

Exploring the vehicle dependence behind mode choice: Evidence of motorcycle dependence in Taipei

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Abstract

We have explored vehicle dependence, taking account of subjective considerations of individual travelers. Vehicle dependence, arising from economic considerations, psychological preference, and habitual behavior, is formulated here as a subjective latent construct that acts in a person's mode choice. The Rasch model is reviewed, and suggested as an instrument to measure such a latent construct. An empirical analysis of motorcycle dependence was performed using self-rated information about eight items from 321 motorcyclists in Taipei. The empirical results showed that motorcyclists in Taipei depend on their motorcycles to achieve unaccompanied, short-distance, multistop trips; motorcyclists under the age of 25 who were inferior in economic terms and did not use an automobile showed relatively higher measures of motorcycle dependence. This paper conceptualizes vehicle dependence in terms of both its socioeconomic and its psychological nature. The results of exploring vehicle dependence should benefit researchers in modifying their formulations of mode choice, and policy makers in enacting more effective policies.

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1. Introduction

The mode choice of travelers has commonly been analyzed in the framework of random utility theory since that theory was introduced (Domencich and McFadden, 1975). However, most mode choice studies have been formulated only in terms of observable economic variables, and this has resulted in a limitation of their predictive abilities. Kahneman et al. (1979) found that individuals facing decision-making tasks in carefully constructed experimental settings often exhibited behavior that was inconsistent with a prediction based on economic variables, and indicated that some unexplored factors other than the observable economic factors might also influence one's choice. Gilbert and Forester (1977) argued that attitudinal variables were important in decisions about mode choice and could significantly increase the explanatory power of mode choice models.

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Collins and Chambers (2005) tested the relative importance of and relationship between psychological and situational factors in predicting mode choice in commuter transport; they found that psychological beliefs played roles as important as situational conditions.

Ben-Akiva et al. (1999) reviewed the literature and pointed out that choice behavior can be characterized as a decision process that is informed by perceptions and beliefs about the available information and is influenced by psychological factors such as affects, attitudes, motives, and preferences. The final choice could be regarded as an outcome of a complicated decision process.

In addition to economic concerns, travelers might be forced to make or willing to make particular mode choices, or could be habituated to those choices. Mode choice could be the combined result of travelers' economic concerns, psychological preference, and habitual behavior. That is to say, people might have some degree of reliance on the usage of one specific vehicle owing to both objective constraints and subjective considerations. In the Oxford Advanced Learner's Dictionary, there are two meanings for the word "dependence": one is "a state of needing the help and support of somebody/something in order to survive or be successful", and the other is "the state of being addicted to something". Therefore, the term "vehicle dependence" was defined as people's reliance on the usage of a specific vehicle in the study described here, and it is expected to provide another auxiliary measure for exploring mode choice.

Exploring the vehicle dependence provides valuable knowledge not only for understanding mode choice, but also for implementing transportation policy. This realization provides an insight into the needs of people for achieving their daily activities, and helps to identify the impact on travelers before a new transportation policy is implemented. Therefore, we have performed an experimental trial aimed at exploring travelers' vehicle dependence. In this paper, we first discuss the development of vehicle dependence and its affecting factors. An appropriate approach to measuring travelers' vehicle dependence is then suggested; we designed a study based on this approach. We then describe an empirical study of the motorcycle dependence of motorcyclists in Taipei, which was performed to ensure that the idea and the findings would be convincing and would contribute towards achieving the above aims.

2. Development of vehicle dependence

Economic considerations are the most common and convincing reasons for travelers' dependence upon specific vehicles (Koppelman, 1981). That is, some travelers are forced to depend on only a specific vehicle because their choice sets are constrained, i.e. they have no other alternative to choose from or their best alternative is out of their acceptable range. The limitations on their choice set may arise from their own abilities (e.g. their ability to operate other vehicles or their ability to afford the cost of using another vehicle) or from environmental conditions (e.g. the lack of a public transportation service). Such travelers are regarded as having structural dependences on a vehicle (Gray et al., 2001), and they are also called "captive riders" (Abe and Sinha, 1973) of that vehicle.

Psychological preferences or considerations also influence travelers' dependence on the usage of vehicles (Fujii and Garling, 2003; Vredin Johansson et al., 2006). Some people depend on a specific type of vehicle because they can receive direct feedback from the use of such a vehicle. For instance, travelers with an enthusiasm for driving automobiles would depend on automobile usage to achieve most of their daily trips. Special preferences or beliefs could also lead a traveler to depend on a specific type of vehicle. For example, travelers who emphasize the value of privacy and comfort during trips would tend to drive or ride in automobiles, and travelers with a strong awareness of environmental issues might tend to use vehicles which produce little pollution.

People's vehicle dependence is also thought to be a result of habitual behavior (Bamberg et al., 2003; Thøgersen, 2006). Habitual behavior can be formulated into two processes: initiation and persistence (Ronis et al., 1989). During the stage of initiation, decisions are still made rationally. However, when the same behavior has been repeated for long enough, decisions that have been made become automatic and habitual as a result of a persistence process. Decision makers then make choices without evaluating any alternatives but just on the basis of their prior experience (Betsch et al., 1998). Chen et al. (2004) showed that travelers' activity rescheduling behavior is mostly habitual behavior. Travelers who habitually choose one vehicle for routine trips will

keep choosing that vehicle until the stimuli (e.g. bad experiences) are strong enough. Travelers' dependence on such vehicles will thus generate a persistence process.

