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Hierarchical fuzzy integral stated preference method for Taiwan's broadband service market☆

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Abstract

The stated preference method (or conjoint analysis) has been a popular method for measuring buyer tradeoffs among multi-attribute products or services. In addition, the multi-nomial logit (MNL) model is a popular model for the stated preference method, although it relies on the assumption that its attributes have no correlations. However, in social problems, attributes are often correlated with each other. Recently, the Choquet integral has been used to solve non-additive problems. This study combines the Choquet integral and the stated preference method to propose the hierarchical fuzzy integral stated preference (HFISP) method, and then analyze the narrowband service users' preferences for broadband service. The results demonstrate that the hierarchical fuzzy integral stated preference method performs better than the partitioned fuzzy integral multi-nomial logit (PFIMNL) model. The HFISP method is effective and can be applied to deal with real life problems since it solves correlated attribute problem in discrete choice behavior.

Keywords: Fuzzy integral; Multi-nomial logit model; Stated preference

1. Introduction

Since the early 1970s, conjoint analysis has received considerable academic and industrial attention as a major set of techniques for measuring buyers' tradeoffs among multi-attribute products and services, new product/concept evaluation, repositioning, competitive analysis and market segmentation [1–9]. Different statistical techniques of conjoint analysis are available to decompose the overall preferences or choices provided by the respondents into utility weights associated with the factors. For discrete choice data, the multi-nomial logit (MNL) model is usually used as an estimation model, although this model supposes that the attributes have no correlation. However, in social problems, attributes are often correlated. Recently, Choquet integral has been applied to evaluate the multi-attribute problems, since it can solve the problem of the interactions among attributes. Ogawa [10] applied the idea of fuzzy measure to utility function. However, when there are more attributes, the Choquet integral model is difficult to handle because $2^n - 1$ parameters (values of fuzzy measure) are generally required for n attributes, so the evaluation model obtained becomes quite complex, and the structure is difficult to grasp [11]. There have been three papers, which proposed solutions for this problem. Tanaka and Sugeno [12] proposed a two-layer evaluation model, which is based on factor analysis and Choquet integral. Sugeno et al. [11] proposed an equivalent hierarchical Choquet integral model constructed by hierarchical combinations of an ordinary Choquet integral model. Sugeno and Kwon [13] proposed a clusterwise regression-type model to cluster the given attributes into macro-attributes and make regressions based on the clustered macro-attributes. However, these three methods are suitable only to solve revealed preference data, which is

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based on actual behavior/choice. Tseng et al. [14] proposed the partitioned fuzzy integral multi-nomial logit (PFIMNL) model to analyze hypothetical choice, which belongs to the stated preference approach. This model utilized Tanaka and Sugeno's concept [12] which partitions the attributes by factor analysis, and determines which parts of the variables are correlative; after which, the Choquet integral is used to integrate the interactive variables to be macro-attributes that are not highly correlated. Finally in Tseng et al. [14], an MNL model was used and applied to analyze IT choice behavior in Taiwan. Nevertheless, for an MNL model, if too many attributes are included there is a danger that the respondents will not be able to respond properly to the survey. Green and Srinivasan [4] suggested limiting the number of attributes of conjoint analysis to 6 or fewer; therefore, when using factor analysis to cluster 6 attributes the results are sometimes not very good, affecting the performance of the PFIMNL model. Therefore, this paper proposes using the hierarchical fuzzy integral stated preference (HFISP) method to solve this problem and applies it to analyze the broadband service choice behavior for narrowband service users in Taiwan. Currently, narrowband service (dial-up) still has the most users for the Internet access market, and from it are drawn the potential customers for broadband service in Taiwan. This current paper analyzes narrowband users' broadband preferences to assist broadband providers in their marketing strategies. The results demonstrate that the HFISP method performs better than partitioned fuzzy integral multi-nomial logit (PFIMNL) model. The HFISP method is effective and can be applied to deal with real life problems since it solves correlated attribute problem in discrete-choice processes.

The rest of this paper is organized as follows: Section 2 describes the HFISP method, Section 3 employs an example of the choice behavior for broadband service in Taiwan, and Conclusions and suggestions are presented in Section 4.

