

Are We Continuously Stretching-out Our Action Spaces? The Changes of Individual Action Space over a Long Term in the Osaka Metropolitan Area, Japan

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Abstract: Individual action space has been an important indicator to indicate individual ability of, and flexibility in, pursuing daily activities under the various constraints. Whilst there have been a number of studies that explore the size and variability of individual action space, there is a lack of knowledge how this individual activity space evolve over a long time period. Using the results of household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, this paper examines temporal changes in individuals' action spaces over a long span of time. By composing a system of Tobit models, stability over time of indices characterizing individuals' action spaces is examined. The result shows that, overtime, workers' commute distance negatively influences the spread of activity locations. While in case of non-workers, activity locations tend to be more dispersed when activities are pursued away from home.

Keywords: Action Space, Long Term-Changes, the Osaka Metropolitan Area.

1. INTRODUCTION

It is often the case that individuals have to travel between places in order to take part in activities. Their ability to travel in space and time depends in part on the resources available to them, e.g., time, money, and car availability (Susilo and Dijst, 2010). Individuals' daily travel patterns and activity locations evolve under the constraints of these resources. Also influential are institutional, social, environmental and transportation network conditions. These factors affect the set of places where an individual visits to carry out activities within a period of a given length. This set shall be called *action space* (Susilo and Kitamura, 2005). Note that action space thus defined refers to a set of locations that are actually visited by an individual. In some studies (Fujii et al., 1999; Schönfelder and Axhausen, 2002, 2003), action space is defined as a set of locations or geographical area that can potentially be visited. Similarly, the concept of "reach" is used to refer to the extension of the locations for potential visit (Dijst and Vidakovic, 1997, 2000; Dijst, 1999). The definition of action space adopted in this study, on the other hand, is a descriptor of observed spatial behavior.

Examining the characteristics of the action space of urban residents is important for several reasons. First, it will indicate their ability of, and flexibility in, pursuing daily activities under the various constraints. It would indicate the diversity of urban residents' spatial choices and the extent of mobility they enjoy. Second, it will show differences in spatial choices and mobility across different groups of urban residents, aiding in identifying who tend to be well endowed with the ability to overcome space to engage in activities, and who tend to be deprived of that ability. Third, it follows that the analysis of action space serves as an approach to the evaluation of quality of life (e.g. McCray and Brais, 2007),

provided that an extensive action space implies a higher quality of life – after the impacts of the built environments have been taken into account. Fourth, it will reveal the social structure of urban space by indicating where different classes of people pursue activities within an urban area.

How, then, can action space be represented quantitatively? In earlier studies of trip chaining, Markov chains are adopted by Horton and Wagner (1969) on a simple zone system to measure the extension of individuals' action spaces. Using activity and travel diary data for three consecutive days (Thursday through Saturday) obtained from two-worker families in two adjacent Dutch municipalities of Utrecht and Houten, Dijst (1999) represent an individual's action space as an ellipse, circle and line. A reachable distance is defined by deploying the notion of travel time ratio (Dijst and Vidakovic, 2000), i.e., the ratio of the travel time to the sum of the travel time to and the activity time at the destination.

Schönfelder and Axhausen (2002), with the Mobidrive six-week travel diary data, develop the confidence ellipse, kernel densities, and minimum spanning tree (network) methods to estimate the size of an individual's actual action space over six weeks period. Further, using the Mobidrive data and Uppsala survey results, Srivastava and Schönfelder (2003) compare the areas of individuals' action spaces across days of the week (workdays, Saturday and Sunday). Defining action space in terms of locations visited over two-week periods, they find that action spaces thus defined tend to repeat themselves over the six-week study period. Susilo and Kitamura (2005), also with the Mobidrive six-weeks travel diary data, examine day-to-day variability of the individual's action space. Action space is represented in this study by the second moment of out-of-home activity locations it contains. The results indicate that on weekdays, when activities tend to be obligatory and routine, activity locations tend to be fixed, especially for workers and students. On the other hands, on weekend days, when the activities tend to be more discretionary, activity locations are more variable and less predictable.

As this brief review has indicated, empirical findings have been accumulated on urban residents' action space. Little is known, however, about the change in, or the stability of, the individual's action space over a long span of time. With the rapid motorization and suburbanization in metropolitan areas of developed and developing countries in the last few decades, urban form, land use distribution, the physical environment for trip making have all drastically changed. Social changes are also numerous. More women are now employed, while household size is shrinking. Various new commodities, appliances and services have been invented to reduce the time required for domestic chores such as cleaning, cooking and yard work. Two-worker households have become a norm rather than an exception, changing the way how household tasks are carried out by its members. All of these amounts to changes in the needs for, resources available for, and constraints imposed on, travel (e.g. Kitamura et al., 1997; Cao et al., 2007; Susilo and Dijst, 2010).