There have been similar formulations of vehicle dependence (mostly automobile/car dependence) in earlier studies. Dupuy (1999) indicated that the expression "automobile dependence" meant that an individual could not live without a car, just like a smoker who cannot live without cigarettes or a drug addict who is unable to live without drugs. His definition implied that automobile dependence could be an individual's subjective consideration, somehow beyond full rationality. Goodwin (1995) indicated that the generation of car dependence is a process influenced by travelers' subjective perception of their daily car usage: if the feedback from their car-driving experience is considered positive, people become more dependent on car usage unawares. His definition is consistent with the argument that vehicle dependence might arise from habitual behavior.

The Transport Studies Unit (1995) at Oxford University conducted research on car dependence and indicated that car dependence may contain two elements: the absolute need for a car in order to maintain mobility without any other available option, and the perception of reliance on a car without actively considering the alternatives. This viewpoint is similar to our concept that the vehicle dependence of travelers arises from three types of reasons: economic considerations, psychological preferences, and habitual behavior. Overall, vehicle dependence could be interpreted as a level of reliance on a specific vehicle usage which is gradually developed as a consequence of travelers' economic concerns, psychological preference, and habitual behavior. Although vehicle dependence has been discussed in previous studies, however, no quantitative method to evaluate it among people with various personal characteristics has been tried. This might be the reason why the idea of vehicle dependence has not been applied to provide any useful information in the area of the description and prediction of mode choice.

3. Measuring vehicle dependence

According to the above discussion, vehicle dependence could be thought of as a latent trait of a traveler that represents the traveler's reliance on a specific vehicle as a consequence of economic concerns, psychological preference, and habitual behavior. How to gather the necessary information and design a measuring tool to evaluate travelers' vehicle dependence to make our idea operational is another issue, which we consider below.

3.1. Questionnaire design for gathering latent information

Latent traits are commonly explored by means of questionnaires that include appropriate items that respondents can answer on the basis of their daily life experience. Since there was no available questionnaire to follow, we had to design our own questionnaire for our study. Essentially, people use and depend on vehicles to meet the needs of their daily activities, and the significant relations between travelers' mode usage and their participation in activities have been widely investigated and discussed (Kitamura, 1988; Pas, 1996). As a result, the need to have a specific vehicle to participate in various possible activities was thought to define the appropriate items in the questionnaire to explore a traveler's dependence on that vehicle. Because the travelers' answers to the items would be given on the basis of their daily travel experience, and depend on subjective judgment and objective constraints, the responses could then be used to reflect the travelers' latent trait of dependence on that specific vehicle.

In psychometric questionnaires, the questions should motivate and guide respondents to express their real considerations and judgments. Therefore, our questionnaire on vehicle dependence would need to be designed to let the respondents express precisely their reliance on a specific vehicle for performing their daily activities. According to our observations, travelers might find it hard to express how they depend on a specific vehicle for their daily trip purposes because they are unaware of their vehicle dependence. However, it might be easier for them to answer how bothersome it would feel if they were not allowed to use a specific vehicle to undertake specific activities. This provided us with a better measuring tool to gather the information from travelers to capture their dependence on specific vehicles.

Furthermore, respondents' answers to the questions in our design did not usually have to be simply "yes" or "no". A well-designed questionnaire should provide an opportunity for respondents to express the degree

of their feeling or judgment about the items referred to. Therefore, the questions designed to measure the latent trait of vehicle dependence included suggested answers on an ordinal scale, with several categories that represented the respondent’s possible level of judgment. However, since ordinal data cannot be used for statistical inference directly, owing to violation of the property of additivity, a special technique was needed to transfer these ordinal responses onto interval scales in order to provide a comparative basis for further discussion.

3.2. The concept of measuring vehicle dependence

Presumably, every traveler n has a unique value of his/her dependence on a specific vehicle, θ_n , which is the person parameter to be measured. Such a latent trait can be revealed by the person’s answers. That is, travelers who have higher dependence on a vehicle will respond with high scores (i.e. a high level of vehicle dependence) on a greater number of items than will those with lower dependence. In addition, travelers’ dependence on a specific vehicle could be different for various activities (i.e. trip purposes). Some trip purposes might be more suitable than others for a specific vehicle usage. Thus, travelers’ vehicle dependence for two types of trip purposes could be different (e.g. bicycle riding might be depended on for achieving in-town travel but not for intercity travel). Such properties for each trip purpose (i.e. the item parameters) can be regarded as an inherent resistance against travelers’ vehicle dependence. It can be assumed that each item (trip purpose) i has a unique resistance parameter b_i . The items with lower resistance parameters b_i are those trip purposes which are inherently suitable for a specific vehicle usage. Therefore, there would be more responses indicating high dependence for those items.

Taking automobile usage as an example, a simplified diagram illustrating this concept is shown in Fig. 1. The right-hand side of Fig. 1 presents the relative levels of automobile dependence of three travelers. Joe has the highest automobile dependence, and Tom has the lowest. The left-hand side of Fig. 1 shows the relative inherent resistance against automobile driving for two different trip purposes. This example indicates that commuting in congested traffic has higher resistance against automobile driving than has weekend outdoor travel.