2. Hierarchical fuzzy integral stated preference method

An MNL model of a qualitative response variable can characterize a choice made from discrete alternatives by a decision maker as a function of attributes associated with each alternative, as well as according to the characteristics of the individual decision maker. Because of its analytical and computational tractability, this model has been applied extensively to discrete-choice processes with great success in such fields such as econometrics [15,16], transportation [17,18], and marketing [19].

The MNL model is usually used as the estimation model of the stated preference methods (or conjoint analysis), but the attributes of this model are assumed to be linear and uncorrelated. However, in social problems, the attributes are often interactive. This current study uses the concepts from Sugeno et al. [11] to combine the Choquet integral [20,21] (the details of the theory are presented in the appendix) and the MNL model (the methodology is presented in the appendix) for a solution.

The steps in the hierarchical fuzzy stated preference method are as follows:

(1) Determine the specific research problem and its objectives, and estimate the amount of available resources.
(2) Decide on the appropriate research population and a sampling procedure for reaching a representative sample of that population.
(3) Select a survey format.
(4) For each attribute, decide on a limited number of attributes and levels that are realistic and related to the problem
(5) Configure attributes and levels into individual concepts.
(6) Design the data collection instrument.
(7) Summarize the opinions of the experts to build the hierarchy of the attributes, and determine which parts of the variables are correlated. This hierarchy has two types, separated and overlapping hierarchies. The separated hierarchy is that in which one attribute belongs to only one macro-attribute, whereas the overlapping hierarchy is that in which one attribute belongs to several macro-attributes.
(8) Design a fuzzy integral questionnaire.
(9) Conduct the survey, including fuzzy integral questions, and choice behavior questions.
(10) Analyze the data, using the hierarchical fuzzy integral stated preference model, which has two types, as shown in Figs. 1 and 2. From step 7, which determined which parts of the variables are correlated, then there are two steps, as follows. Fig. 1 shows the separated HFISP model in which each attribute belongs to only one macro-attribute. Fig. 2 shows the overlapping HFISP model in which one attribute belongs to multiple macro-attributes.
    Step 1: Apply the Choquet integral to integrate the non-additive attributes into a macro-variable, after which the macro-attributes are additive.
    Step 2: Based on the results of Step 1 for macro-attributes, develop the MNL model.
(11) Validate the results, both internally and externally.
(12) Interpret the results and draw conclusions.

3. Illustrative case: broadband service choice behavior in Taiwan

Choice behavior is a complex problem type in the real-life world. Many attributes affect consumers to choose/buy the products or service. These attributes are often correlated with each other. Since the narrowband service users' choice behavior for broadband service in Taiwan also fits the above situations, we use it as an example to show that the HFISP method is effective and feasible. Section 3.1 introduces

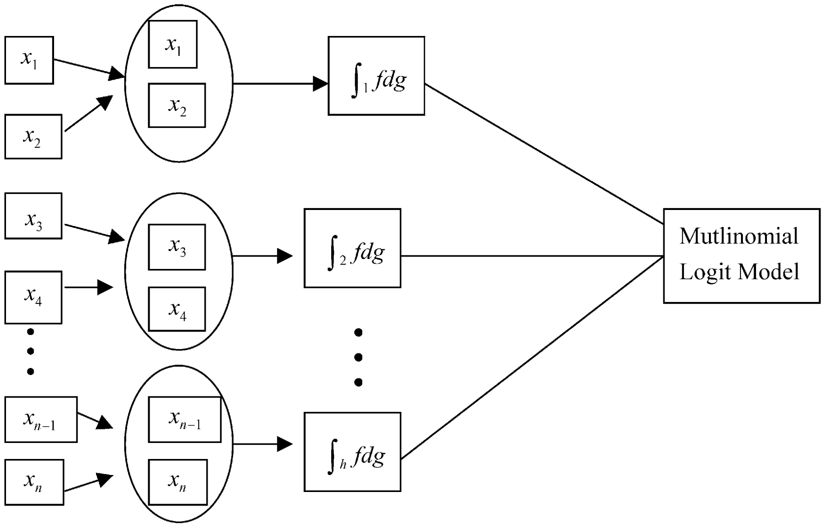

Fig. 1. Separated HFISP t model.

