et al. (2009a), interaction terms between individual characteristics and apartment attributes are statistically significant and improve the model goodness of fit in a statistically significant manner. However, the improvement with respect to the model without interaction terms is fairly small (McFadden adjusted R-Square equals 0.481 instead of 0.479), and thus on the basis of parsimony considerations the current version of the model does not include interaction terms between individual characteristics and apartment attributes. Apartment attributes specified in the model include price, structural features (i.e., number of rooms, renovation status, floor, security bars), location amenities (i.e., view, parking, noise level, proximity to campus), electrical appliances (i.e., air conditioning system and solar water heater), number of roommates and smoking policy.

4. MODEL ESTIMATION RESULTS

Table 1 presents the estimation results for the described two versions of the semi-compensatory model with flexible error structure. The first version is a semi-compensatory model with correlated thresholds at the choice set formation stage and a nested correlation patterns across alternatives at the choice stage (MMOP-NL). The nested structure is defined according to floor number, which differentiates between apartments located on the ground floor and other apartments. The second version is a semi-compensatory model with correlated thresholds at the choice set formation stage and random taste variation across the population at the choice stage (MMOP-RCL). Random taste variation is investigated with respect to the responsiveness of the population to the availability of security bars, the availability of a stunning view and apartment renovation. The two models are compared to the semi-compensatory model formulation with an i.i.d error structure at the choice stage (MOP-MNL), which is described by Kaplan et al. (2009a).

Three criteria are represented in the estimated model: apartment sharing, neighborhood and monthly rent price. These criteria were ranked as the most important rental apartment attributes in a preliminary survey among 74 students and were utilized for searching the database by the entire population sample.

Apartment sharing and neighborhood are represented by binary probit models. The criterion of apartment sharing differentiates between vacant and shared apartments, and is treated in the current study as an ordered criterion since, given no other information, vacant apartments are naturally better than shared apartments. The neighborhood criterion differentiates between two neighborhood types that are attractive to students. The first type, represented by the Neveshanan neighborhood, is adjacent to the campus but offers little employment or leisure opportunities. The second type, represented by the Carmel neighborhood, is located farther away from the campus but offers abundance of shopping and leisure opportunities, as well as high accessibility to student jobs located in a nearby high-technology compound. The two neighborhoods are treated as ordered by their perceived location amenities since, according to the results of the questionnaire, the neighborhood of Carmel received on average higher scores than the neighborhood of Neveshanan in terms of amenities. The price threshold is best described by the ordered-response probit model with 11 categories (200, 250,…,700). The chosen criteria yield 41 threshold combinations that lead to the formation of non-empty choice sets. Spearman's correlations across the criteria serve as an input for model estimation. Spearman's correlation between monthly rent price and neighborhood is 0.415, between monthly rent price and apartment sharing is 0.674, and between apartment sharing and neighborhood is 0.313. All the correlations are significant at the 0.001 significance level.

The relevant universal realm for the population sample contains 200 apartments, which are all the available apartments in the generated database for the above mentioned neighborhoods. A priori availability constraints are not imposed on the alternatives. However, for each ranked choice, the alternatives with higher priority ranking are excluded from the choice set prior to model estimation, since respondents could not rank the same alternative twice. In the current study, repeated choices of the same individual are treated as independent and data are analyzed as pooled cross-sectional data.

The first three parts of table 1 describe the determinants of threshold selection related to apartment sharing, neighborhood and monthly rent price, respectively. The fourth part presents the relative importance of apartment attributes at the utility-based choice stage, given the viable choice set. The interpretation of the model results is provided in section 4.1 and 4.2 for the conjunctive heuristic and the utility-based choice, respectively.

