Working Paper

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Publication Date:
2010

Permanent Link:
https://doi.org/10.3929/ethz-a-006125583 →

Changes in Variations of Travel Time Expenditure: Some Methodological Considerations and Empirical Results from German Mobility Panel[1]

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Word Count: 6,195 words + 5 tables/figures = 7,445 equivalent words (max. = 7,500)

Key Words: Travel time expenditure, behavioral change, variation property, observation, German Mobility Panel

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[1] Paper submitted to the 90th Annual Meeting of the Transportation Research Board, January 23-27, 2011, Washington D. C.

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ABSTRACT

This paper attempts to develop a method for capturing changes in variations of travel time expenditure, and show the empirical results by using German Mobility Panel data, a multi-day and multi-period panel data. This is intended to provide some useful information from observation side, bearing improvement of evaluation methods of the benefits from transport infrastructure investment in mind. The proposed methodology can deal with changes and variations simultaneously and explicitly, and it can be easily extended to other model types as long as the model defined as one kind of generalized linear model. The empirical analysis indicate that travel time expenditures become more dependent on the situational attributes, rather than their individual or household attributes, implying that the travel time expenditures change towards diversifications and that longer behavioral observation becomes more important to describe people's travel time expenditure. The results also imply that the understanding of dynamic aspects of behavior is still important and remain as a big challenging issue to be revisited, not only to improve forecasting models, but also to reconsider the benefits from transportation investment.

1. INTRODUCTION

Recently, Metz (*1*) argues that the benefit of investment in transport infrastructure is perceived as an improvement in access rather than as a travel time saving. Consequently, he underscores that current cost benefit analysis, in which a travel time saving plays a significant role, may not be reliable guide for infrastructure investment decisions. Although this viewpoint is not perfectly accepted by all researchers/practitioners and we still don't have a common view on how to evaluate an infrastructure investment (e.g., *2-5*), the point of controversy is crucially important for better transportation planning and decisions, and further discussions are certainly needed. To reconsider the way to evaluate the impacts of infrastructure investment, we should obtain additional information that is useful for improving a behavioral basis which underlies existing demand forecasting models and evaluation methods. In this process, both theory-based and observation-based reconsiderations might be needed. Although the development of these two aspects might depend on each other, this study especially focuses on the observation side, and its implications for theoretical considerations are going to be discussed. That is the primary aim of this paper. The more specific focus of this paper is described below.

The above mentioned Metz's contention is mainly derived from the fact that there is little empirical evidence to support that infrastructure development reduces people's travel time expenditure. He referred to the fact that the average travel time is quite stable over the last 30 years in UK (385 hours) whilst the average distance traveled has increased by 60%, implying that the saved travel time is just used for additional travel. In fact, such phenomena have been reported by many researchers under the discussion on the stability of travel time expenditure, i.e., travel time budget (e.g., *6-10*). The existence of stable travel time expenditure implies that the conventional forecasting methodology, in which trip rates and OD (origin-destination) matrix are assumed to be fixed over time, is not flexible enough to express the changes in their travel behavior by the improvement of infrastructure. Weis and Axhausen (*11*) showed the properties of induced travel during the last 30 years in Switzerland, and found that the increase in accessibility considerably generates the longer travel distance.

The implications derived from the constant total amount of travel time are not only for demand forecasting models, but also for policy evaluation methods. Mokhtarian and Chen (*12*) argue "travel time minimization principle underlies a great deal of policy-making as well as virtually all regional travel demand forecasting models, and is used to justify monetizing the benefits of transportation improvements on the basis (primarily) of travel time savings. But obviously, under a TTB [travel time budget], travel time is not minimized but is kept constant. If that is true, then, for example, the typical travel demand model is asking the wrong question". This argument might be essential for reconsidering benefit evaluation methods: even if we avoid the evaluation based on travel time saving and try to apply the concept of value of access, how to monetize the benefits of the improvement of access should be clarified. People's travel distance may become longer probably because there is more attractive activity (or residential) locations, implying that benefit from the improvement of access should be calculated based on the improvement of the quality of activity conducted at the destination. This discussion is certainly related with activity-based approach in which travel is assumed to be a derived demand (*13*). Travel time and costs may have to be offset against the benefits obtainable from activities engaged in at the destination (*14*), and understanding such expenditures might be helpful for clarifying people's travel decisions and therefore benefits from activity engagements. Thus, focusing on the stability of travel time expenditure, we should further discuss on why or how the value is relatively stable over time and space, rather than the fact of stability itself. In other words, even if the travel time expenditure is stable, how this varies around the average, and what kinds of changes are potentially hidden behind it, should be further investigated.

In this context, some researchers investigated on variation in travel time expenditures, which probably comes from various sources including individual, spatial, and situational attributes (e.g., *14-16*). Also, some studies emphasized the importance of capturing the impacts of various kinds of changes (changes in technology, composition of population, spatial patterns, etc.) on travel time expenditure (e.g., *17-18*). The results of these studies on variations and changes have surely provided useful insights into the reconsideration of behavioral basis that underlies demand forecasting models and policy evaluations. On the other hand, changes and variations are often mixed up especially when the cross-sectional data is adopted, for example, to predict travel demand. Kitamura (*19*) mentioned that applying one-day data to forecasting involves longitudinal extrapolation of cross-sectional variations, and changes in behavioral over time would be predicted based on differences in behavior across individuals. This confusion of changes and variations partly comes from the lack of behavioral observations, but even when we obtain longitudinal data, the methodology, that can deal with both variations and changes explicitly, is not well established.