These changes would imply changes in urban residents' action space over time. As far as the authors of this paper know, however, there have not been any studies that have examined the change in, or the stability of, the individual's action space. Susilo and Kitamura (2008) have shown that the individual's activity engagement and travel are not stable but expanding over a long span of time. It would then follow that the individual's action space has also been expanding over time. This conjecture, however, has not been examined in Kitamura and Susilo (2005) as the study did not incorporate spatial measures of the individual's travel. Since the extension of action space has many implications as noted at the beginning of this section, one would naturally wish to determine the empirical validity of this conjecture.

This study is concerned with the change in the individual's action space over a long span of time. Its aim is to determine empirically whether action space has been expanding,

and if so, to assess, albeit within the limitation of data availability, whether the expansion has been contributing to the individual's welfare. As in Susilo and Kitamura (2005), the extension of action space is represented by the second moment of activity locations it contains. The data used in the analysis of this study are from conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000 (Kitamura et al., 2003). The study area comprises Hyogo, Kyoto, Osaka, Shiga, and Wakayama Prefectures, and contains the three major cities of Kyoto, Osaka and Kobe. The travel data have been supplemented with land use and network data for the analysis.

The next section offers a description of the representation of action space by the second moment of activity locations as well as the model systems and the behavioral hypotheses of this study. After that, the study area and the samples used are described, and sample profiles are presented, including descriptive statistics of second moments. The result of model estimation is discussed and the stability analysis of the individuals' action space is presented. The study is concluded with a summary of results.

2. ACTION SPACE REPRESENTATION BY SECOND MOMENTS OF ACTIVITY LOCATIONS

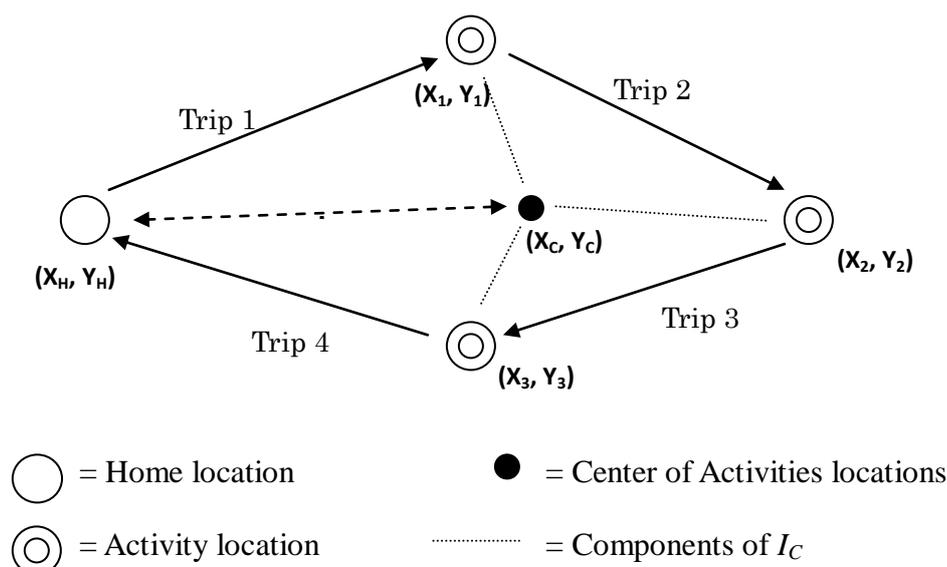
In this study, the action space of an individual is represented by the second moment of the out-of-home activity locations it contains. The method is originally implemented to measure individual action space by Susilo and Kitamura (2005). In this study, simple trip makers and complex trip makers are distinguished and differences in action space characteristics and their change over time are examined. The relationships between second moment indices and socio-demographic and other factors are also investigated.

2.1 Second Moments of Activity Locations

The concept of the second moment of out-of-home activity locations is described as follows. Let C be the centroid of the locations of the out-of-home activities pursued by an individual on a given day, and let I_C be the second moment of the activity locations about C , evaluated in terms of Euclidean distance. Also let I_H be the second moment of the centroid about the home location, i.e., $I_H = L^2$, where L is the distance between the home and the centroid.