Table 1 – Estimation results for the semi-compensatory model with a flexible error structure

Variable	Description	MOP-MNL		MMOP-NL		MMOP-RCL	
		est.	t-stat.	est.	t-stat.	est.	t-stat.
Apartment sharing threshold coefficients							
Marital status	Single [a]	-	-	-	-	-	-
	Married	1.257	8.37	1.823	8.88	1.822	8.86
Gender	Female [a]	-	-	-	-	-	-
	Male	-0.518	-5.29	-0.775	-5.83	-0.773	-5.83
Age	Years	0.020	2.97	0.026	2.75	0.026	2.74
Car availability	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	0.391	3.82	0.537	3.91	0.539	3.92
Trip frequency to campus	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	-0.415	-4.44	-0.634	-5.04	-0.633	-5.02
On-campus studying to benefit from teacher-student communication factor		-0.124	-4.54	-0.155	-3.95	-0.154	-3.93
Monthly expenses	< $750 [a]	-	-	-	-	-	-
	$ 750 - 1000	0.504	3.47	0.756	3.70	0.753	3.69
	$1000 - 1750	0.606	5.54	0.930	5.18	0.930	5.17
Current residential arrangement	Dormitories [a]	-	-	-	-	-	-
	Parents	-	-	-	-	-	-
	Roommates	-0.647	-4.91	-0.918	-5.13	-0.922	-5.15
	Alone	0.793	4.64	1.073	4.46	1.070	4.45
	Spouse	0.987	8.12	1.353	8.24	1.351	8.22
Current residential location	Haifa city [a]	-	-	-	-	-	-
	Haifa suburbs	-0.610	-3.01	-0.851	-2.96	-0.852	-2.96
	Haifa outskirts	-0.918	-3.75	-1.267	-6.59	-1.265	-6.59
	Center of Israel	-	-	-	-	-	-
Location threshold coefficients							
Price-quality ratio consciousness factor		-0.289	-7.84	-0.395	-7.54	-0.395	-7.53
Age	Years	0.044	4.91	0.055	4.36	0.055	4.36
Car availability	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	0.511	5.61	0.696	5.50	0.698	5.51
Faculty location	Main campus [a]	-	-	-	-	-	-
	Medical campus	0.538	3.38	0.774	3.40	0.776	3.40
Monthly expenses	< $ 750 [a]	-	-	-	-	-	-
	$ 750 - 1500	0.393	3.69	0.637	4.25	0.636	4.23
	> $1500	0.651	5.29	0.995	5.76	0.994	5.75
Income source	None/scholarship [a]	-	-	-	-	-	-
	Part-time job	-0.392	-3.45	-0.558	-3.46	-0.558	-3.45
	Full-time job	-	-	-	-	-	-
Difference in job opportunities		0.086	3.60	0.113	3.36	0.113	3.36
Difference in green space availability		0.214	7.37	0.299	7.32	0.299	7.30
Preference to study on campus in order to increase study efficiency factor		-0.142	-6.04	-0.188	-5.68	-0.188	-5.68
Trip frequency to campus	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	-0.313	-3.56	-0.461	-3.74	-0.460	-3.74
Price threshold coefficients							
Marital status	Single [a]	-	-	-	-	-	-