As presented above, the reconsiderations of benefit from infrastructure investments is quite complicated and we may have to form a positive circulation between theory-based and observation-based investigations. This study is related to the latter investigation. Specifically, we attempt to conduct a study on how to consolidate the observed information on changes and variations in travel time expenditure obtained from multi-day and multi-period panel data. After the methodological discussion, we will show the empirical results of changes and variations in travel time expenditure. For empirical analysis, we used data from German Mobility Panel, one-week continuous travel diary survey conducted every year since 1994. It is expected that such methodological considerations and empirical analysis of changes and variations could stimulate the importance of multi-day and multi-period panel data, as well as provide basic but useful information for the reconsiderations of policy evaluation methods. The feedback to theoretical considerations is also discussed in this study.

The paper organized as follows: In the next section, after giving the definitions of changes and variations, we shall describe a methodology for capturing changes and variations simultaneously. After that, the data used in the empirical analysis are briefly explained and described. We shall then discuss about the empirical results. In the final section, some major findings and avenues for future research will be summarized.

2. METHODOLOGY

2.1. Definitions of Changes and Variations

In this study, “variations” are defined as “fluctuations/dispersions of behavior, observed at a certain time period which is short enough to be assumed that a causal structure of behavior and its determinant factors is stable”, while “changes” are defined as “structural changes in behavioral mechanism as time passes (i.e., a causal structure of behavior and its determinant factors becomes different states as time passes)”. In empirical analysis, the continuous one-week survey period in each year is employed as “certain time period” in which the causal structure is assumed to be stable. Under the above defined “variations” and “changes”, it should be noted that there is a possibility that “changes” occur in the variations of travel time expenditure, even though the observed travel time expenditure at aggregate level is perfectly constant. A simple example is that if the travel time expenditure for commuting becomes bigger while the other travel time for other trip purpose becomes shorter, we judge changes certainly occur even though the observed travel time expenditure is stable over time. In other instances, if the day-to-day variations within an individual become bigger, we also judge changes in travel time expenditure certainly occur. This judgment would also be done regardless of the existence of the stability of travel time expenditure. This study focuses on such changes in variations of travel time expenditure.

Until now, a lot of studies have focused on variations and changes in activity-travel behavior. As for the variations, many of them have investigated distinguishing different variation types, especially inter-individual and intra-individual variations (*20-24*). For this distinction, a multi-day data is certainly needed. In addition, some researchers pointed out the existence of inter-household variations (*25*) and spatial variations (*26*), and the above mentioned multiple variation types have been simultaneously examined (*27, 28*). As for the changes, the discussions on changes in activity-travel behavior have been actively done especially since 1980s (*29-31*). Analyzing mode switching behavior, response lags, response leads, residential relocations and habit persistence are crucial for a better understanding of changes, and to measure these changes at the disaggregate level, a multi-period panel data is certainly needed (*32*). However, while many studies have analyzed either variations or changes, a simultaneous investigation on variations and changes is rarely done, because 1) only a limited number of multi-day and multi-period panel survey have been conducted, that is certainly needed for the analysis of changes and variations simultaneously, and 2) a methodology that can deal with both changes and variations is not well developed. In the following sub-section, we shall make the methodological discussions.

2.2. Modeling of Changes in Variations of Travel Time Expenditure

This study attempts to examine the changes in variations of travel time expenditure by developing a Tobit type model with complex functions of variances. The basic thought for employing the Tobit type model is to take into account zero travel time expenditure, i.e., immobile day. A noteworthy aspect of the model is treating variance as a function of certain variables: this treatment allows us to model changes in variations occurred at different levels, including intra-individual and inter-individual variations. Concretely, this study employs the following Tobit type model:

$$TTE_{idt} = \begin{cases} f\left(y^*_{idt}\right) & \left(if\ \ y^*_{idt} > 0\right) \\ 0 & \left(if\ \ y^*_{idt} \le 0\right) \end{cases}, \qquad (1)$$

where, TTE_{idt} represents individual i's travel time expenditure on day d in year t. And y^*_{idt} is a latent variable defined as follows:

$$y^{*}_{idt} = \beta_{t} x_{idt} + \gamma_{it} + \varepsilon_{idt} \,, \tag{2}$$

where, x_{idt} indicates explanatory variables and β_t is a coefficient factor associated with x_{idt} and can vary with time. Let γ_{it} be an unobserved inter-individual variation and ε_{idt} be an unobserved intra-individual variation. These two unobserved variations are assumed to be normally distributed as follows:

$$\gamma_{it} \sim N\left(0, \sigma_{\gamma}^{2}(t)\right), \;\; \varepsilon_{idt} \sim N\left(0, \sigma_{\varepsilon}^{2}(t)\right), \tag{3}$$

where $\sigma_{\gamma}^{2}(t)$ and $\sigma_{\varepsilon}^{2}(t)$ are the variances that vary associated with time-dependent factors at macro-level, including time itself as well as the changes in GDP, number of automobiles, total road length in the survey area, etc.

The feature of the above defined model can be found in the variance of y^{*}_{idt} at a certain discrete time point $\tilde{t}$:

$$Var\left(y^{*}_{id\tilde{t}}\right) = Var\left(\beta_{\tilde{t}} x_{id\tilde{t}}\right) + \sigma_{\gamma}^{2}(\tilde{t}) + \sigma_{\varepsilon}^{2}(\tilde{t}) \,. \tag{4}$$