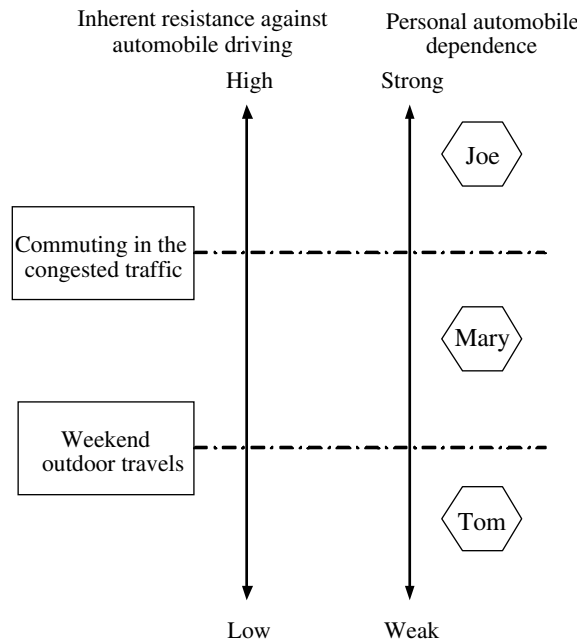


Fig. 1. Conceptual example of travelers’ automobile dependence, and inherent resistance against automobile driving for various trip purposes.

Under the assumption that the item parameters are independent of the person parameters, some conclusions could then be drawn from the information provided in Fig. 1. Namely, all three travelers are more likely to drive an automobile for weekend outdoor travel than for commuting in congested traffic, because the former has lower inherent resistance against dependence on automobile driving. On the other hand, the tendencies to drive an automobile are in the order Joe, Mary, and Tom, from high to low, no matter whether for commuting in congested traffic or for weekend outdoor travel, on the basis of the magnitudes of their dependence on an automobile. If we consider the above characteristics, it is apparent that the difference between the person parameter θ_n and the item parameter b_i will determine the tendency of traveler n to depend on a given vehicle for achieving trip purpose i . This tendency could then be formulated as a function of a probability and determined by the value of $\theta_n - b_i$.

In order for us to provide a theoretical basis for comparisons, the person parameters (vehicle dependence) and item parameters (inherent resistance against vehicle dependence) must be measured on a consistent interval scale. However, all of the responses of travelers to the questionnaire were collected on an ordinal scale in order to provide room for respondents to describe their judgments more precisely. Therefore, a statistical technique to convert the ordinal raw data into data on an interval scale was needed; we chose the Rasch measurement model (Rasch, 1960) for the purpose of this study. A brief review of the Rasch model is given below.

3.3. Review of the Rasch model

The Rasch model has been intensively used to estimate values on an interval scale from ordinal responses in psychometric studies (Fisher et al., 1995; Massof and Fletcher, 2001). To simplify our review of the Rasch model, we shall consider only dichotomous responses to begin with. The questions are assumed to be of the type “Will you feel it bothersome if you are not allowed to use a specific vehicle to achieve a specific trip purpose?” The responses are either “yes” or “no”. A score of 1 is assigned to an item which a traveler feels is bothersome; otherwise, a score of 0 is assigned. The probability that a traveler n will feel that item i is bothersome is then expressed as

$$P(1|\theta_n, b_i) = \frac{e^{\theta_n - b_i}}{1 + e^{\theta_n - b_i}}; \quad (1)$$

the probability that a traveler n will not feel that item i is bothersome is

$$P(0|\theta_n, b_i) = 1 - P(1|\theta_n, b_i) \frac{1}{1 + e^{\theta_n - b_i}}; \quad (2)$$

the odds that a traveler n will feel that item i is bothersome are

$$\frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = e^{\theta_n - b_i}; \quad (3)$$

and the logarithm of the odds ratio, called the “logit”, is

$$\ln \frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = \theta_n - b_i, \quad (4)$$

which isolates the parameters of interest.

The person and item parameters in the case of dichotomous responses can be estimated from response odds ratios in the data set using the formulation in Eq. (4). In addition to dichotomous responses, the Rasch model has been modified to be applicable to polytomous rating-scale instruments, such as the five-point Likert scale (Andrich, 1978; Masters, 1982). The modified Rasch model decomposes a polytomous response into several dichotomous responses and formulates one multinomial-choice problem in terms of several binary-choice problems. That is, it assigns b_{ix} as the value of the item parameter (i.e. the inherent resistance against dependence in this study) for the rating category x to item i , and assumes that Eq. (1) refers to the probability of subject n responding with rating category x rather than $x - 1$ to item i . In other words, we can model the log odds of the probability that a person responds in category x for item i , compared with category $x - 1$,

as a linear function of the person parameter (i.e. the person's vehicle dependence in this study) θ_n and the relative parameter of category x , namely b_{ix} , for item i :

$$\ln \left(\frac{P_{nix}}{P_{ni(x-1)}} \right) = \theta_n - b_{ix}. \quad (5)$$

Following Andrich's modification of the Rasch model for a polytomous response, two types of formulation are widely applied in assessing the values of item and person parameters, namely the "rating-scales model" and the "partial-credit model". The rating-scales model is used only for instruments in which the definition of the rating scale is the same for all items, while the partial-credit model is used when the definition of the rating scale differs from one item to another. Specifically, the partial-credit model is similar to the rating-scales model except that each item i has its own threshold parameters F_{ix} , for each category x (Wright, 1977). This is achieved by a reparameterization of Eq. (5):

$$b_{ix} = b_i + F_{ix}, \quad (6)$$

and the partial-credit model becomes

$$\ln \left(\frac{P_{nix}}{P_{ni(x-1)}} \right) = \theta_n - b_i - F_{ix}. \quad (7)$$

