An exploration of the interdependencies between trip chaining behavior and travel mode choice

Jianchuan Xianyua,b*

aAntai College of Economics and Management, Shanghai Jiao Tong University, 535 Fahuazhen Rd., Shanghai 200052, China
bBusiness School, Shanghai Dian Ji University, 1350 Ganlan Rd., Shanghai 201306, China

Abstract

The modeling of travel behavior is complicated by the joint and causal relationships among multiple endogenous variables. And it is generally accepted that commute mode choice and the choice of including intermediate activities on a work tour are interrelated. But the nature of the interrelationship is not clear. In order to give an in depth exploration on this, this paper presents a mathematical model to investigate the decision order of trip chaining and travel mode choice. By using household travel survey data from Beijing, China, this paper applies the co-evolutionary approach to capture the interrelationship between travel mode choice and trip chaining. The co-evolutionary approach is combined with two MNL models, one for travel mode choice and the other for trip chaining behavior. The empirical results show that the order of the transport mode and trip chaining decisions varied among commuters. But the pattern that trip chaining drives mode choice is the dominating trend.

1. Introduction

The search for effective ways to decrease the volume of private vehicle travel and enhance the attractiveness of public transport has long been the focus of transportation planning. And the activity-based approach to travel behavior analysis is the most promising one. The approach views travel as a demand derived from the need to pursue activities distributed in time and space. It recognizes the complex interactions in activity and travel behavior and emphasizes the need and desire to participate in activities is more basic than the derived travel (Axhausen & Garling, 1992). Home-based work tour is a sequence of travel that begins and ends at the home.

* Corresponding author. Tel.:86-21-52301396; fax: 86-21-52301396.
E-mail address: jianchuanxy@gmail.com
location. With work as a mandatory activity and the home and work location as pegs, other activities can be pursued on the way to work and the way back home from work. And this may entail additional travel needs (Sakano & Benjamin, 2011). Therefore, the work tour serves as the basic organization unit for commuters’ daily activity and travel anticipation and gives the demonstration of interrelationships between travel and activity facets.

Owing to the rapid suburbanization and dispersion of job and residential locations, individuals tend to insert non-work activities on the work tour to get a more efficient time table. And this also requires the travel modes to be spatial and temporal flexible, convenient to access and multi-objective travel friendly (Wan, Chen, & Wang, 2011). Obviously, private modes, like the car, are more suited to this complex travel pattern. While public transport alternatives, which may be more sustainable, are not so attractive (Dong et al., 2006). It is not clear whether the behavior of linking activities to the work trip is conditional on the commute mode choice or vice versa. And the answer may influence the hierarchical structure of the travel behavior modeling system and come up with different outcomes in travel demand management measure simulation.

The objective of this paper is to investigate the nature of the underlying interdependencies between the two choice facets of mode choice and trip chaining in work tours and to examine how much of the variation in this interrelationship can be captured by explanatory variables at the individual and household levels by application of the co-evolutionary approach.

The remainder of this paper is organized as follows. The next section provides a brief review of related literature. Then, the household travel survey and the sample statistics are described, followed by the model development, specification, calibration, and results explanation. Finally, conclusions are drawn, and directions for further research are discussed in the last section.

2. Literature Review

The phenomenon of combining non-work stops in commute tours has been noted by several researchers. McGuckin et al. (2005) examined trip-chaining related to the work trip and contrasted travel characteristics of workers who trip chain with those who do not. They found an increase in commute trips linked with non-work trips, mostly in the direction of home to work. Chu (2002) investigated commute stop-making propensity and reached the conclusions that female workers exhibited a greater tendency than males to make morning and evening commute stops, an increase in age had a positive effect on the likelihood of an individual worker making stops during the commute, and household income increased the propensity for workers to make commute stops.