Here, the first component represents observed variations in travel time expenditure, including the differences between male and female, urban and rural areas, rich and poor, and so forth. The changes of such differences can also be captured. For example, the study of Zahavi and Talvitie (*7*) focused on this first component, and concluded that travel time expenditures can be attributed to factors as the socioeconomic characteristics of households, transport system supply, and urban structure. They also mentioned the transferability of travel time expenditure between cities and over time in a country. However, this confirmation was only done focusing on the first component and remaining parts were not discussed well. In addition, recently it becomes clear that many factors, such as psychological factors, potentially influence activity-travel behavior but cannot be specified easily, and consequently nonnegligible unobserved variations still remain (e.g., *27-28*). In order to deal with such situation, the second and third components in Eq. (4), unobserved inter-individual and intra-individual variations, should be introduced in the discussions of travel time expenditure. Although the quantitative identification of these unobserved variations cannot explicitly answer to the question "why travel time expenditures vary?", we think that discriminating inter-individual and intra-individual variations itself (and of course its temporal changes), is quite important to reconsider the behavioral basis behind demand models and policy evaluation methods. For example, whether activity-travel behavior becomes diversified over time or not can be clarified only when we distinguish inter-individual and intra-individual variations and identify changes in the variations. Here, we would like to consider about what kinds of discussions could be stimulated by such clarification. One possible reason for the diversification of activity-travel behavior is that it becomes easy to reallocate travel time budget, partly due to the expansion of transportation infrastructure. This implies that there is a possibility that infrastructure development allows people to easily adjust their activity schedule and then to easily choose the more desired and attractive destinations. In other words, there is a possibility that the impacts of infrastructure investment can be discussed by the improvement of the flexibility of their activity schedule or by the easiness of schedule adjustments. Based on the above mentioned considerations, this study hypothesizes that the increase of flexibility of travel behavior might induce the increase of intra-individual variation, probably because they can easily adapt travel plan to the needs of the circumstances of that time. Confirming this hypothesis itself (i.e., diversification of travel time expenditure) is not directly related to the improvement of benefit evaluation, but we believe that this clarification can provide the basic information and stimulate further research on the relevant topics.

More specifically, in empirical analysis, we will specify the following model:

$$ln(TTE_{idt}) = \begin{cases} y^*_{idt} & (if \ y^*_{idt} > 0) \\ 0 & (if \ y^*_{idt} \le 0) \end{cases}, \qquad (5)$$

where

$$y^*_{idt} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \gamma_{it} + \varepsilon_{idt}, \qquad (6)$$

$$\gamma_{it} \sim N(0, \sigma^2_\gamma(t)), \quad \varepsilon_{idt} \sim N(0, \sigma^2_\varepsilon(t)), \qquad (7)$$

$$\sigma^2_\gamma(t) = exp(\alpha'_0 + \alpha'_1 t + \alpha'_2 t^2), \qquad (8)$$

$$\sigma^2_\varepsilon(t) = exp(\alpha''_0 + \alpha''_1 t + \alpha''_2 t^2). \qquad (9)$$

Here, α_0, α_1 and α_2 are the parameters related to the changes in the average travel time expenditure, α'_0, α'_1 and α'_2 are the parameters related to the changes in inter-individual variations of travel time expenditure, and α''_0, α''_1 and α''_2 are the parameters related to the changes in intra-individual variations of travel time expenditure. The above defined empirical model is one of the simplest formulations but it may be enough to check 1) whether the travel time expenditure stable or not (related to the parameters α_1 and α_2), and 2) whether the intra-individual variation is increasing over time or not (related to the parameters α''_1 and α''_2). We will use the model for different groups, including male/female, younger/elder, and car/season-ticket owners, as well as for whole samples.

The model defined above can be regarded as a kind of multilevel model with structured nonlinear variances and its likelihood function can be written as follows:

$$L(\alpha, \alpha', \alpha'' \mid \mathrm{TTE}, t) = \int_{\gamma_{it}} \left\{ \prod_{TTE_{idt}>0} \left[\frac{1}{\sigma^2_\varepsilon(t)} \varphi\left(\frac{TTE_{idt} - \alpha_0 - \alpha_1 t - \alpha_2 t^2 - \gamma_{it}}{\sigma^2_\varepsilon(t)} \right) \right] \times \prod_{TTE_{idt}=0} \left[\Phi\left(\frac{\alpha_0 - \alpha_1 t - \alpha_2 t^2 - \gamma_{it}}{\sigma^2_\varepsilon(t)} \right) \right] \right\} g(\gamma_{it} \mid \sigma^2_\gamma(t)) d\gamma_{it}, \qquad (10)$$

where φ is a standard normal density distribution function and Φ is a standard normal cumulative distribution function. For estimating this model, several estimation methods have been proposed in literature (*33*). This study employs a Markov Chain Monte Carlo (MCMC) method, in which the integration appeared in Eq. (10) is replaced by a sampling procedure (*34, 35*). Concretely, the posterior distribution, which is used for successive sampling of model's parameters, can be written as follows:

$$p(\alpha,\alpha',\alpha''|\mathrm{TTE},t)=\left\{\prod_{TEE_{idt}>0}\left[\frac{1}{exp(\alpha''_0+\alpha''_1 t+\alpha''_2 t^2)}f\left(\frac{TEE_{idt}-\alpha_0-\alpha_1 t-\alpha_2 t^2-\gamma_{it}}{exp(\alpha''_0+\alpha''_1 t+\alpha''_2 t^2)}\right)\right]\times\prod_{TEE_{idt}=0}\left[\Phi\left(\frac{-\alpha_0-\alpha_1 t-\alpha_2 t^2-\gamma_{it}}{exp(\alpha''_0+\alpha''_1 t+\alpha''_2 t^2)}\right)\right]\right\}\times g(\gamma_{it}|exp(\alpha'_0+\alpha'_1 t+\alpha'_2 t^2))\times h(\alpha)h(\alpha')h(\alpha''), \quad (11)$$

where, $g(\gamma_{it}|exp(\alpha'_0+\alpha'_1t+\alpha'_2t^2))$, $h(\alpha)$, $h(\alpha')$, and $h(\alpha'')$ are assumed to be normal distributions. Here, $h(\alpha)$, $h(\alpha')$, and $h(\alpha'')$ are called as prior distributions. In the empirical analysis, non-informative prior distributions are assumed for all parameters, and thus the estimated parameters in this paper are asymptotically equivalent to the parameters obtained through a simulated maximum likelihood method (*35*). The term $g(\gamma_{it}|exp(\alpha'_0+\alpha'_1t+\alpha'_2t^2))$ creates a so-called hierarchical sampling structure which is often used in a multilevel model estimation, mixed logit model estimation, etc. (*33*-*35*). Draws from the posterior are obtained using the software WinBUGS (Bayesian inference Using Gibbs Sampling (*36*)). The convergence of the estimation results reported in this paper were checked by using the Geweke diagnostic (*37*), and the results indicated that the models reported in this paper are well converged.