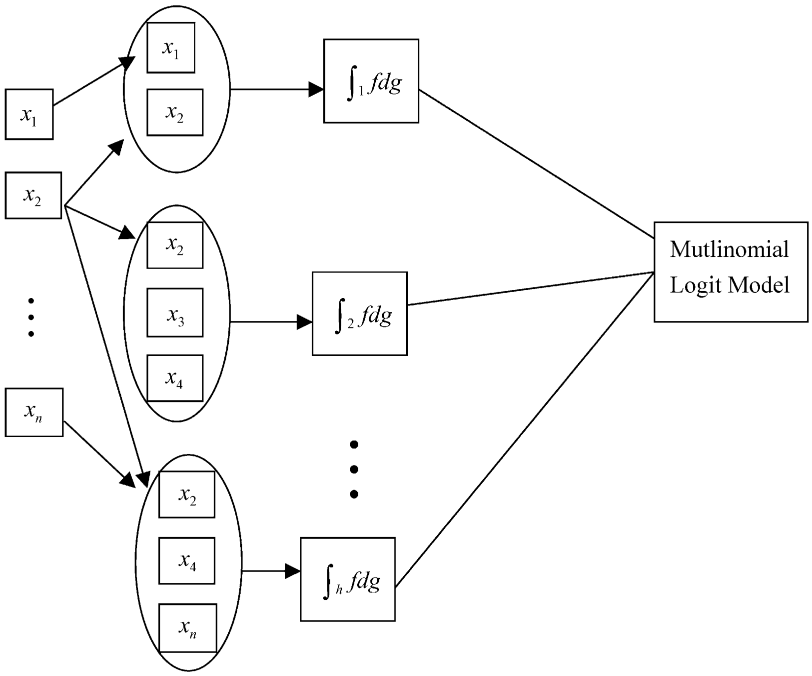

Fig. 2. Overlapping HFISP model.

information on broadband service in Taiwan, and Section 3.2 uses the HFISP model to analyze broadband service choice behavior and compares it with the PFIMNL model.

3.1. Taiwan's broadband service market

Use of the Internet at home has become almost ubiquitous within the last few years, and in this market the emphasis is increasingly placed on connection speed. However, by far the most popular method remains the standard dial-up connection, with broadband technologies just beginning to grow [22]. By the end of 2002, 56.4 million homes had subscribed to broadband Internet services worldwide, for which xDSL (Digital Subscriber Line, DSL), cable operators and service providers will continue to remain the market leaders. In addition, Strategy Analytics predicts only limited

Table 1
Chunghwa telecom ADSL service price

Chunghwa Telecom Internet services fees	Installation fee	1500 (each time)					
	Change setting fee	200 (each line)					
	PPPOE software installatiion fee	300 (each time per circuit)					
	Fixed system	Upload/download rates	512 K/64 K	512 K/512 K	768 K/128 K	1536 K/384 K	
		Single computer	700	—	1200	1500	
	Non-fixed type	Download/upload rate	Minimum monthly fee	Available hours for minimum monthly fee	Fee for hours beyond minimum monthly time	Upper limit of fee	
		512 K/64 K	299	8 h	NT $0.6/min	499	
		1536 K/384 K	NT$888 (unlimited access)				
ADSL circuit fees	ADSL rate (download/upload)	512 K/64 K	512 K/512 K	768 K/128 K	1536 K/384 K	3 M/512 K	6 M/640 K
	Hook-up fee	1500 (each time per computer)					
	Change setting fee	200 (each time)					
	User equipment malfunction inspection fee	900 (each time)					
	Monthly circuit leasing fee	595	1299	800	899	1400	3000

Source: http://ww.cht.com.tw/CHTFinalE/Web/Product.php?CatID=640.

success for emerging platforms such as satellite, fiber, power line and fixed wireless [23]. The US Federal Communications Commission (FCC) defined 'broadband' as having the capability of supporting, in both the provider- to-consumer (downstream) and the consumer-to-provider (upstream) directions, a speed (in technical terms, 'bandwidth') in excess of 200 kilobits/s (Kbps) in the last mile. This rate is approximately four times faster than the Internet access received through a standard phone line at 56 or 64 Kbps [22].