Let N be the number of activity locations. If N is 1, then $I_C = 0$ and $I_H = L^2$, where L in this case equals the length of the trip from the home to the activity location. If N is greater than 1, then I_C indicates how spread the activity locations are, and I_H indicates how far away from the home they collectively are. Thus I_C and I_H describe how far away from the home the center of activities locations is (I_H), and how spread the activity locations are around their center (I_C).

Like any other method, the second moment as a method of representing action space has its advantages and disadvantages. For example, it does not represent the topology of an action space. Also, the second moment alone may misrepresent the spread of activity locations in urban space. Despite these limitations, use of second moments offers the advantage that the expansion of action space can be represented by just two parameters, I_H and I_C , which are well defined and easy to compute. Its simplicity is an important advantage as it facilitates application of standard statistical methods (Susilo and Kitamura, 2005). Note that the analysis of this study is concerned with actual action space, but not with potential action space or predicted reachable distance as in Djist (1999) and Schönfelder and Axhausen (2003), or activity space of Golledge and Stimson (1997).



$$I_H = L^2 = (X_H - X_C)^2 + (Y_H - Y_C)^2, \quad X_C = \frac{1}{3} \sum_{i=1}^3 X_i \text{ and } Y_C = \frac{1}{3} \sum_{i=1}^3 Y_i$$

$$I_C = \sum_{i=1}^3 \left\{ (X_i - X_C)^2 + (Y_i - Y_C)^2 \right\}$$

Figure 1. Second Moment of Activity Locations (Source: Susilo and Kitamura, 2005)

2.2 The Relationships of I_H and I_C

The relationship between I_H and I_C is expected to be different between simple trip makers and complex trip makers. For a simple trip maker, $N = 1$, $I_H = L^2$ and $I_C = 0$. On the other hand, complex trip makers have I_C and I_H values that are correlated with each other. As an individual only has limited time to make travel, there will be a trade-off between the degree of sprawl of activity locations (I_C) with the distance of the activity locations' center to home location (I_H). The longer activity locations' center from home, the less available time for individual to make his/her activity locations more spread. The correlation of those two indices is presumed to be dependent on the locations of obligatory or committed activities, which act as "pegs" (Pred, 1977), as well as on their daily routine activities, which are strongly associated with their roles.

It is reasonably anticipated that an individual's action space is defined primarily by the residential location and the locations of obligatory activities, such as work or school, and other activities are located around the axis defined by these locations (Cullen and Godson, 1975; Pred, 1977; Golledge and Stimpson, 1997). Since obligatory-activity locations tend to be fixed, the spatial orientation of the individual's daily travel is anticipated not to vary substantially over time.

If activity locations are distributed around the residential and obligatory-activity locations, then I_H , the distance between the center of activity locations and the home location, would tend to be stable. With six-week continuous travel diary data, Susilo and Kitamura (2005) have shown that the within-person variation of I_H is indeed small across weekdays.

Moreover, it is reasonable to assume that the spatial orientation of travel is determined for an individual with obligatory trips before the location of non-work activities. Non-work activities, in turn, are determined given residence and obligatory-activity locations

based on, among others, accessibility to potential activity locations and resources available to him (e.g., time available to engage in activities, travel modes that are available). Indeed it has been customary to view a commuting route as affording accessibility to potential activity locations (Oster, 1979; Adiv, 1983).

Then, for workers and students who engage in regular obligatory activities, it is logical to expect that the value of I_H will be primarily determined by the residence and obligatory-activity locations, i.e., the geodetic (crow-fly) commute distance, and will not be influenced by the value of I_C . On the other hand, it can be expected that the value of I_C is influenced by obligatory activities (e.g., working duration) and commute distance (Nishi and Kondo, 1992). Longer work hours or longer commute would reduce the time available to travel to activity locations and engage in non-work activities. One would then anticipate a negative correlation between I_H and I_C .