3. DATA DESCRIPTION

The German Mobility Panel data (*38*), a multi-day and multi-period panel data, is used for the empirical analysis. The German Mobility Panel survey have been conducted since 1994 and totally 15 waves are available in this study, but we only use the data from 1999 to 2008 when the survey area includes all Germany (until 1998, data from West Germany was only collected). In the survey, each respondent was asked to report a period of continuous one week travel behavior over each of three years.

Key statistics of the data are shown in Table 1. From the table, we can confirm that there seems to be no specific direction of changes in average number of trips, ratio of mobile persons, and average travel time expenditure. The average travel distance per person-day and travel speed are also not likely to have big changes, but these values seem to slightly edge up roughly speaking. In fact, focusing on the changes in travel distance per person-day in the last 35 years in Germany, a structural development stagnating demand have been observed as shown in Zumkeller (*37*). He also mentioned that "this structural stagnation of highly aggregated values can be misunderstood in the sense of a quite low level of behavioral changes for all subgroups of the population. However, when looking at the subgroups, the dynamics of changes are even stronger than during the previous decades of growth". Such hidden changes should be examined to avoid misunderstanding of changes. Figure 1 shows changes in average travel time expenditure, number of trip and travel distance by subgroups (divided by gender, age category, and mobility tool ownership). One interesting finding from the figure is that travel time expenditure seems to be relatively stable especially compared to average travel distance. For example, female, younger, and elder people have quite shorter travel distances compared to those of the other subgroups, whilst travel time expenditures are not so different. Since the differences in the number of trips across subgroups are not the same with the differences in travel time expenditure and travel distance, it can be said that we should carefully use these three different mobility measures. Although in this study we only focus on travel time expenditure in the following section, it would be worth investigating on the differences of the other mobility measures. Another interesting point from Figure 1 can be found in the changes in travel time expenditure of "season ticket owner" group. The value demonstrates an upward trend steadily whilst the number of trips is not in increasing tendency. Since the travel distance is dramatically increased during the 10 years, "season ticket owner" tend to allocate more time to travel to move farther away, rather than move more frequently.

We will take into account such group differences by developing the model for each group, not by introducing corresponding explanatory variables. This is because the description of heterogeneity by introducing explanatory variables is quite different from that by segmenting population groups: the former describes heterogeneities regarding the baseline differences of travel time expenditure by introducing both observed and unobserved variables, while the latter describes the different effects of these introduced variables among population groups. Thus, when we segment a population based on gender, age category or mobility tool ownership, our interest is in "how the differences in the impact of other variables show up", rather than its own impacts on behavior. More concretely, the differences of changes in variations of travel time expenditure across groups are the main concern in the analysis, rather than the effects of those individual attributes on the travel time expenditure itself.

4. EMPIRICAL RESULTS

For the model estimation, we will use a MCMC method as we mentioned above. The non-informative prior distributions are given for all parameters, and we carry out a total of 300,000 iterations in order to obtain 10,000 draws: the first 100,000 iterations are used for burn-in mitigate start-up effects and the remaining 200,000 iterations are used to generate the 10,000 draws, i.e., every 20 iterations are retained. The results of Geweke diagnostic (*37*) indicates all parameters are well converged.

Table 2 shows the estimation results of the models with all samples as well as with subgroup samples: classified by gender (male and female), by age category (10-24 years old, 25-64 years old and 65+ years old), and by mobility tool ownership (car owner, season ticket owner, and no car no season ticket owner). Figure 2 and Table 3 present the characteristics of the changes in variations, which are our main interests.

Focusing on the estimation results with all samples, as expected, the significant changes in average travel time expenditure are not observed. This is consistent with the results shown by a number of researchers (e.g., *1*, *6-10*), and as discuss in Section 1, there is a possibility that the travel time saving is not a good measure at least to capture the impacts of infrastructure investments during the last 10 years. As for the inter-individual variations, it can be confirmed that the estimated value tends to be decreasing over time (Figure 2). Here might be several possible explanations for the shrinkage of inter-individual variations, but one plausible explanation can be made from equity perspective. It is known that "equity" can be defined as several different meanings even only focusing on the transportation field (*39*). The simplest equity is *Egalitarianism*, in which everybody is treated as the same, regardless of who they are. Since the empirical analysis does not take into account any observed variables, zero inter-individual variations can be regarded as the achievement of full *Egalitarianism*.

Under this definition of equity, the empirical results imply that the equity has been improved over time. The different definitions of equity may also be able to be treated by introducing the relevant control variables, including socioeconomic, geographical, and demographic attributes including living environment, mobility tool ownership, age, household income, etc. (what kinds of variables should be introduced is dependent on the definition of equity). Such observation of inter-individual variation changes could provide useful information to reconsider the evaluation of transportation investment from the equity perspective, and further empirical studies might be needed to clarify the usefulness of the analysis focused on inter-individual variations in equity-related discussions. As for the intra-individual variations, the value has increased during the last 10 years, as expected (see Figure 2). This result implies that the flexibility of travel behavior could have increased over time, under the assumptions that increasing mobility level enhances the easiness of schedule adjustment and their needs to travel strongly depend on the situations of that time, as discussed in the Section 2.2. Although the finding is valid only when the assumptions are acceptable, relevant empirical studies are very little, due to the data and methodological limitations: to the authors' knowledge, this is the first empirical analysis that examines behavioral changes with explicit consideration of the existences of both inter-individual and intra-individual variations. And the results indicate that inter-individual variations has decreased whilst intra-individual variations has increased over time, implying that the influential factors on their travel time expenditure may have transitioned from socioeconomic, geographical, or demographic factors to situational factors including schedule adjustments by a call from friends, whether changes, etc.