According to the Strategy Analytics' research, broadband connections will increase in the US by 40% in 2003 from 17.9 million homes (27% penetration) to 25.3 million homes. Subscribers are projected to grow to 64 million by 2008 (more than 70% penetration). By the end of 2003, cable modem subscribers are expected to have grown to 16.1 million, while DSL connections will have grown to 7.9 million. Another 1.3 million homes are projected to subscribe to alternative broadband services by the end of 2003. In contrast broadband has a 7.5% annual growth rate in Europe, with 6.3 million homes having signed up for service in 2002 [23]. In Taiwan there has been cable modem service since 1998, and the DSL service started from the end of 1999, as provided by Chunghwa Telecom Co. Ltd. [23]. By the end of July 2002, in Taiwan there were 5.01 million dial-up home users, and 1.4 million ADSL (Asymmetric Digital Subscriber Line) subscribers, with 0.21 million cable modem connections [24].

By 2002 with the opening of this market, there were about 10 broadband service provider companies in Taiwan. Chunghwa Telecom's ADSL market share had reached 76% and it also controlled over 95% of the ADSL lines [25]. The ADSL ISPs (Internet service providers) include Chunghwa Telecom Co., Digital United Inc., GigaMedia, Taiwan Fixed Network (TFN), Taiwan Telecommunication Network Services (TTN), Eastern Broadband Telecom, Asia Pacific Online Service Inc (APOL), Infoserve, and New Infocomm Tech Co. Ltd. The cable modem service providers are Eastern Broadband Telecom and GigaMedia [25]. The ADSL service's Explanation of Rates Chunghwa Telecom Co. is shown in Table 1.

3.2. *Broadband service choice behavior*

Most customers still use the narrowband service for Internet access and its users include most potential customers for broadband service. This section uses the separated HFISP model to analyze their broadband service choice behavior in Taiwan. And in order to show the performance of the separated HFISP method, the PFIMNL model is for comparison with the HFISP model.

According to the HFISP method, to solve this problem the above 10 steps are followed: Step (1): The objective is to find out the narrowband service users' choice behavior for broadband service in Taiwan. As broadband access develops quickly, it holds a special attraction for narrowband service users.

Steps (2) and (3): The population of this study includes the north, middle and south of Taiwan. The population density is used to decide the number of samples for three areas. This stage as conducted by cluster random sampling.

Steps (4)–(7): There are 17 attributes for broadband access service, which have been summarized according to reports and brainstorming. However, the more attributes there are in a questionnaire, the more difficult it is for respondents to discriminate between them. Thus, Green and Srinivasan [4] suggested limiting the number of attributes of conjoint analysis to 6 or fewer. Therefore, this questionnaire was used to determine dial-up home users' preference. The questionnaire contained three parts: the first part included the respondents' Internet access behavior, while the second part was their important factors in choosing broadband service and corresponding tolerance limits. Consumers recognized that the importance of broadband service attributes were designed to measure respondents' perceptions and attributes toward broadband service attributes, using five-point Lickert scales. The third part was socio-economic data.

This stage as conducted by cluster random sampling. Altogether, 2000 questionnaires were sent out to narrowband service users, of which 934 copies were retrieved, with 725 valid questionnaires. The broadband attributes are presented and ranked in Table 2. Therefore, the first 6 attributes were chosen to be the critical attributes for narrowband users who decide to use broadband access service. They are upload speed, download speed, usage fees (per month), data transmission safety, connection stability and frequency of traffic jams.

For the HFISP method, according to expert opinions and related reports, upload speed and download speed have some correlation and were extracted and denoted as transmission speed, while, connection stability and traffic jam were extracted and denoted as transmission quality.

For the PFIMNL model, there were two factors extracted from the six broadband attributes by factor analysis using the principal components method and varimax rotation method for 100 rotations. The extracted factors were "transmission speed and fees" (including upload speed, download speed and usage fees (per month)) as well as "transmission quality" (including data transmission safety, connection stability and frequency of traffic jams).

Step (8): Design a fuzzy integral questionnaire. The questionnaire included two parts: (a) personal socio-economic information and (b) fuzzy integral questions.