A non-worker, on the other hand, does not in general have fixed obligatory-activity locations and I_H and I_C are determined primarily by the spatial distribution of activity locations relative to the residence location. Although a non-worker would have activity locations he/she frequents, they would not be as fixed as a worker's obligatory-activity locations. Consequently, a non-worker has much larger degrees of freedom in determining the value of I_H , i.e., how far to travel away from home. He/she would decide how to allocate available resources between travel and activity. For example, he/she may travel to nearby locations and allocate more time to activities there or visit more locations. Alternatively, he/she may travel to farther, presumably more desirable, locations at the cost of reduced time available for activities there (Susilo and Djist, 2009). Then, one would anticipate a negative association between I_H and I_C for non-workers as well. Yet, one may consider a competing hypothesis that, given a non-worker has spent a large amount of time and other resources to reach a destination, he/she would not spend just a small amount of time there for activities (Dijst and Vidakovic, 2000), and that he/she would tend to visit some of the opportunities afforded by traveling there. This would lead to a positive association between I_H and I_C .

A set of models for I_H and I_C are developed in this study to empirically examine these competing hypotheses and reveal characteristics of activity-travel engagement and action space. Let the explanatory (pre-determined) variables of the models be d_x = one-way commute distance, m_c = commute mode, m_x = fraction of trips by a certain mode on a given day, t_w = work duration, v_w = the number of visits (stops) for work activities and let I_H and I_C be formulated in general form as:

Simple trip workers

$$I_{H_W} = f_{I_{H_W}}(d_x, m_c, R, W)$$

Simple trip non-workers

$$I_{H_{NW}} = f_{I_{H_{NW}}}(m_x, R, W)$$

Complex trip workers

$$I_{H_W} = f_{I_{H_W}}(d_x, m_x, m_c, R, W)$$

$$I_{C_W} = f_{I_{C_W}}(d_x, m_x, m_c, t_w, v_w, R, W, I_{H_W})$$

Complex trip non-workers

$$I_{H_{NW}} = f_{I_{H_{NW}}}(I_{C_{NW}}, m_x, R, W)$$

$$I_{C_{NW}} = f_{I_{C_{NW}}}(I_{H_{NW}}, m_x, R, W)$$

where

(1)

- $I_{H_w} = I_H$ for worker,
- $I_{H_{NW}} = I_H$ for non-worker,
- $I_{C_w} = I_C$ for worker,
- $I_{C_{NW}} = I_C$ for non-worker,
- R = the vector of variables representing the residence and work areas, including accessibility indices, and
- W = the vector of individual and household attributes.

The distance from residence location to the center of metropolitan area is introduced as an explanatory variable to examine the effect of regional activity center toward the individual's action space. The UMOT (Unified Mechanism of Travel) Project in the 1970s shows that action space tends to be oriented toward the agglomeration center (Zahavi, 1979; Beckman, Golob, and Zahavi, 1983).

The simple trip pattern is examined by a general Tobit model of I_H value greater than zero. The general form of the Tobit model is:

$$y_i^* = \beta' x_i + \varepsilon_i, \varepsilon_i \approx N[0, \sigma^2] \tag{2}$$

if $y_i^* \leq 0$ then $y_i = 0$; if $y_i^* > 0$ then $y_i = y_i^* = \beta' x_i + \varepsilon_i$

For complex trip workers, it is presumed that individual's spatial orientation is highly influenced by their work location, which is represented by their I_H . The length of I_H then will influence the spread of their non-obligations activities (I_C). The specific functional forms for complex trip workers are:

$$I_{H_w} = \begin{cases} I_{H_w}^* = \beta_{I_{H_w}}' X_{I_{H_w}}, & \text{if } I_{H_w}^* > 0 \\ 0, & \text{if } I_{H_w}^* \leq 0 \end{cases} \tag{3}$$

$$I_{C_w} = \begin{cases} I_{C_w}^* = \hat{I}_{H_w} (\beta_{I_{C_w}}' X_{I_{C_w}}), & \text{if } I_{C_w}^* > 0 \\ 0, & \text{if } I_{C_w}^* \leq 0 \end{cases}$$

As for non-workers, as discussed earlier, since they do not have fixed obligatory locations they have flexibility to decide their I_H and I_C simultaneously. Therefore, it is assumed that the distance of the activity centroid from home (I_H) is influenced by the spread of activity locations (I_C) and simultaneously, the I_C value is influenced by I_H . The specific functional forms for complex trip non-workers are:

$$I_{H_{NW}} = \begin{cases} I_{H_{NW}}^* = \beta_{I_{H_{NW}}} (X_{I_{H_{NW}}} + I_{C_{NW}}), & \text{if } I_{H_{NW}}^* > 0 \\ 0, & \text{if } I_{H_{NW}}^* \leq 0 \end{cases} \tag{4}$$

$$I_{C_{NW}} = \begin{cases} I_{C_{NW}}^* = \beta_{I_{C_{NW}}} (X_{I_{C_{NW}}} + \hat{I}_{H_{NW}}), & \text{if } I_{C_{NW}}^* > 0 \\ 0, & \text{if } I_{C_{NW}}^* \leq 0 \end{cases}$$

All models in this study are estimated by LIMDEP version 8.0, econometric software by Econometric Software, Inc.