The partial-credit model (Masters, 1982) is used for items where (1) credits are given for partially correct answers, (2) there is a hierarchy of cognitive demand on the respondents for each item, (3) each item requires a sequence of tasks to be completed, or (4) there is a batch of ordered response items with individual thresholds for each item. In assessing the vehicle dependence of travelers, it is not necessary to assume that the rating scales of the items are the same, and thus we adopted the partial-credit model for our empirical study.

The Rasch model is regarded as a prescriptive approach rather than a descriptive approach (Bond and Fox, 2001). In other words, the data must fit the model, or the assumptions of the model must be rejected for a particular data set. As a result, some assumptions must be made when we try to apply the Rasch model to measure vehicle dependence: (1) the travelers differ in their vehicle dependence, (2) the travelers' responses to items depend only on their vehicle dependence, (3) the responses are probabilistic and conditional on their vehicle dependence, and (4) the odds of achieving an item increase monotonically with the difference between the traveler's vehicle dependence parameter θ_n and the inherent resistance parameter b_i of the item.

Indices of reliability and validity for assessing a latent construct are also provided by the Rasch model via the person and item aspects, respectively (Wright and Master, 1982). Reliability indices help us to examine whether the model is convincing and the material is replicable, and validity indices help us to examine whether the properties of our material are consistent with the assumption of the Rasch model. For detailed illustrations and formulations of these indices, readers can refer to the relevant literature or to the textbook by Smith and Smith (2004).

4. Design of empirical study

To demonstrate our conceptual framework and measurement approach for vehicle dependence, an empirical study was performed to explore motorcyclists' dependence on motorcycle usage in Taipei, Taiwan. Motorcycles are used intensively as a mode of daily road transportation in Taiwan and some other Asian countries. In addition to identifying and measuring the motorcycle dependence of motorcyclists, we also expect that our findings for Taipei could serve as reference information for traffic authorities in other areas where motorcycles are intensively used.

4.1. Background on transportation in Taipei

Taipei, the political and commercial center of Taiwan, has an area of 272.80 km², in which nearly 4.5 million people (Official statistics, 2005) live or travel every day. To provide residents and visitors with efficient travel inside this intensively occupied city, Taipei offers a high-density public transportation service, including mass rapid transit (MRT), commuter rail, buses, and taxis. However, it still encounters daily traffic congestion

in rush hours, just like many other metropolises around the world. According to official statistics, households in Taipei possess 1.17 motorcycles and 0.49 automobiles on average; 28.72% of people in Taipei travel by automobile, 32.34% of people travel by motorcycle, 30.58% of people travel by public transportation, and the remainder travel by taxi, bicycle, or walking. The common use of motorcycles results in many problems in traffic engineering, management, and safety (Chang, 2002); worst of all, it reduces the effectiveness of investment in public transportation.

The Taipei traffic authorities have enacted many policies to encourage motorcyclists to travel by public transportation instead of by motorcycle (e.g. exclusive bus lanes, discounts on public transportation fares, and motorcycle parking charges around the commercial area). However, the usage of motorcycles has still been growing steadily in recent years (Chang and Yeh, 2007). This hints that people in Taipei have a strong dependence on motorcycle usage, and such motorcycle dependence might arise not merely from economic considerations, but also mental preferences or habitual behavior.

4.2. Questionnaire design and data collection

A questionnaire was designed, in terms of eight items which represented the most common activities that attracted people to ride motorcycles, in order to explore motorcyclists' dependence on motorcycle usage in Taipei (Table 1). The respondent motorcyclists were asked to answer how bothersome it would feel if they could not ride their motorcycles in Taipei City to achieve the respective eight possible trip purposes. In addition to these items designed to measure motorcycle dependence, some characteristics of the respondents were also included in the questionnaire. These were age, gender, monthly income, whether the respondent was a dual-mode user (i.e. whether he/she drove an automobile as well or not), and the ownership of exclusive automobile parking space (i.e. whether the respondent motorcyclist had his/her own automobile parking space or not). The reason for investigating dual-mode user status and parking space ownership arises from the competing usage between these two private vehicles. Some people in Taipei own and use both an automobile and a motorcycle for their daily trips; such travelers are referred to as dual-mode users in the following discussion.