Focusing on the estimation results of male and female, there are no big differences between the variation properties of them, although around 10 minutes differences are observed between the average travel time expenditure (see Figure 1). One small difference in variation properties is that inter-individual variations for female are slightly larger than those for male for all time points. This means that travel time expenditure of female fluctuates more within an individual, compared to that of male. This might be because of the differences of their role in society, i.e., male may take more planned and fixed travel behavior such as commuting trips, while female's travel behavior might be more flexible, like shopping trips.

As for the estimation results for each age category (10-24 years old, 25-64 years old, and over 65 years old), the big differences can be found between people aged 65 or over and the other. There are two notable differences between them. First, inter-individual variations for people aged 65 or over have dramatically decreased, implying that the differences of travel time expenditure across elderly have been shifted toward better equity defined as *Egalitarianism* within elderly people. Second, the intra-individual variations for elderly remain unchanged during the 10 years, while these for other subgroups have been increasing. One possible reason for this is that elderly travel behavior has been already enough to be flexible compared to others, and thus the intra-individual variations remain at the high level stably.

Finally, the estimation results for the subgroups of car owner, season ticket owner, and no car/no season ticket owner are discussed. From Figure 2, we can confirm that there are big differences in the variation properties between mobility tool owners and non-mobility tool owners. Concretely, the former has changed towards the increase of intra-individual variations whilst the latter has not. One can assume that most of non-mobility tool owners are elderly, but in fact the share is not so high: 16.4% of car owners, 18.6% of season ticket owners, and 24.3% of non-mobility tool owners are elderly (aged 65 or over). Thus, it could be said that mobility tool ownerships had certain impacts on travel behavior, although the differences between them become smaller over time.

In summary, there are two important findings from the empirical results. First, the differences of variation properties across subgroups become smaller over time. Second, intra-individual variations become bigger whilst inter-individual variations become smaller as time passes. These results indicate that people's travel time expenditures become more dependent on the situational attributes, rather than their individual or household attributes, implying that the travel time expenditures change towards diversification, i.e., observed travel time expenditures might become sensitive to the situation of that time even within an individual. This means that the accuracy of describing travel behavior based on conventional one-day data information might be reduced over time. Although this study did not identify the sources of the intra-individual variations, it could be said that the longer observation might become more important and needed to describe the decisions on travel time expenditure, since their travel behaviors are less dependent on inter-individual variations which could be captured by one-day behavioral observation. The observations in this study are made only focusing on travel time expenditure, and it is certainly interesting whether the same observation can be made focusing on the other behavioral aspects. The proposed method in Section 2 can be easily extended to other model types as long as the model defined as one kind of generalized linear model. This might be the important contribution of this paper to stimulate the use of multi-day and multi-period data and relevant discussions. The implication to the theoretical considerations from the above mentioned results of observation side is that, even only within the observed 10 years, changes in variations of travel time expenditure certainly occurred, which means that "time axis" should be considered in the theoretical reconsiderations of evaluation methods. In this context, treating travel behavior as the process, not a state, might be important to improve our behavioral understanding, and consequently to improve our policy evaluation methods. Goodwin (*40*) argues "ignoring dynamic factors could give misleading results not only for behavioral forecasts, but also for interpretation of the values and utilities underpinning them". In this context, it could be said that the understanding of dynamic aspects of behavior is still important and remain as a big challenging issue to be revisited, not only to improve forecasting models, but also to reconsider the benefits from transportation investment.

5. CONCLUSIONS

With the needs for improving evaluation methods of transport infrastructure investment in mind, this paper presented a method for capturing changes in variations of travel time expenditure, and showed the empirical results by using German Mobility Panel data that is a multi-day and multi-period panel data. Although reconsidering evaluation methods is not so simple task and we only investigated small part of the whole discussions from the perspective of the observation side, we believe that there are several important findings and contributions.

First, the methodology proposed in this study, in which each level of variance (inter-individual and intra-individual levels) varies associated with time-dependent factors, could expand the possibilities for the use of multi-day and multi-period data. The proposed method can also be easily extended to other model types as long as the model defined as one kind of generalized linear model. Moreover, it is also possible to incorporate the different types of variations such as household variations and spatial variations straightforwardly (*27*, *28*). Such methodological development might be a primary contribution that comes in the form of stimulating further empirical studies, i.e., discussions from observation side.

Second, there are several important findings from the empirical results. One of the most important findings is that travel time expenditures become more dependent on the situational attributes, rather than their individual or household attributes, implying that the travel time expenditures change towards diversifications and that longer behavioral observation becomes more important to describe people's travel time expenditure. In fact, unlike the model development, data collection is only possible at that time: if we missed the timing, we would never have a chance to collect the detailed behavioral data, which may just be stored in short term memory that could not answer in the retrospective survey. In addition, these results imply that the process of changes should be further investigated especially from the theoretical perspective at least at the first stage of reconsiderations of evaluation methods. This might be to create fundamental basis for empirical models. Concretely, if we tried to get the implications related to "changes" from static data or one-day behavioral data, this would force "observed" variations into "virtual" changes, causing misunderstanding of the variations and changes.

This is the first investigation aiming at exploring changes in the variations of activity-travel behavior and obtaining some useful insights for the benefit reconsiderations. There are several important issues that need to be further examined. First, empirical studies focusing on different behavioral aspects should be further investigated. The application of different multi-day and multi-period survey data set is also interesting. Perhaps, one of the most important future tasks is how to differentiate activity opportunities provided at different locations. We can imagine that people tend to live in suburban area probably because of the lower cost and wider living space, and people tend to go shopping at a large suburban shopping mall probably because many tasks can be done simultaneously. Although it can be expected that these benefits are bigger than the travel burdens (i.e., longer trip distance) partly because of the improvement of transportation systems, how to measure these benefits is still not well elaborated. This might be an important challenging issue which should be discussed from the theory-based and observation-based perspectives.