2.3 Behavioral Hypotheses

The primary objective of this study has been to determine long-term trends in urban residents'

action spaces and also explore the factors that influence the extension of action space. To this end, testable hypotheses are formulated in this section and presented along with the hypotheses on I_H and I_C postulated earlier in this paper. Using household travel survey data from the Osaka metropolitan area, it has been shown that the individual's travel and activity engagement have been increasing over time (Kitamura and Susilo, 2005). The following hypothesis then follows:

H_1 : The individual's action space has been expanding over time.

The dense and well developed transit networks provide superb accessibility to opportunities around transit terminals to transit users in the Osaka metropolitan area. Hence,

H_2 : Transit users in the Osaka metropolitan area have more extensive action spaces than auto users.

H_3 : The fast line-haul service offered by rail, combined with slow local movement on foot around rail stations, tends to produce a large I_H and small I_C for transit users.

An individual's activity engagement is influenced by the accessibility provided by the transportation networks in the urban area and also by the time available for activity and travel; his action space is positively influenced by accessibility and time availability. This leads to the following hypothesis for workers, which is related to H_3 above:

H_4 : A worker's I_H is determined primarily by his commute distance, and I_C by time availability, which is determined by the work duration and commute trip duration, and accessibility at the workplace.

Since an individual's action space is primarily defined by the residential and obligatory-activity locations, a worker, whether with a simple pattern or complex pattern, tends to have a more stable action space than a non-worker. Then, collectively one would expect:

H_5 : Worker's I_H and I_C are more stable over time compared with those of non-workers.

Finally, on the relationship between I_H and I_C ,

H_6 : I_H and I_C are negatively associated with each other.

3. STUDY AREA CHARACTERISTICS AND THE DATA

The Osaka metropolitan area is Japan's second largest after the Tokyo metropolis, with three core cities of Osaka, Kyoto, and Kobe. With a population totaling about 20 million as of 2000,¹ it is one of the largest metropolitan areas in the world. The area has very dense, mixed-use land developments, and has well-developed rail networks. At the metropolitan level, the residential population has steadily increased through 2000, although the rate of growth has visibly declined. Fukui (2003) shows how the residential population in the Osaka metropolitan area has decentralized; the number of younger residents has been increasing in the suburbs, while the populations are aging in older neighborhoods closer to the nuclei of the metropolis. Kitamura et al. (2003) note the average number of vehicles per household in the Osaka metropolitan area increased from 0.41 in 1970 to 0.66 in 1980, 0.88 in 1990, and to 0.97 in 2000. The area, which is densely populated and well-served by public transit, has had a lower rate of vehicle ownership than the nationwide average, which was 1.12 vehicles per household in 2000. The older parts of the metropolitan area, including commercial centers and mixed commercial and residential areas, have very slow rates of motorization. Newly developed suburbs in general show higher levels and faster growth rates of vehicle ownership. On the other hand, mode use has practically unchanged in commercial areas, and the fraction

¹ Source: Japanese Statistic Bureau, Ministry of Internal Affairs and Communications

of auto trips has increased only slightly in old suburbs. Similar tendencies are found with mixed commercial/residential areas. An increase in the fraction of auto trips and a decline in the share of public transit trips are noticeable in new suburbs, and the auto trips are starting to dominate in urbanizing areas. For more comprehensive discussion about changes in the Osaka Metropolitan Area, see Fukui (2003), Kitamura et al. (2003) and Kitamura and Susilo (2005).

3.1 Data used in the analysis

The data used was obtained from conventional large-scale household travel surveys that were conducted in the Osaka metropolitan area of Japan in 1970, 1980, 1990 and 2000, with sampling rates of 2.4–3.0%. For this longitudinal analysis, the Osaka metropolitan area person trip datasets for the years 1980, 1990, and 2000 were used. The 1970 data is excluded due to the unavailability of accessibility indices and also due to the comparability of the collected data over the observed period, for the subsequent analyses. Scrutinizing the data collection method and observed values of the variables, the previous studies on this dataset (e.g. Fukui, 2003) have confirmed that the data between 1980 and 2000 are comparable. The dataset contains the socio-demographic characteristics of the observed respondents, including children, as well as their household characteristics. Information on children under the age of 15 years is entered by a responsible adult. The data also include the duration, purpose and number of activities and trip engagements of the observed respondents on the observed day and the chosen mode, as well as home and work locations (zone) of the observed individual. To support our study, these datasets have been supplemented with land use and network data from Fukui (2003) and Susilo and Kitamura (2008).