And a number of studies have been carried out to model the interdependencies of tour decisions. Bhat (2001) proposed a methodological framework to analyze the activity and travel pattern of workers during the evening commute. The framework uses a discrete-continuous economic system to model jointly the decision to participate in an activity and includes various activity- and travel- attributes. Wen and Koppelman (2000) proposed a two-stage structure to model activity and travel behavior. In the first stage, the choices for the number of household maintenance stops and the allocation of stops and autos to household members are determined. And in the second stage, the choices for the number of tours and the assignment of stops to tours for each individual are made conditional on the choices in the first stage. Ye et al. (2007) examined the relationship between mode choice and the complexity of trip-chaining patterns for commuters using the recursive simultaneous bi-variate probit model. Their findings showed that driving was associated with higher propensities toward complex commute chains. Susilo and Kitamura (2008) examined the structural changes over time in commuters travel patterns. And their research results challenge the conventional wisdom that auto travelers tend to chain trips; transit commuters make more stops and chain trips more often than do auto commuters in the Osaka area, suggesting that travel patterns are heavily influenced by transportation networks and land use developments. Sakano and Benjamin (2011) developed a structural equations model to examine commuter’ decision about activities and modes on a work day.
The results show that when the commuter is faced with a mix of travel modes over time, the mode choice becomes a significant predictor of non-work activities.

Although the researches reviewed in this paper arrived at the common conclusion that the formation of complex work tours are closed related to land use characteristics, spatial-temporal constraints and household characteristics, the nature of the causal relationship between trip chaining behavior and travel mode choice is not clear. Hence, current research aims to address the decision order about work trip chain complexity and commute mode.

3. Methodological Approach

3.1. the Co-evolutionary logit model

To account for the interdependencies between activity and travel choice facets, the co-evolutionary approach developed by Krygsman et al (2007) is adopted.

Consider a commuter faced with the problem to make two interrelated decision \((D_i, i = 1, 2)\) , namely work tour complexity and travel mode. Each decision involves a choice among a set of known alternatives, which are independent of other decisions. Both of the choices are based on the utilities of the alternatives. And the commuter chooses the alternative with the maximum utility according to the logit modeling framework. Since the two decisions are interrelated the utilities of the choice alternatives for one decision depends on the outcome of the other. And the utility function for decision can be expressed as follows:

\[
E[U'(d_i)] = \sum_r \beta^r \sum_{d \in S} P^r X_i(d | s) \forall d \in D_i, D_i \in D
\]

Where \(t\) is the index of the moment in the decision process, \(E[U'(d)]\) is the expected utility of choice alternative \(d \in D_i, i = 1, 2\) at decision moment \(t\), \(S\) is the set of possible outcomes of decision \(D_i(i \neq i)\), \(X_i(d | s)\) is the value of attribute \(r\) for alternative \(d\) at states, \(\beta^r\) is the related parameter. \(P^r\) is the possibility that states occurs at moment \(t\). It is defined as

\[
P^r = \prod_{d \in S} P^r(d), \forall d \in D_i, \forall D_i \in D, \forall s \in S
\]

Assuming an MNL model, the probability of choosing alternative \(d\) based on equations (1) and (2) can be expressed as follows

\[
P^i(d) = \frac{\exp(E[U'(d_i)])}{\sum_{d \in D_i} \exp(E[U'(d)])}, \forall d \in D_i, \forall D_i \in D, t > 0
\]

3.2. the Decision process

From the above equations we can see that in the co-evolutionary model for trip chaining (or travel mode) the utility values of choice alternatives are dependent on the outcomes of travel mode (or trip chaining) choice. And the availability of choice alternatives may also be dependent on other decisions. The two decisions are thus interdependent and the results can not be surely determined during the process. And the co-evolutionary procedure to arrive at the final decision can be described as the following iteration steps:

Step 1. Set \(t=0\).

Step 2. Calculate \(P^i(d) \forall d \in D_i, \forall D_i \in D\).

Step 3. Calculate the degree of convergence \(C^{t}\), which is defined as
where $GOF$ is a chosen measure of goodness-of-fit. And if $C' < C_0$ and $t \geq 2$ repeat Step 3 with $t = t + 1$.

Step 4. Calculate the amount of uncertainty related to decision $D_i$, which is expressed as the following entropy

$$H(D_i) = -\sum_{d \in D_i} P(d) \times \log_2 \{P(d)\}, \forall D_i \in D$$

Make a choice on the decision with the lowest entropy.