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List of Tables/Figures

TABLE 1 Some Key Statistics

year	number of sample			average number of trips/person.day	Ratio of mobile persons	Average travel time expenditure	Average travel distance/person.day	Average travel speed
	person	person.day	trip					
1999	1887	13209	46386	3.51	92.1%	84.2	40.2	28.7
2000	1618	11326	38262	3.38	91.5%	77.8	38.0	29.3
2001	2009	14063	49594	3.53	93.1%	83.0	39.4	28.5
2002	1769	12383	43254	3.49	91.7%	77.6	36.9	28.5
2003	1996	13972	49407	3.54	92.2%	81.6	38.6	28.3
2004	1838	12863	44373	3.45	91.7%	78.5	40.1	30.6
2005	1727	12087	42168	3.49	91.5%	83.3	42.9	30.9
2006	1555	10885	38246	3.51	91.5%	82.8	41.0	29.7
2007	1567	10969	37520	3.42	91.7%	81.4	42.1	31.0
2008	1783	12481	43029	3.45	91.8%	79.8	39.8	29.9
total	17749	124238	432239	3.48	91.9%	81.0 [min]	39.9 [km]	29.6 [km/h]

TABLE 2 Estimation Results

	All		Gender				Age						Mobility tool ownership					
			Male		Female		10-24 years		25-64 years		65+ years		Car owner		Season ticket owner		No car, No season ticket	
param	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]	mean (s.d.)	[2.5%, 97.5%]
α_0	3.829 (0.022)	[3.789, 3.875]	3.914 (0.036)	[3.851, 3.993]	3.751 (0.034)	[3.682, 3.815]	3.830 (0.057)	[3.713, 3.938]	3.886 (0.031)	[3.825, 3.947]	3.633 (0.064)	[3.510, 3.761]	3.898 (0.028)	[3.844, 3.952]	3.892 (0.058)	[3.781, 4.012]	3.732 (0.048)	[3.635, 3.822]
α_1	-0.011 (0.009)	[-0.031, 0.005]	-0.008 (0.015)	[-0.041, 0.019]	-0.014 (0.014)	[-0.039, 0.014]	-0.025 (0.023)	[-0.067, 0.023]	-0.004 (0.013)	[-0.03, 0.022]	-0.028 (0.026)	[-0.080, 0.023]	0.002 (0.012)	[-0.020, 0.024]	0.015 (0.022)	[-0.031, 0.058]	-0.078 (0.020)	[-0.116, -0.037]
α_2	0.001 (0.001)	[-0.001, 0.003]	0.001 (0.001)	[-0.002, 0.003]	0.001 (0.001)	[-0.001, 0.004]	0.002 (0.002)	[-0.002, 0.006]	0.000 (0.001)	[-0.002, 0.003]	0.003 (0.002)	[-0.001, 0.008]	-0.001 (0.001)	[-0.003, 0.001]	-0.001 (0.002)	[-0.005, 0.003]	0.007 (0.002)	[0.003, 0.010]
α'_0	-0.727 (0.06)	[-0.841, -0.605]	-0.788 (0.084)	[-0.951, -0.625]	-0.693 (0.082)	[-0.856, -0.535]	-0.686 (0.166)	[-1.012, -0.369]	-0.920 (0.071)	[-1.056, -0.778]	-0.304 (0.123)	[-0.552, -0.063]	-0.865 (0.079)	[-1.016, -0.709]	-0.665 (0.124)	[-0.903, -0.414]	-0.58 (0.105)	[-0.786, -0.375]
α'_1	0.090 (0.026)	[0.036, 0.138]	0.081 (0.035)	[0.013, 0.149]	0.095 (0.034)	[0.03, 0.162]	-0.03 (0.071)	[-0.163, 0.111]	0.094 (0.03)	[0.035, 0.151]	0.139 (0.051)	[0.038, 0.244]	0.058 (0.033)	[-0.007, 0.122]	0.027 (0.049)	[-0.072, 0.122]	0.148 (0.045)	[0.06, 0.236]
α'_2	-0.011 (0.002)	[-0.015, -0.006]	-0.009 (0.003)	[-0.015, -0.003]	-0.012 (0.003)	[-0.018, -0.006]	-0.002 (0.006)	[-0.015, 0.010]	-0.009 (0.003)	[-0.015, -0.004]	-0.018 (0.005)	[-0.027, -0.009]	-0.006 (0.003)	[-0.012, 0.000]	-0.006 (0.004)	[-0.015, 0.002]	-0.017 (0.004)	[-0.025, -0.009]
α''_0	0.523 (0.017)	[0.490, 0.556]	0.475 (0.025)	[0.426, 0.525]	0.569 (0.023)	[0.524, 0.613]	0.525 (0.042)	[0.444, 0.608]	0.425 (0.021)	[0.384, 0.465]	0.801 (0.040)	[0.724, 0.879]	0.470 (0.024)	[0.425, 0.517]	0.584 (0.039)	[0.507, 0.66]	0.536 (0.033)	[0.472, 0.602]
α''_1	-0.019 (0.007)	[-0.034, -0.006]	-0.031 (0.011)	[-0.052, -0.01]	-0.011 (0.009)	[-0.03, 0.007]	-0.027 (0.017)	[-0.06, 0.006]	-0.016 (0.009)	[-0.033, 0.001]	-0.012 (0.017)	[-0.044, 0.020]	-0.038 (0.010)	[-0.058, -0.019]	-0.054 (0.016)	[-0.084, -0.023]	0.056 (0.015)	[0.027, 0.084]
α''_2	0.003 (0.001)	[0.002, 0.004]	0.004 (0.001)	[0.002, 0.006]	0.002 (0.001)	[0.001, 0.004]	0.004 (0.002)	[0.001, 0.007]	0.003 (0.001)	[0.001, 0.004]	0.001 (0.001)	[-0.001, 0.004]	0.005 (0.001)	[0.003, 0.007]	0.007 (0.001)	[0.004, 0.009]	-0.005 (0.001)	[-0.008, -0.002]
LL0	-334,426		-159,771		-174,641		-52,153		-217,101		-65,130		-194,661		-80,581		-80,760	
LLC	-223,614		-104,096		-119,229		-34,395		-140,738		-47,544		-126,490		-53,106		-57,141	
LLβ	-200,916		-93,176		-107,641		-31,514		-126,489		-42,475		-114,037		-48,226		-50,963	
Sample	124,238		58,692		65,546		19,416		79,888		24,920		71,628		29,552		30,855	