Item 1 was designed to explore how motorcyclists depend on motorcycles for trips related to work or to visiting businesses; Item 2 was aimed at collecting information about motorcyclists' motorcycle dependence for commuting purposes; Item 3 was designed to find out how motorcyclists depend on motorcycles for multistop shopping in the streets; Item 4 was designed to explore motorcyclists' dependence on motorcycles for participating in recreational activities; Item 5 was designed to show the extent to which motorcyclists need to ride motorcycles to visit their relatives and friends in Taipei; Item 6 was designed to show the extent to which motorcyclists count on motorcycle riding for achieving particular journeys in a limited length of time;

Table 1
Content of the questionnaire

Variable/question	Type
<i>Items to explore self-rated dependence:</i>	
How bothersome will it feel if you cannot ride a motorcycle to achieve the following trips in Taipei city?	
Item 1: trips necessary for work or for visiting businesses	5-point scale
Item 2: trips for commuting to/from workplace	5-point scale
Item 3: trips for multistop street shopping	5-point scale
Item 4: trips for participating in recreational activities	5-point scale
Item 5: trips for visiting relatives and friends	5-point scale
Item 6: trips for achieving travel in a limited length of time	5-point scale
Item 7: trips for achieving occasional travel requirements	5-point scale
Item 8: trips for loitering around the streets without a specific purpose	5-point scale
<i>Respondent's personal characteristics</i>	
Age	Numeric response
Gender (male, 0; female, 1)	Binary response
Monthly income (in NTD)	Open response
Dual-mode user (yes, 1; no, 0)	Binary response
Exclusive automobile parking space (owned, 1; otherwise, 0)	Binary response

Item 7 was designed to explore motorcyclists' motorcycle dependence for occasional travel demands, such as accessing a transit station or picking up visitors; and Item 8 was designed to see how motorcyclists depended on their motorcycles for no specific trip purpose but just for loitering around the streets. All of these eight items were answered on a five-point Likert scale, namely "not bothersome at all", "a little bothersome", "bothersome", "strongly bothersome", and "very strongly bothersome". The responses in these five categories, from "not at all" to "very strongly", for each item, represented the motorcycle dependence, from low to high, respectively.

The data for this empirical study were collected by investigating 321 motorcyclists selected randomly in Taipei. The respondents' self-rated dependence for each item and their personal characteristics were gathered through completing the questionnaire with the assistance of well-trained investigators. Of these 321 motorcyclists, 187 (58.3%) were male and 134 (41.7%) were female; their average age was 28.7 years; and their average monthly income was about 28,000 NTD. There were 167 (52.0%) respondents who also traveled by driving, and only 43 of them had their own automobile parking spaces. The distributions of the respondent motorcyclists' gender and age were compared with those of registered motorcyclists published in official statistics, and no significant differences were found at $\alpha = 0.05$. It was believed that the sampled motorcyclists could reasonably represent the population.

4.3. Application of Rasch analysis

The Rasch measurement model provides a means for constructing interval measures from raw ordinal category data. On the basis of the Rasch model, a value on an interval scale was estimated for each item (i.e. the item parameter) and for each respondent (i.e. the personal parameter). The responses of the 321 motorcyclists for the eight items were analyzed with WINSTEPS (Linacre and Wright, 1997), an iterative computer program, which estimated θ_n for motorcyclist n and b_i for item i in logit units. WINSTEPS helps to deal with polytomous responses by applying the Masters–Andrich modification (Masters, 1982) of the Rasch model. The estimated parameters and model fit statistics could be therefore calibrated via a joint maximum-unconditional-likelihood estimating procedure (Wright, 1996).

The estimated parameters and fit statistics of our whole Rasch model are shown in Table 2. The Rasch assessment fixed the average measure of all item parameters at zero logit to be a comparative basis of the relative interval scale; the average value of the vehicle dependence of all of the motorcyclists was 1.46 logit. Such a positive value indicates that these motorcyclists generally depend on motorcycles highly. Before we start detailed discussions and interpretations of the estimated item and person parameters, however, the reliability and validity of this Rasch model must be discussed first.

Reliability is commonly defined as the consistency of the responses to a set of items or the consistency of scores from the same instrument. It is also defined as the degree to which scores are free from measurement errors. The WINSTEPS program provided reliability information for both items and persons, as shown in Table 2. The person and item reliability coefficients can be interpreted similarly to a Cronbach alpha reliability coefficient for the internal consistency of responses to items (Wright, 1996). The personal reliability index of 0.81 and item reliability index of 0.97 indicate that the data here are consistent with the assumptions of the Rasch model from the viewpoints of both items and persons.

Validity refers to the creation or selection of items to measure the same construct in performing a measurement of a latent characteristic. The validity information is expressed by the fit statistics in a Rasch measure-

Table 2
Model estimation and fit statistics obtained from Rasch analysis

	Raw score	Number of observations	Measure	Standard error	Infit Zstd	Outfit Zstd
<i>Items: 8 input, 8 measured</i>						
Mean	1207.2	321	0.0	0.54	0.0	0.1
						Item reliability: 0.97
<i>Persons: 321 input, 321 measured</i>						
Mean	30.1	8	1.46	1.45	-0.1	-0.1
						Person reliability: 0.81

ment. With the help of a comparison of the expected and the observed patterns, the fit statistics aid in quality control and in identification of data which do not meet the requirements of the model. Two fit statistics were estimated by WINSTEPS, namely an information-weighted fit (“infit”) and outlier-sensitive fit (“outfit”) (Smith, 1991). The infit and outfit are expressed as normalized residuals in Table 2. The Z-standardized fit statistic (Zstd) has previously been used to select items at the 0.05 significance level and according to ± 2 . In our model, the infit and outfit statistics of the estimated parameters for both persons and items are all near to zero, which implies that the overall validity of our model is acceptable.