Step 5. Repeat with $t = t + 1$ from Step 2 until the two decisions, namely trip chaining and travel mode, have been made.

The process begins with an initial probabilities of equal values, i.e.:

$$P^0(d) = \frac{1}{|D_i|}, \forall d \in D_i, \forall D_i \in D$$

where $|D_i|$ is the number of alternatives for decision $D_i$. And in Step 4, making a choice means assigning one to the chosen probability of the alternative with the highest probability and zero to the chosen probability of each other alternative. Decisions are irreversible. Once a decision is made the choice probabilities for all alternatives of that decision are not changed anymore in subsequent iterations. For each observation the order of the decision sequence and the final outcome are recorded.

4. Data

4.1. Sample and descriptive statistics

The primary data source used for analysis and model estimation in this research is the household travel survey of a municipal city in China conducted in 2005. This study emphasizes the trip chaining and mode choice of the home-based work tour and the interdependencies of the two choices. Home-based work tour is defined as a sequence of travel having work as the main activity, which begins and ends at the home location. Here the alternatives for work travel mode choice include walk, bike, transit and car. With respect to the chaining pattern of a work tour, individuals can insert no additional non-work activities, which comes up with a simple tour; or they can insert intermediate activities, in which case the work tour becomes a complex one. Therefore the trip chaining choice has two alternatives, namely simple and complex tour.

After data checking and cleaning, the final data set consisted of 7156 work tours. Table 1 shows the cross-tabulation of travel mode and trip chaining for the dataset. An examination of the column percentages indicates that one third of complex tours involve the use of car as the commute transportation mode while only about 8 percent complex tours are pursued by those commute with public transport. It appears that there is a correlation between mode choice and complexity, namely car is used to a greater degree in complex tours. Similarly, an examination of the row percentages demonstrate that compared with commuters who use transit those who drive to work have much higher probability to insert non-work activities to their work tour. Thus it seems that transit work tours are likely to be simpler.

Table 1. Crosstabulation of travel mode and trip chaining

| Travel mode | Trip chaining | Total |
|-------------|--------------|-------|
|              | Simple       | Complex |       |
| Walk        | 471          | 214    | 685   |
| Travel mode | Row percent | Complex | Total |
|-------------|-------------|---------|-------|
| Walk        | 68.76%      | 31.24%  | 100.00% |
| Bike        | 82.82%      | 17.18%  | 100.00% |
| Transit     | 96.86%      | 3.14%   | 100.00% |
| Car         | 85.95%      | 14.05%  | 100.00% |
| Total       | 68.76%      | 31.24%  | 100.00% |

| Travel mode | Column percent | Complex | Total |
|-------------|----------------|---------|-------|
| Walk        | 7.57%          | 22.81%  | 9.57% |
| Bike        | 26.13%         | 35.93%  | 27.42% |
| Transit     | 35.20%         | 7.57%   | 31.58% |
| Car         | 31.09%         | 33.69%  | 31.43% |
| Total       | 100.00%        | 100.00% | 100.00% |

4.2. Variable specification

Three categories of explanatory variables that influence the travel mode and trip chaining of a work tour are considered, namely individual and household socio-demographics, transportation related measures, and activity-travel characteristics. The choice of the explanatory variables for inclusion in the model was guided by previous theoretical and empirical work on commute behavior and statistical tests of the parameter estimates. Table 2 provides the definitions of the explanatory variables and the associated descriptive statistics in the sample.

Table 2. Explanatory variable definitions and sample statistics (N=7156)