Table 2
Broadband attributes' descriptions

Macro-attributes	Broadband attributes	Rank
Transmission speed	Upload speed	1
	Download speed	6
	Usage fees (include circuit fees and network fee)	3
	Data transmission safety	5
Transmission quality	Connection stability	2
	Traffic jam	4
	Lower settle down cost	9
	Famous access company	16
	Service quality of access company	8
	Service speed when apply	11
	Quickly deal with customer question	7
	Fixed IP address	13
	Always collect line	14
	Brand of broadband access company	17
	More wide access of broadband access company	10
	Wide bond access to worldwide	15
	Multimedia service	12

Steps (9)–(12): This subsection used a questionnaire to survey broadband service preferences. In total 600 respondents who were narrowband service users were interviewed by several researchers from April to June 2002. The questionnaire contained three parts: (a) personal socio-economic information, (b) importance level of the related attributes, and (c) broadband access service choice questions. The socio-economic information included variables such as gender, age, highest education and personal income. The respondents considered the importance level of the correlated attributes, two attributes were included, and then the respondents needed to consider that the two attributes occurred in the same time. The scoring was from 1–10, with higher scores indicating greater importance. The third part contained two broadband questions. In the broadband choice questions, four alternatives were presented for the choice set: ADSL (fixed IP), ADSL (non-fixed IP), cable modem and narrowband (dial up).

The perpendicular design of the attribute value, some of which employs four levels, of the four alternatives is shown in Table 3. Some attribute ranges for the four alternatives are also specified differently in order to reflect the different actual ranges of the four types of access services. The four levels of this study can be formulated by an orthogonal table of three rows of two levels; therefore, the manner of division into levels is presented as an orthogonal table L_{32} (2^{31}), which is overlapped by an orthogonal table $L_{32}(4^6 \times 3^3 \times 2^4)$. Each of the experimental designs includes 32 kinds of scenarios and

Table 3
Attribute ranges of the four broadband access services

Broadband attributes	Cable modem				ADSL (non-fixed)				ADSL (fixed)				Narrowband	
Upload speed	128 K	256 K	768 K	2 M	64 K	128 K	384 K	768 K	64 K	128 K	256 K	1 M		12.8 K
Download speed	3 M	6 M	10 M	36 M	512 K	1024 K	1536 K	3 M	512 K	1024 K	768 K	7 M		56 K
Usage fees/month	1199	999	699	400	1129	929	729	400	2600	2000	1000	400		400
Data transmission safety		Common		Yes		Common		Yes		Common		Yes	Common	No
Connection stability	Haven't		A little	Have	Haven't		A little	Have	Haven't		A little	Have		Haven't
Traffic jam		Haven't		Have		Haven't		Have		Haven't		Have		Have

Table 4
Examples of broadband service choice questions

	Cable modem	ADSL (no fixed)	ADSL (fixed)	Dial up
Situation 1				
Upload speed	768 K	128 K	256 K	12.8 K
Download speed	6 M	2 M	1024 K	56 K
Usage fees (per month)	799	729	3500	400 (can use 22 hours)
Data transmission safety	Common	Yes	Common	No
Connection stability	A little	Have	Have	Haven't
Traffic jam	Have	Have	Haven't	Have
Rank*	( )	( )	( )	( )
Situation 2				
Upload speed	1 M	64 K	1 M	12.8 K
Download speed	36 M	512 K	7 M	56 K
Usage fees (per month)	1199	400	5000	400 (can use 22 hours)
Data transmission safety	Yes	Common	Common	Common
Connection stability	A little	A little	Have	Haven't
Traffic jam	Haven't	Haven't	Haven't	Have
Rank*	( )	( )	( )	( )

*Rank the performance of the provide alternatives.

each scenario is represented by one question of this survey. Then these 32 kinds of scenarios were chosen randomly and two questions were placed in each of the questionnaires. An example of a question related to broadband service is presented in Table 4.

For this survey, Limdep software was used to analyze the two parts of the broadband service choice model.

This study used the Choquet integral, together with the results of Tables 5 and 6 to calculate the value of the fuzzy integral of each extracted factor. The attribute values of each alternative, f_{ij}, were the scenarios in the questionnaire. Therefore, every respondent has four extracted factors of HFISP model: transmission quality, transmission speed, usage fees and data transmission safety. However, every respondent has two extracted factors of PFIMNL model, “transmission quality” and “transmission speed and fees”. The first choice of alternative for each respondent was used to develop a broadband services choice model. Tables 5 and 6 presented the results of the HFISP model and of the PFIMNL model.