Note: A shaded cell represents the credible interval (2.5and 97.5% quantiles) does not include zero, which means the corresponding variables are statistically significant at the 5% level.

TABLE 3 Changes in Variation Ratios between Inter-individual and Intra-individual Variations

	Variation type	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
All	Inter-individual variation	24.0%	25.2%	26.0%	26.3%	26.0%	25.2%	23.9%	22.2%	20.2%	17.9%
	Intra-individual variation	76.0%	74.8%	74.0%	73.7%	74.0%	74.8%	76.1%	77.8%	79.8%	82.1%
Male	Inter-individual variation	23.8%	25.1%	26.0%	26.4%	26.3%	25.7%	24.6%	23.1%	21.2%	19.0%
	Intra-individual variation	76.2%	74.9%	74.0%	73.6%	73.7%	74.3%	75.4%	76.9%	78.8%	81.0%
Female	Inter-individual variation	23.7%	24.9%	25.5%	25.7%	25.3%	24.3%	22.9%	21.1%	19.0%	16.6%
	Intra-individual variation	76.3%	75.1%	74.5%	74.3%	74.7%	75.7%	77.1%	78.9%	81.0%	83.4%
10-24 years	Inter-individual variation	22.8%	22.4%	21.8%	21.0%	20.0%	18.9%	17.6%	16.2%	14.8%	13.3%
	Intra-individual variation	77.2%	77.6%	78.2%	79.0%	80.0%	81.1%	82.4%	83.8%	85.2%	86.7%
25-65 years	Inter-individual variation	22.3%	23.6%	24.5%	25.0%	25.0%	24.5%	23.6%	22.3%	20.7%	18.8%
	Intra-individual variation	77.7%	76.4%	75.5%	75.0%	75.0%	75.5%	76.4%	77.7%	79.3%	81.2%
65+ years	Inter-individual variation	27.4%	29.3%	30.5%	30.8%	30.3%	29.0%	27.0%	24.3%	21.2%	17.8%
	Intra-individual variation	72.6%	70.7%	69.5%	69.2%	69.7%	71.0%	73.0%	75.7%	78.8%	82.2%
Car owner	Inter-individual variation	22.3%	23.4%	24.1%	24.4%	24.2%	23.7%	22.8%	21.5%	19.9%	18.1%
	Intra-individual variation	77.7%	76.6%	75.9%	75.6%	75.8%	76.3%	77.2%	78.5%	80.1%	81.9%
Season ticket owner	Inter-individual variation	23.5%	24.2%	24.5%	24.3%	23.6%	22.5%	20.9%	19.1%	16.9%	14.7%
	Intra-individual variation	76.5%	75.8%	75.5%	75.7%	76.4%	77.5%	79.1%	80.9%	83.1%	85.3%
No car, No season ticket	Inter-individual variation	26.2%	27.3%	28.0%	28.2%	28.0%	27.3%	26.1%	24.5%	22.6%	20.5%
	Intra-individual variation	73.8%	72.7%	72.0%	71.8%	72.0%	72.7%	73.9%	75.5%	77.4%	79.5%