| Variables | Definition                                                                 | Mean | SD  |
|-----------|---------------------------------------------------------------------------|------|-----|
| Male      | 1 if the commuter is a male                                               | 0.55 | 0.50 |
| Old       | 1 if the commuter is 50 years or older                                     | 0.39 | 0.15 |
| Lic       | 1 if the individual has driver license                                     | 0.47 | 0.59 |
| Card      | 1 if the individual has public transportation card                         | 0.17 | 0.38 |
| Inc1      | 1 if individual belongs to low income household group                      | 0.30 | 0.46 |
| Inc2      | 1 if individual belongs to middle income household group                   | 0.52 | 0.50 |
| Child     | 1 if there are one or more children younger than 15 years old in the household | 0.33 | 0.47 |
| Uadults   | 1 if there are one or more unemployed adults in the household             | 0.44 | 0.50 |
| NBike     | Number of bikes in the household                                          | 1.52 | 1.00 |
| NCar      | Number of cars in the household                                           | 0.47 | 0.53 |
| Walk      | 1 if individual walks to work                                              | 0.10 | 0.29 |
| Bike      | 1 if individual bicycles to work                                          | 0.27 | 0.45 |
| Transit   | 1 if individual use public transport to work                               | 0.32 | 0.47 |
| Car       | 1 if individual drives a car to work                                       | 0.31 | 0.46 |
5. Model Results

In this section, the parameter estimation results of the models are discussed with the emphasis on the explanatory capacity for interdependencies between commute mode choice and trip chaining. Parameter estimates of the final model are presented in Table 3. All coefficient estimates have the expected signs and are statistically significant at a 95% confidence or more. A positive estimate for a variable in the mode choice model means that the likelihood of using the related travel mode increases with an increase in the value of the corresponding variables. Similarly, a positive estimate for a variable in the trip chaining model means a higher likelihood of including non-work activity in the work tour as the result of an increase in the value of that variable.

Table 3. Model estimates (N=7156)

| Variables | Travel mode choice | Trip chaining choice |
|-----------|--------------------|----------------------|
|           | Bike | Transit | Car | Complex |
| Constant  | -0.65 | -3.26 | -1.89 | -3.33 | -1.46 | -6.27 | -1.30 | -9.44 |
| Male      | /    | /     | -0.41 | -3.33 | 1.34 | 10.37 | -0.11 | -2.28 |
| Old       | /    | /     | -0.15 | -2.85 | -0.01 | -2.81 | /     | /     |
| Card      | -0.60 | -2.04 | 1.92 | 5.13 | -1.08 | -2.87 | -0.26 | -2.26 |
| Nbike     | 0.23 | 3.10 | / | / | / | / | / | / |
| Near      | / | / | / | / | 0.32 | 5.92 | / | / |
| Lic       | / | / | / | / | 1.19 | 4.57 | / | / |
| Cdis      | / | / | 3.20 | 39.33 | 3.20 | 39.33 | / | / |
| Short     | 0.59 | 6.20 | / | / | / | / | / | / |
| Complex   | 0.67 | 5.89 | -0.31 | 1.52 | 0.45 | 3.10 | / | / |
| Uadult    | / | / | / | / | / | / | -0.20 | -4.11 |
| Child     | / | / | / | / | / | / | 0.83 | 17.41 |
| Inc1      | / | / | / | / | -0.20 | -4.15 | -0.25 | -3.43 |
| Inc2      | / | / | / | / | -0.09 | -4.61 | -0.11 | -4.59 |
| Se        | / | / | / | / | / | / | -0.41 | -5.68 |
| El        | / | / | / | / | / | / | -0.41 | -5.10 |
| Bike      | -0.766 | -11.26 | / | / | / | / | / | / |
| Transit   | -2.49 | -23.53 | / | / | / | / | / | / |
| Car       | / | / | / | / | / | / | -1.00 | -14.25 |
| Rho squared (zero) | 0.51 | / | / | / | / | / | / | / |

5.1. Travel mode choice model results

In general, the results are in line with existed researches on travel mode choice.
For public transport mode, the utility decreases with an increase in the age of the commuter. Similar negative effect exists in the utility of car mode. This appears logical since the decay of body strength and energy caused by old age may hinder the individual from taking such stressed travel modes as transit and driving a car. Males are more willing to drive to work and less willing to take public transport. Public transport card can be considered as a relatively long-term investment in commute travel mode. The model result shows that transit card subscribers are likely to be more transit-oriented. Similar principle also applies to bike and car mode. The utility of commute by bike increases with the number of household bicycles. And the increase in the number of household vehicles brings an increase to the chosen utility of car mode. Those who has a driving license are mostly car drivers so the possession of a license has a positive effect on the utility of car mode. Commute distance is also an important influence. Bike seems to be a more suitable mode choice when the commute distance is within 1.5 kilometers. And with the increase in commute distance the probabilities of driving and taking public transport increase with nearly the same magnitude. As to household income, commuters from low and middle household income groups are relatively less likely to be car drivers.