	Married	0.637	6.57	0.928	7.29	0.926	7.28
Gender	Female [a]	-	-	-	-	-	-
	Male	-0.253	-4.00	-0.393	-4.86	-0.393	-4.85
Age	Years	0.042	4.33	0.052	3.81	0.052	3.81
Monthly expenses	< $ 500 [a]	-	-	-	-	-	-
	$ 500-750	0.247	3.43	0.361	3.51	0.361	3.50
	$ 750-1500	0.572	6.18	0.853	7.04	0.853	7.02
	> $1500	0.684	5.69	1.093	6.81	1.093	6.81
Income source	None/scholarship [a]	-	-	-	-	-	-
	Part-time job	0.140	2.30	0.149	1.77	0.148	1.76
	Full-time job	-	-	-	-	-	-
Car availability	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	0.210	2.83	0.337	3.61	0.337	3.61
Price-knowledge factor		0.107	5.80	0.160	6.07	0.161	6.06
Apartment search experience	≤3 apartment changes [a]	-	-	-	-	-	-
	> 4 apartment changes	-0.363	-4.62	-0.548	-3.24	-0.547	-3.24
Trip frequency to campus	Monthly/weekly [a]	-	-	-	-	-	-
	Daily	-0.224	-2.41	-0.533	-5.80	-0.533	-5.79
Current residential arrangement	Dormitories [a]	-	-	-	-	-	-
	Roommates	-0.330	-2.72	-0.330	-2.71	-0.329	-2.70
	Alone/parents	0.225	4.62	0.258	2.12	0.260	2.13
	Spouse	0.645	6.65	0.847	6.62	0.847	6.62
Current residential location	Haifa –low/medium class neighborhoods [a]	-	-	-	-	-	-
	Haifa – upper class neighborhoods	0.231	2.74	0.210	1.73	0.208	1.72
	Haifa Suburbs	-	-	-	-	-	-
	Haifa outskirts	-	-	-	-	-	-
	Center of Israel	0.551	6.61	0.755	6.53	0.754	6.52
Non-motorized modes preference factor		-0.038	-2.35	-0.038	-1.66	-0.038	-1.66
Travel minimization preference factor		-0.064	-3.42	-0.083	-3.11	-0.083	-3.09
Cut-off points	200 [a]	-	-	-	-	-	-
	250	-0.440	-0.15	-0.296	-0.71	-0.297	-0.71
	350	0.379	1.29	0.329	0.78	0.328	0.78
	350	0.648	2.19	0.733	1.74	0.732	1.74
	400	0.858	2.90	1.049	2.49	1.048	2.48
	450	1.293	4.35	1.689	3.98	1.688	3.97
	500	1.749	5.86	2.351	5.53	2.349	5.52
	550	2.369	7.92	3.236	7.59	3.232	7.59
	600	2.610	8.71	3.580	8.38	3.577	8.37
	650	2.991	10.02	4.111	9.64	4.108	9.63
	700	3.145	10.52	4.325	10.13	4.321	10.12
Correlations across thresholds							
Rent price and neighborhood		-	-	0.415	fixed	0.415	fixed
Rent price and apartment sharing		-	-	0.674	fixed	0.674	fixed
Neighborhood and apartment sharing		-	-	0.313	fixed	0.313	fixed

Choice stage coefficients given the selected choice set						
Rent price (monthly)	-0.001	-2.05	-0.001	-2.19	-0.001	-2.62
Number of rooms	0.584	12.00	0.453	8.81	0.634	12.04
Number of roommates	-0.394	-4.63	-0.364	-5.03	-0.363	-3.76
Walking time to campus	-0.083	-15.96	-0.062	-10.55	-0.089	-15.91
Quiet apartment	1.475	25. 18	1.134	11.52	1.507	24.30
Parking	0.298	4.432	0.257	4.70	0.346	4.89
Floor	-0.071	-3.10	-0.073	-2.78	-0.067	-2.74
Smoking allowed	-0.385	-5.16	-0.310	-5.05	-0.412	-5.26
Security bars (mean)	0.185	3.63	0.104	2.51	0.209	3.58
Security bars (standard deviation)	-	-	-	-	0.213	0.23
Stunning view (mean)	0.377	6.65	0.267	4.79	-1.369	-1.71
Stunning view (standard deviation)	-	-	-	-	4.517	3.02
Renovated (mean)	0.565	9.48	0.468	7.88	0.356	2.82
Renovated (standard deviation)	-	-	-	-	2.190	4.70
Air conditioner	0.290	5.01	0.223	4.77	0.321	5.27
Solar water heater	0.442	5.43	0.348	5.30	0.453	5.36
λ_1 Non ground floor apartment	-	-	0.802	14.19	-	-
λ_2 Ground floor apartment	-	-	0.638	8.30	-	-
Number of observations		1893		1893		1893
Number of parameters		65		70		71
Log-likelihood at zero		-20431.414		-20431.414		-20431.414
Log-likelihood at estimates		-10859.440		-10700.996		-10692.686
McFadden's adjusted R^2		0.465		0.473		0.473

4.1 Conjunctive heuristic

4.1.1 Determinants of apartment sharing

The propensity to delimit the universal realm to vacant apartments increases according to the progression of the respondents' lifecycle in terms of age, marital status, monthly expenses, and travel independence related to daily car availability.

The propensity to delimit the universal realm to shared apartments increases with daily trips to campus and the preference to study there in order to benefit from teacher-student interaction. Possibly, respondents who spend more time on campus than in their apartment prefer to ease apartment chores by sharing them.

The propensity to retain a certain apartment type increases with a reference to a status-quo apartment type, as students tend to retain apartments that match their current residential arrangement. Namely, respondents who currently reside with roommates have a greater propensity to retain only shared apartment, while respondents who reside alone or with their spouse tend to retain only vacant apartments.