The log-likelihood ratio index ρ^2 was used to decide whether or not the choice behavior was well captured. From Table 7, the PFIMNL with the log-likelihood index ρ^2 is not a good model, because $\rho^2 = 0.1458 < 0.2$. With the HFISP model, the log-likelihood index has better market prediction value ($0.2067 > 0.2$). The test of non-nested hypothesis, 1985 was used to compare the explained performance of the PFIMNL model and the HFISP model. The null hypothesis was that model 1 is the true specification of the non-nested hypothesis, so the following holds asymptotically:

$$P(\rho_2^{2^*} - \rho_1^{2^*} > z) \leqslant \Phi\{-[-2z\mathrm{LL}(0) + (s_2 - s_1)]^{0.5}\}, \quad z > 0, \tag{1}$$

where $\rho_m^{2^*}$ is the adjusted likelihood ratio index for model $m = 1, 2$, s_m the number of parameters in model m, and

Table 5
Fuzzy densities of HFISP for the important attributes

Extracted factors	Attributes	λ	Fuzzy density $g(\bullet)$
Transmission speed	Fast upload speed		0.53
	Fast download speed	−0.58	0.68
	Fast upload speed and download speed		1.00
Transmission quality	High connection stability		0.59
	No traffic jam	−0.40	0.67
	High connection stability and No traffic jam		1

Table 6
Fuzzy densities of PFIMNL for the important attributes

Extracted factors	Attributes	λ	Fuzzy density $g(\bullet)$
Transmission speed and fees	Fast upload speed		0.533333
	Fast download speed		0.683333
	Low usage fees	−0.91	0.622222
	Fast upload speed and download speed		0.881864
	Fast upload speed and low usage fees		0.850694
	Fast download speed and low usage fees		0.914952
	Fast upload speed, download speed and low usage fees		1
Transmission quality	High safety		0.594444
	High connection stability		0.666667
	No traffic jam	−0.95	0.727778
	High safety and connection stability		0.884223
	High safety and no traffic jam		0.910786
	High connection stability and no traffic jam		0.933021
	High connection stability, safety and no traffic jam		1

Table 7
Results of PFIMNL and HFISP

Items	PFIMNL		HFISP	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant A	2.1041	6.2818	1.1123	2.4387
Constant B	1.8563	5.4591	1.0978	2.5619
Constant C	1.4351	4.0785	1.2577	2.5984
Transmission speed			1.1658	2.9229
Transmission quality			0.8672	2.7741
Usage cost			−2.0451	−3.9207
Data transmission safety			−0.5608	−3.0620
LL(0)	−274.486		−274.486	
LL(β)	−239.549		−217.758	
ρ^2	0.1458		0.2067	
ρ^{2*}	0.1458		0.1921	

A, cable modem; B, ADSL(no fixed); C ADSL(fixed),; LL(0) = log-likelihood at zero, LL(β) = log-likelihood, LL(c):log-likelihood constant only.

Table 8
Comparison between MNL, PFIMNL, HFISP and Ogawa's method

	MNL	PFIMNL	Ogawa's method	HFISP
The relationship of attributes	Additive	Non-additive	Non-additive	Non-additive
Methods	MNL	Factor analysis, Choquet integral MNL	Fuzzy integral	Brain storming Choquet integral MNL
Applied problems	Revealed/stated preference	Revealed/stated preference	Revealed preference	Revealed/stated preference
Easy to use	Yes	Yes	More than 3 attributes are complexity	Yes
Time complexity	Less	More	Less	More

Φ the standard normal cumulative distribution function. If $\Phi(^*)$ approaches 0, then model 2 is better than model 1. Because $\Phi(-5.90)$ approaches 0, the HFISP model is better than the PFIMNL model. From Table 7, it can be seen that the narrowband service users emphasized transmission speed, transmission quality, usage cost and data transmission safety. Among these 4 attributes, narrowband service has an advantage only in usage fees. Therefore, the marketing strategies of the ADSL or cable modem service providers must emphasize their price strategies.

3.3. Discussions

A comparison between MNL model, HFISP, PFIMNL model and Ogawa's method [10] using a fuzzy integral for the utility function is shown in Table 8. When the attributes have interactive characteristics, the MNL model is unsuitable, whereas the HFISP model, PFIMNL model and Ogawa's method can each solve this problem. The limitation of Ogawa's method is that with more attributes it becomes increasingly complex, so it cannot be used to solve stated preference choice data. Therefore, the HFISP and PFIMNL models are suitable for use with revealed and stated preference choice data and they can solve the attributes for choice behavior without independence. Although the HFISP and PFIMNL models have the greatest time complexity, these two models are both suitable and effective for realistic choice behavior.