5. Findings and interpretation

5.1. Findings for item parameters

Estimates of the item parameters are displayed in Table 3. The first column contains a description of each item; the second contains the raw score (a linear combination of item scores) for each item; the third shows the estimate for each item; and the fourth and fifth show the infit and outfit statistics, which provide the evidence to determine the validity for each item. The fit statistics for these eight items are all in the range ± 2 , which implies that the item responses do not deviate significantly from the assumptions of the Rasch model. The items in Table 3 have been ordered by their estimated values for comparison purpose.

It is important to notice that all estimates from a Rasch model are relative. It is generally suggested that the average for all item estimates should be fixed at zero logit, and therefore the estimates for each respective item and person have been calibrated with reference to that average item estimate. The items with lower raw scores are those trips which are generally considered as less bothersome when motorcycle riding is not available. Such trip purposes would be assessed as having higher estimates of their item parameters, which can be interpreted as meaning that those trips would have higher inherent resistance against dependence on motorcycle riding and people would tend not to travel by motorcycle. In contrast, items with higher raw scores would be assessed as having lower estimates of their item parameters, which can be interpreted meaning that these kinds of trips would have lower inherent resistance against dependence on motorcycle riding and would tend to attract people to travel by motorcycle.

The item parameter estimates for the eight trip purposes are shown in Table 3. The study results show that Item 3 has the lowest value of the item estimate, which indicates that multistop street shopping trips have the lowest resistance against dependence on motorcycle riding, and will attract people to travel by motorcycle most and induce the highest motorcycle dependence. The scarcity of automobile parking spaces near roadside stores forces people not to approach them by car, and the long distance that people have to walk results discourages them from going there by public transportation. Motorcycle riding provides riders with convenience in accessing each stop of their shopping tour. Therefore, motorcycle riding has a dominant superiority over automobile driving and public transportation usage for the purpose of multistop street shopping, and this might be the reason why multistop street shopping is the most important activity in inducing people’s motorcycle dependence in Taipei.

Items 8, 7, and 2 are the other three items with negative values of the item parameter. This indicates these three kinds of trips also have a relatively low resistance against dependence on motorcycle riding and may

Table 3
Estimates of item measures and fit statistics from Rasch analysis (ordered by item parameter)

Item	Raw score	b_i	Infit Zstd	Outfit Zstd
Item 3: trips for multistop street shopping	1384	-0.81	-1.4	-1.7
Item 8: trips for loitering around the streets without a specific purpose	1320	-0.49	-2.0	-1.9
Item 7: trips for achieving occasional travel requirements	1294	-0.32	-0.4	-1.0
Item 2: trips for commuting to/from workplace	1291	-0.29	1.6	1.9
Item 6: trips for achieving travel in a limited length of time	1230	0.02	1.2	1.3
Item 4: trips for participating in recreational activities	1103	0.50	0.6	0.9
Item 1: trips necessary for work or for visiting businesses	1099	0.59	-1.4	-1.3
Item 5: trips for visiting relatives and friends	1069	0.79	1.1	1.6

induce motorcycle dependence in the long run. Motorcycle riding provides maneuverability that is advantageous for loitering around the streets without a specific purpose. Riders can easily ride or stop their motorcycles on main streets or minor alleys in the city. In the case of occasional travel requirements, the convenience of riding a motorcycle provides people with much flexibility to meet their needs. Some motorcyclists depend on motorcycle riding to commute, for it enables them to escape from jammed traffic more easily in the rush hour. The reasons that drive motorcyclists to depend on motorcycle usage might vary between different motorcyclists. However, the trip purposes with negative values of the item estimate are consistent with prior observations (Chang, 2002).

Oppositely, Item 5 was found to have the highest positive value among all eight estimated item parameters. This indicates that trips for visiting relatives and friends have the highest resistance against dependence on motorcycle riding. It might be the case that people usually perform these trips accompanied by family members and therefore these trips are not suitable for motorcycle usage. In addition, motorcycle riding is customarily considered as a symbol of inferior socioeconomic status in Taiwan. Thus, people tend to drive automobiles to represent their social status when participating in formal or official visiting.

Items 1 and 4 also have high positive values of the item parameter. This means that these two types of trips have somewhat high inherent resistances against dependence on motorcycle usage. Some work or business trips might be performed with colleagues or with heavy documents or materials, and would therefore not be suitable for motorcycle riding. As to trips for recreational activities, people tend to travel accompanied by family or friends. This makes motorcycle riding less applicable, owing to the capacity constraints. Finally, Item 6 has an item parameter value near to zero. This indicates that there was no significant tendency to achieve requirements for travel in a limited time by motorcycle riding, as compared with other trip purposes.

5.2. Findings for person parameters

The Rasch model also helped us to estimate the self-rated vehicle dependence of the 321 motorcyclists who participated in the study. Some summarized relative measures of vehicle dependence and fit statistics for persons are shown in Table 4. The raw score of each person has been transformed monotonically into a measure of motorcycle dependence on a logit scale from -2.96 to 5.00 . The fit statistic for each person's motorcycle dependence estimate is generally acceptable, which shows that the person responses generally fit the Guttman scale (Guttman, 1950) well.