4.1.2 Determinants of neighborhood selection

The propensity to delimit the universal realm to the Neveshanan neighborhood is related to its proximity to the campus, as respondents who travel daily to campus or prefer to study there tend to retain only apartments in Neveshanan in their choice set.

The propensity to delimit the universal realm to the Carmel neighborhood increases according to: (i) daily car availability as it allows disperse activity patterns and provides easy accessibility to campus; (ii) studying in the Faculty of Medicine as the Carmel neighborhood offers better accessibility to the medical campus; (iii) greater perceived difference in accessibility to student jobs and availability of green areas in favor of Carmel relatively to Neveshanan, (iv) the tendency to retain only vacant apartments, indicating that tradeoffs exist between apartment sharing and location at the choice set formation stage.

4.1.3 Determinants of monthly rent price

The propensity to select higher price thresholds increases according to: (i) progression of the student's lifecycle and socio-economic status, as respondents who are married or have higher monthly expenses tend to select higher price thresholds; (ii) self-reported price knowledge; (iii) reference to the status quo apartment price, as respondents who currently rent an apartment alone or with their spouse have a greater propensity to select higher price thresholds than respondents who reside in the dormitories or with roommates; (iv) higher perceived product quality, as respondents who retain vacant apartments or apartments in the Carmel neighborhood tend to select higher price thresholds.

The propensity to select higher price thresholds decreases according to: (i) habit to travel daily to campus, likely related to shorter time spent in the apartment with respect to the campus; (ii) greater apartment search experience, likely reflecting a greater propensity to undergo the burden of replacing a status quo alternative with a more cost-efficient one.

4.2.1 Apartment attributes

For each respondent, apartment sharing and neighborhood are determined at the choice set formation stage and do not vary within the viable choice set. Monthly rent price and the number of roommates vary within the viable choice set and hence serve as explanatory variables at the utility maximization stage.

The propensity of renting an apartment increases according to an increase in terms of: (i) quality of structural features, such as greater number of rooms and renovation; (ii) availability of security bars; (iii) availability of cost-efficient electrical appliances such as solar water heater; (iv) availability of an air conditioning system, a necessity in the hot Mediterranean

climate; (v) parking availability; (vi) environmental location amenities, such as quietness and a nice view.

The propensity of renting an apartment decreases according to an increase in terms of: (i) apartment monthly rent; (ii) floor number, as apartments located on lower floors are preferred, possibly due to the scarcity of elevators in the two neighborhoods; (iii) number of roommates; (iv) distance from campus, as an increase in walking time to the campus decreases the attractiveness of the apartment; (v) roommates' pro-smoking policy, possibly since 87.0% of the respondents in the sample are non-smokers.

4.2.2 Effect of incorporating a flexible error structure: correlated thresholds and nested correlation patterns across alternatives

The likelihood-ratio (LR) test value when comparing the MMOP-NL model with the MOP-MNL model is equal to 316.9, which is greater than the critical chi-square value of 11.07 for the five additional coefficients at the 0.05 significance level. Hence, the LR test rejects the null hypothesis of independently and identically distributed error terms.

The nesting coefficients are significant, positive and within the range between zero and one, hence the model is consistent with random utility maximization at the choice stage. Both nesting coefficients are significantly different than unity (Student's t-test value for testing the hypothesis λ_1=1 equals -3.50, and Student's t-test value for testing the hypothesis λ_2=1 equals -4.72), thus rejecting the null hypothesis of independent correlation patterns among the alternatives within each nest.

4.2.3 Effect of incorporating a flexible error structure: correlated thresholds and random taste variations across the population

The LR test value when comparing the MMOP-RCL model with the MOP-MNL model is equal to 333.51, which exceeds the critical chi-square value of 12.59 for the six additional coefficients at a significance level of 0.05. Hence, the LR test rejects the null hypothesis of independently and identically distributed error terms.