4. Conclusions and suggestions

The MNL model is a linear model, which assumes the uncorrelation and additivity of attributes, although in social situations these attributes are often correlated. To solve this problem, this study combines the Choquet integral and the stated preference to propose the HFISP method and then applies it to analyze narrowband users' choice behavior for broadband services in Taiwan. Results of the non-nested test showed that the HFISP model performed better than the PFIMNL model, so the marketing strategies of broadband access service providers should emphasize price strategy.

The HFISP method is effective and can be applied to deal with discrete choice behavior since it can solve the attributes for choice behavior without independence.

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Appendix A. Review of Choquet Integral and Multinomial Logit Model

A.1. Fuzzy measure

Fuzzy measure g is a set function defined on the power set $P(X)$ of X satisfying the following properties [20,26–30]:

$$g : P(X) \to [0, 1]$$

(1) $g\{\phi\} = 0, g(X) = 1$
(2) If $A, B \in P(X)$ and $A \subset B$, then $g(A) \leqslant g(B)$
(3) If $F_n \in P(X)$ for $1 \leqslant n < \infty$ and a sequence $\{F_n\}$ is monotone, then $\lim_{n\to\infty} g(F_n) = g(\lim_{n\to\infty} F_n)$.

λ-fuzzy measure g_i is a fuzzy measure with the following property [13]:

$$\forall A, B \in P(X), A \cap B = \phi,$$

$$g_\lambda(A \cup B)$$

$$= g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B) \text{ for } \lambda > -1 \quad \text{(A.1)}$$

In the case of λ-fuzzy measure for a finite set $X = \{x_1, \ldots, x_n\}$, fuzzy density $g_i = g_\lambda(\{x_i\})$ leads to the following equation:

$$g(X_l) = g(\{x_1, x_2, \ldots, x_l\})$$
$$= \sum_{i=1}^{l} g_i + \lambda \sum_{i_1=1}^{l-1} \sum_{i_2=i_1+1}^{l} g_{i_1} g_{i_2} + \cdots + \lambda^{l-1} g_1 g_2 \cdots g_l$$
$$= \frac{1}{\lambda} \left[\prod_{i=1}^{l} (1 + \lambda g_i) - 1 \right]. \tag{A.2}$$

A.2. Choquet integral [20,21]

Consider a fuzzy measure g of $(X, P(X))$ and X is a finite set. Let $f : X \to [0,1]$ and assume without loss of generality that the function $f(x_j)$ is monotonically decreasing with respect to j, i.e. $f(x_1) \geqslant f(x_2) \geqslant \cdots \geqslant f(x_n)$. Renumber the elements in X if necessary.

In practice, f can be considered to be the performance on a particular attribute for the alternatives, while g represents the grade of subjective importance of each attribute. A fuzzy integral of f with respect to g gives the overall evaluation of the alternative. Furthermore, we can use the same fuzzy measure but Choquet's integral instead of the fuzzy integral; that is

$$(c) \int f \, \mathrm{d}g = f(x_n) g(H_n) + [f(x_{n-1}) - f(x_n)] g(H_{n-1})$$
$$+ \cdots + [f(x_1) = f(x_2)] g(H_1), \tag{A.3}$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \ldots, H_n = \{x_1, x_2, \ldots, x_n\} = X$.

A.3. Multi-nomial logit model

The choice probability of alternative i is equal to the probability of the utility of alternative i, U_{ik}, which is greater than or equal to the utility of all other alternatives in the choice set A_k. This can be written as follows [1]:

$$P_{ik} = P(U_{ik} > U_{jk}, \forall i \neq j \in A_k), \tag{A.4}$$

where P_{ik} is the probability of the ith alternative for the kth individual, and U_{ik} is the utility of the ith alternative for the kth individual. Each utility can be partitioned into two components as follows:

$$U_{ik} = V_{ik} + \varepsilon_{ik}, \tag{A.5}$$

where V_{ik} is called the systematic (or representative) components of the utility i, and ε_{ik} is the random part, which is called disturbances.

It assumed that all of the disturbances are independently and identically distributed (IID) and has the same gumbel distribution, the MNL model as follows:

$$P_{in} = \frac{e^{V_{ik}}}{\sum_{j=1}^{J} e^{V_{jk}}}. \tag{A.6}$$

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