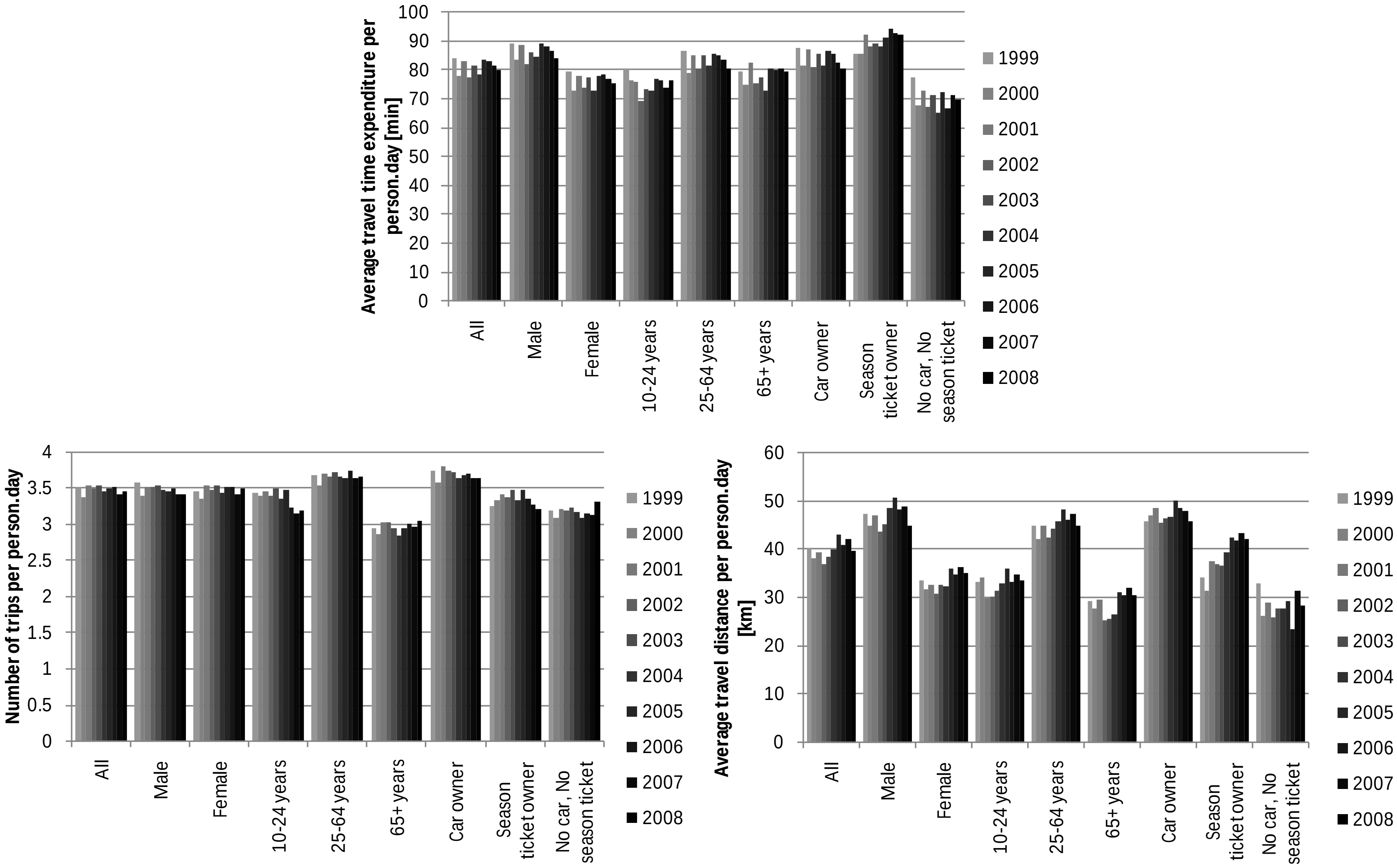

FIGURE 1 Travel time expenditure, number of trips, and travel distance by groups.

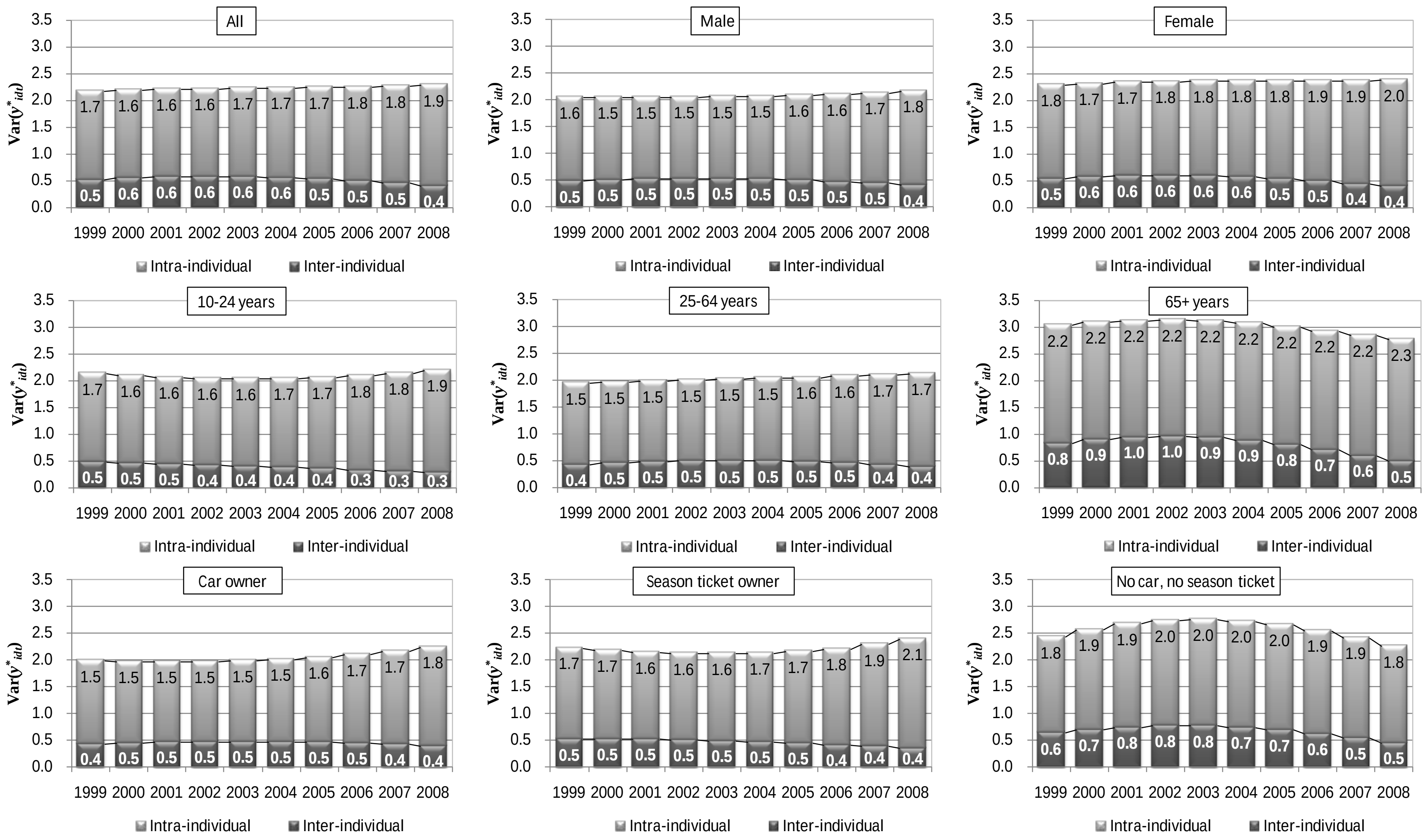

FIGURE 2 Changes in variations of travel time expenditure.