Fig. 2 illustrates the distribution of infit and outfit Zstd statistics for the estimates of θ . Each data point represents the infit and outfit Zstd values for an individual respondent. About 15% of the surveyed motorcy-

Table 4
Summarized estimates of person parameters and fit statistics obtained from Rasch analysis

Person number	Raw score	θ_n	SE	Infit Zstd	Outfit Zstd
18	39	5.00	1.08	-0.1	-0.4
37	38	4.14	0.81	0.1	0.6
22	37	3.57	0.71	1.7	2.1
9	36	3.12	0.64	0.9	0.8
24	35	2.73	0.60	0.8	0.7
314	34	2.38	0.57	-1.6	-1.5
236	20	-0.91	0.45	-1.2	-1.2
292	19	-1.11	0.46	-1.2	-1.1
296	18	-1.32	0.46	-1.2	-1.0
186	16	-1.78	0.49	1.4	1.7
277	13	-2.61	0.57	-1.1	-1.1
178	12	-2.96	-0.62	-0.7	-0.6
Mean	30.1	1.46	0.55	-0.1	-0.1
SD		1.45	0.12	1.4	1.4

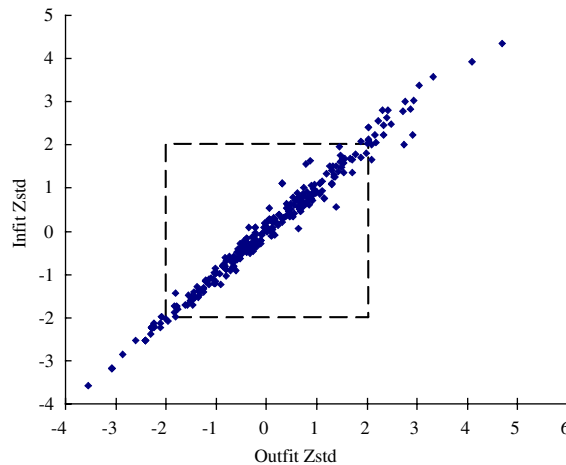


Fig. 2. Scatter plot of infit and outfit statistics for estimates of person measures. Each point represents a different respondent. The square bounds the 95% confidence limits.

clists have fit statistics outside the ± 2 Zstd tolerance box. The scattered points located in the upper right area outside the tolerance box imply that these person responses are over-dispersed compared with the Guttman scale. Such a result is generally derived from a violation of the monotonic property in the Rasch model. That is, respondents might achieve the requirement easily for items with higher difficulty but behave poorly for items with lower difficulty. Oppositely, the scattered points located in the lower left area outside the tolerance box in Fig. 2 imply that these person responses are under-dispersed compared with the Guttman scale. Such results might arise from respondents who are unable to judge the relative level of categories well; that is, their responses do not vary with the difficulty of items. Both over-dispersed and under-dispersed responses are regarded as indicating respondents that may possibly violate the properties of the Rasch model. If a person estimate is going to serve as a variable in an extended study, it has been suggested that these questionable responses should be modified or deleted (Bond and Fox, 2001).

In order to explore the useful information contained in the person parameters estimated from the Rasch model, the estimated person parameters were then further investigated by studying their corresponding personal characteristics. Only the 273 well-fitted respondents, who obeyed the assumptions of the Rasch model, were used for this extended study and discussion. The self-rated motorcycle dependence and personal characteristics of these 273 well-fitted motorcyclists are shown in Table 5. These respondents were categorized into two groups for each characteristic, namely age, gender, monthly income, and automobile-driving status. The 144 respondent motorcyclists who also traveled by automobile are referred to here as dual-mode users. These dual-mode users were further divided into two groups by their ownership of a personal, exclusive parking space. The average measures of motorcycle dependence for each group were calculated and compared with their counterpart groups. The statistical significance of the mean differences between groups for each social characteristic was tested, and the p -value is shown in the last column in Table 5.

The average motorcycle dependence for motorcyclists aged under 25 is significantly higher than that for motorcyclists aged over 25. This implies that younger motorcyclists in Taipei tend to depend more on motorcycle riding to achieve their trips than older motorcyclists do. The difference between the motorcycle dependence of male and female motorcyclists is not significant, which indicates there is no obvious gender gap in the motorcycle dependence of motorcyclists in Taipei. Motorcyclists with a monthly income lower than 30,000 NTD depend on motorcycles significantly more than do those with a monthly income higher than 30,000 NTD. In view of the average monthly income per capita of 40,142 NTD in Taipei (Official statistics, 2005), it appears that those who are economically inferior in Taipei tend to depend more on motorcycles to travel.

The dual-mode users have significantly lower dependence on motorcycles than have those motorcyclists who do not drive automobiles. It might be the case that the former have the “car-driving” alternative for travel available, and therefore depend less on motorcycle riding than do the latter. This is consistent with the

Table 5
Self-rated motorcycle dependence for different groups of motorcyclists

Personal characteristics	Group	Number of observations	Mean of estimated motorcycle dependence	<i>p</i> -value
Age	≥25	179	1.289	0.010 ^a
	<25	94	1.720	
Gender	Male	162	1.378	0.453
	Female	111	1.501	
Monthly income	≥30,000 NTD	113	1.188	0.004 ^a
	<30,000 NTD	160	1.651	
Dual-mode user	Yes	144	1.095	0.000 ^a
	No	129	1.829	
Exclusive automobile parking space ^b	Owned	39	0.982	0.000 ^a
	Nonowned	105	1.427	

^a Significance level at $\alpha = 0.01$.