The model estimation results indicate that while there is no random taste variation with respect to the availability of security bars, large taste variations exist with respect to the availability of view and apartment renovation. Accordingly, results demonstrate the importance of introducing random taste variation into semi-compensatory models. While the model with an i.i.d error structure (MOP-MNL) indicates that in general students prefer apartments with a stunning view, the introduction of random taste variation (MMOP-RCL) indicates that the mean tendency of students is to prefer apartments without a view, but since

large taste variation exists across the population, some students strongly prefer apartments with a view. Similarly, while both the MMOP-MNL model and the MMOP-RCL model agree about the mean tendency of a positive preference of renovated apartments, according to the MMOP-RCL model some students do not care about renovation status or tend to prefer non-renovated apartments.

CONCLUSIONS

The current study proposes a semi-compensatory model that jointly represents a sequence of an elimination-based choice set formation governed by the conjunctive heuristic and a choice derived from the principle of utility maximization. The proposed model alleviates the simplifying assumptions embedded in existing semi-compensatory models with respect to three main themes: (i) the number of alternatives, (ii) the representation of choice set formation and (iii) the error structure.

With respect to the number of alternatives, the proposed model is suitable for choice situations entailing a large numbers of alternatives. In the current study, the model is estimated for a universal realm of 200 alternatives. For this universal realm, traditional semi-compensatory models require the consideration of 1.6E+60 theoretically possible choice sets for model estimation, hence these models become intractable. In the current study, 41 non-empty choice sets are considered, which facilitates the model estimation without loss of generality, since these choice sets were the only ones that were actually considered by the sample population according to the information gathered regarding the choice set formation.

With respect to the representation of choice set formation, the proposed model offers a detailed representation of the criteria thresholds that delimit the universal realm of alternatives to a viable choice set. The criteria are represented as ordered-response variables that are a function of individual socio-economic characteristics, perceptions and preferences. The proposed model relaxes the three prevailing assumptions related to threshold representation in semi-compensatory models: independence of individual characteristics, normal distribution across the population and independence across thresholds of different criteria.

The proposed semi-compensatory model introduces a flexible error structure into the representation of both the choice set formation and the utility-based choice from the viable choice set. By introducing a flexible error structure, correlations across thresholds, nested substitution patterns across alternatives within the viable choice set and random taste variation across the population are represented. The model estimation results show the

importance of incorporating a flexible error structure into semi-compensatory models, as both model variations incorporating a flexible error structure are superior in terms of goodness of fit relatively to the semi-compensatory model with the independent error structure.

The traits of the proposed semi-compensatory model, namely applicability to large universal realms, refined threshold representation at the elimination-based choice set formation stage and flexible error structure at both the choice set formation stage and the utility-based choice stage, make the proposed model a viable option for real-world applications related to regional, urban and transport planning.

The empirical analysis in this paper applies the semi-compensatory model with a flexible error structure to examine off-campus apartment rental choices by students. According to the empirical results, the choice set formation, which is governed by price, apartment sharing and neighborhood, depends on the progression of the respondent's lifecycle in terms of age, marital status and economic status, travel independence, price perceptions, place of study and travel preferences. Upon the formation of the viable choice set, relevant apartment attributes for students include structural features and physical conditions, size, number of roommates and their smoking attitudes, appliances that influence recurrent costs, air conditioning system and neighborhood environmental amenities. The results further indicate the existence of nested substitution patterns across apartments according to their floor number, and the existence of large taste variation across the population with respect to the preference for apartments that are renovated or have a nice view.

Several possible directions exist for further development of the proposed semi-compensatory model with a flexible error structure. First, the model can be applied to other spatial and transportation related choices (e.g., car rental, flight tickets, and destination choice) and be estimated from revealed preference data retrieved from actual on-line transactions in a digital economy environment. Second, the explanatory ability and the behavioral realism of the model can be further enhanced by considering various generalized extreme value (GEV) models for representing correlation patterns across alternatives at the utility-based choice stage. Last, the conjunctive stage is represented in the current study by ordered-response criteria. Indeed, many criteria (e.g., price, size, distance) are naturally ordered. However, some criteria, such as location, may induce multinomial response as well. Certainly, multinomial criteria can be incorporated into the proposed model by transforming them into ordered criteria. In fact, in the current study, location is treated as an ordered variable, and the two neighborhoods are ordered by the level of their perceived amenities. However, since

tradeoffs may exist between neighborhood amenities and accessibility, the representation of multinomial criteria can enhance the explanatory strength of the model.

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