The insertion of non-work activities in the commute tour brings a decrease to the utility of public transport mode and an increase to the utility of bike and car mode. This reflects that individuals who take public transport to work have to face the rigid time schedule. Relatively fixed transit schedule, together with relatively fixed work start time, lead to decreased ability to participate in non-work activities on the way to work or back home. Therefore, compared with commuters of other modes, public transport commuters are less likely to deviate from the fixed public route for a non-work activity.

5.2. Trip chaining choice model results

Gender has negative effect, which reflects that males are less likely to have a complex commute than females. This is consistent with the expectation that women take larger part of household maintenance responsibilities and choose to arrange related stops in the commute chain for efficient time use.

The presence of unemployed adult members has a negative effect on the likelihood of non-work activity participation on the work tour. This seems reasonable because without the constraint of work schedule an unemployed adult has more free time and tends to put more effort in household affairs and thus the need for non-work stops by commute members reduces.

The presence of young children has a positive effect on commuters’ non-work stop making propensity on the commute tour. This is consistent with the fact that young children often requires accompanies on their way to school or back home, which increases the need for mandatory non-work activities on the work tour.

For household income, commuters from low and middle income groups are relatively less likely to insert non-work activities into work tour. And work schedule also shows strong effect on trip chaining behavior. For those with early work start time or late end time the commute tours are mostly simple ones as a result of the constraint of limited time available for non-work activities.

Commute choice is another important factor. The negative signs of bike, transit and car demonstrate that compared with commuters walking to work those using bike, transit or car are less likely to take non-work stops on work tour. And the absolute value of the transit mode shows that it is the least likely mode choice for a complex work tour.

5.3. Co-evolutionary model results

The co-evolutionary model converged in all of the 7156 observations. On average 4.05 iterations with a standard deviation of 0.47 were needed to arrive at a final decision. In general, \( n+1 \) iterations would be sufficient to establish \( n \) decisions if the choice facets are fully independent. And a higher iteration number indicates significant interdependencies exist between the choice facets. TABLE IV shows the predicted decision order in
the sample. As shown in the table, nearly 70% of the commuters make trip chaining decision (or activity participation choice) prior to mode choice. And another less than 30% of the workers make mode choice first, which supports the fact that considerable variation in decision order exists between different commuter groups.

Table 4. Decision order for different categories of travel mode and trip chaining

| Travel mode | Trip chaining first | Travel mode first | Total Predicted |
|-------------|---------------------|-------------------|-----------------|
| Walk        | 604 (76.48%)        | 186 (23.52%)      | 790             |
| Bike        | 1291 (71.47%)       | 516 (28.53%)      | 1807            |
| Car         | 1417 (62.35%)        | 855 (37.65%)      | 2272            |
| Transit     | 1729 (75.61%)       | 558 (24.39%)      | 2287            |
| Total       | 5041 (70.44%)       | 2115 (29.56%)     | 7156            |

6. Discussion and conclusions

We have developed a co-evolutionary MNL model system to analyse the interdependence between mode choice and trip chaining behavior for the home-based work tour. To establish a sound behavioral basis for the study, explanatory variables relating to individual and household socio-demographic characteristics, transportation measures, and activity-travel attributes were explicitly examined. Results from this study provide methodological and empirical evidence that could lead to approaches for predicting commute mode and trip chaining behavior simultaneously. Empirical analysis results from this research indicate that most commuter determine the organization of activity and travel on the work tour first. And mode choice is then derived by the chosen activity pattern. And it is important to note that a considerable variation in decision order exists which is supported by the fact that nearly 30% of the cases show a mode choice first decision order in the study. And this may point out a further research direction for us: an in depth analysis of the causes of decision orders based on a thorough classification of the decision makers.

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