^b This analysis was based on the 144 dual-mode users.

findings of previous studies (Chang, 2002) that automobile driving and motorcycle riding are partially competitive for residents of Taipei.

In addition, the dual-mode users who owned their personal automobile parking spaces were found to have less motorcycle dependence than those who did not own automobile parking spaces. In such an intensively occupied city as Taipei, owning a personal, exclusive automobile parking space is very costly. It is much harder to find a free or cheap automobile parking space than to find a free motorcycle parking space in Taipei. Therefore, once a dual-mode user without his/her own automobile parking space parks his/her automobile on a cheap or free parking space, that person will try his/her best to travel by motorcycle unless he/she is forced to travel by automobile to perform some special activity. This is a common behavior in Taipei, especially for those who belong to the medium-income group, and can be used to explain the relationship between automobile parking space ownership and motorcycle dependence for dual-mode users.

6. Discussion

In this study, vehicle dependence was conceptualized as the combined effect of an individual's objective constraints and subjective considerations on the usage of a specific vehicle, and was thought of as a latent trait that is determined by economic considerations, psychological preference, and habitual behavior. The need to travel by a specific vehicle (i.e. a motorcycle) to achieve all possible daily activities for a person was used to design the items of a questionnaire to measure people's dependence on that vehicle. The Rasch model was used to estimate the parameters on an interval scale from the ordinal raw data collected via the questionnaire. The application of the Rasch model enabled us not only to estimate each person's vehicle dependence, but also to identify the difficulty of each test item, which represented the inherent resistance against using a specific vehicle to achieve each daily activity. An empirical analysis of motorcycle dependence was performed by use of self-rated information about eight items, contained in responses from 321 motorcyclists in Taipei. Convincing results from this empirical study supported our conceptual framework related to vehicle dependence. This study introduced the previously unexplored aspect of the psychological nature of vehicle dependence, suggested an operational method to measure such a latent construct, provided information about how much travelers need a specific vehicle to maintain their daily life, and offered an insight into travelers' behavior in relation to their mode usage.

In our experimental exploration of the self-rated motorcycle dependence of motorcyclists, we used a Rasch assessment to score this latent trait. Some other approaches, such as factor analysis and path analysis, are also widely applied in measuring latent constructs related to travelers. However, those approaches accept raw scores at face value and rely heavily on inferential arguments to validate scales that are calibrated. The Rasch analysis offers a more reasonable approach to transferring ordinal responses to interval scales, which enables researchers to estimate a latent variable through assessing the performance of each item as a contributor to the

measurement. Such an approach is especially useful when one is trying to measure a construct that is not extensively discussed in references. Not only can the validity of items for exploring the construct be examined, but also the findings from the measures of both items and persons can be interpreted as useful information.

Saleh and Farrell (2007) argued against the theory of equilibrium as the basis for the forecasting models in travel demand; they pointed out that travelers' willingness should be taken into account in predicting their travel behavior after a new policy is implemented. Exploring vehicle dependence enables policy makers to realize why and how people rely on their vehicles and provides important cues to them for enacting their policies effectively. This study provides a new concept and approach to pretest the practicability of a new policy. When a policy is enacted, vehicle usage for trip purposes with lower resistance parameters will be relatively hard to alter. Therefore, if a policy is to seriously influence people's travel demands, policy makers should provide travelers with acceptable alternatives in advance. Otherwise, such a policy would induce strong resistance from people and thus fail. Recently, some policy makers have been aware of this point and have started to adjust the content of their policy in response to such possible obstacles. For example, credit-based congestion pricing (Kockelman and Kalmanje, 2005) is a novel road-pricing strategy that both ensures people's basic right to travel and encourages people to reduce their unnecessary private-vehicle usage.

Although motorcycle usage is not popular in some western countries because of the historical background and climatic limitations, it still plays an important role in road transportation in some developing countries, such as Taiwan, Vietnam, the Philippines, Malaysia, and Thailand (Hsu et al., 2003). These countries have some common patterns in their economic development. First, their industrialization started after World War II. Second, the urban areas of these countries are intensively occupied. Third, government investment in public transportation during the early period of industrialization was insufficient owing to a national shortage of finance. As a result, the traffic authorities in these countries let their people ride motorcycles in a *laissez-faire* approach to offset the scarcity of public transportation services. Now, according to the empirical evidence from Taipei, even though mass public transit and bus services have been established, operated, and intensively promoted, the high dependence on motorcycle usage generated by travelers' daily experience is still hard to change. A significant proportion of travelers would like to choose motorcycle riding rather than the use of public transportation. The lesson learned from Taipei indicates that overindulging people who ride motorcycles will raise their dependence on motorcycle usage, which might result in inefficiency in subsequent investment in public transportation. This could serve as a real reference for countries with intensive motorcycle usage.

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