3.2 Analyzed samples

Because the size of the datasets is enormous, the analyzed samples are drawn from the original data files randomly at the rate of approximately 10%. In order to eliminate extreme second moment values that are difficult to analyze meaningfully, the analysis only includes trip makers whose trips on the survey day are all contained inside the study area. Individuals who did not make a trip at all or made trips to outside the study area are excluded from the analysis. The number of used samples for 1980, 1990 and 2000 are 14685, 15191, and 14444, respectively.

The analysis focuses on working-age adult individuals, who are grouped into workers and non-workers. Children, students and individuals over 65 years old are excluded from the analysis. Workers here refer to those individuals who made at least one work trip on the survey day; those employed who did not make a work trip on a given day are excluded here. The number of cars per adult household member, the driving license ownership and the accessibility indices have been steadily increased from 1980 to 2000. On the other hand, the presence of a dependent child has continuously decreased from 1980 to 2000. The trip and activity engagement rates of the sample workers are shown in Table 1.

In the household travel survey, the respondent's activity locations are recorded using a geographical zone system, which is rather coarse in this study area. Second moments of activity locations are computed in this study using the coordinates of the centroids of the zones to which activity locations belong. This of course is an approximation and a more precise evaluation of second moments would have been possible had activity locations been geo-coded using a coordinate system. Using the zone system creates a problem that many activity locations lie in the same zone as the respondent's zone of residence. In this case it is difficult to determine I_H or I_C based on the information available in the data set. Although the

trip length can be estimated based on the reported duration of the trip and the travel mode used, this will not offer sufficient information on activity locations to determine I_H and I_C . Consequently, I_C is set equal to 0 when a respondent's activity locations all lie in the same zone as the centroid of his activity locations, and I_H and I_C are both set to zero when all the activity locations lie within his residence zone. In other words, a null I_C indicates that all activity locations fall within the same zone, and a null I_H indicates that all activity locations fall in the residence zone of the respondent. In order to account for this deficiency, those respondents with a zero I_H or I_C form their own categories in the analysis presented below.

Table 1. Activity and Activity Engagement of All Samples in the Osaka Metropolitan Area

	1980	1990	2000
Total number of trips per day, per capita	2.55	2.50	2.62
Total number of activity locations per day, per capita	1.35	1.39	1.49
Percent of simple-trip makers	72.5%	73.8%	68.3%
Average fraction of car trips per day	0.26	0.34	0.37
Average fraction of transit trips per day	0.28	0.28	0.26
Average fraction of non-motorized trips per day	0.46	0.38	0.37
Average I_H	73.38	86.65	106.96
Average I_C	1.01	1.37	2.21
Percent of workers whose activity centroids were outside the home zones ($I_H > 0$)	44.7%	49.3%	52.6%
Percent of workers who pursued activities in multiple zones ($I_C > 0$)	2.54%	2.52%	3.48%
Percent of individuals who made commute trips (workers)	65.5%	69.2%	65.7%
The average commute distance (km)	6.14	6.81	7.75

Table 1 shows that residents of the Osaka metropolitan area have expanded their travel and action space in the last 20 years. The number of trips and the number of activity locations per day increased and the fraction of simple-trip makers decreased from 1980 to 2000. Other indices of travel—the fraction of individuals who traveled outside the residence zone, the fraction of travelers who pursued activities in multiple zones, and second moment values—indicate expansion of travel. In particular, the total second moment has increased by 48% between 1980 and 2000. It can also be seen that the fraction of trips by auto has steadily increased, and that of non-motorized trips has decreased over the two decades.

The increase in I_H implies that workers in the Osaka metropolitan area have been engaging in activities at locations that are increasingly farther from home. Likewise the increase in I_C shows that they have been pursuing activities at increasingly dispersed locations. Consistent with this, the fraction of those respondents who engaged in activities outside their residence zone is increasing, and so are those who pursued activities in multiple zones. Note that the increases in second moments are not simply due to the increased number of activities. The number of activities increased only by 10.4% from 1.35 in 1980 to 1.49 in 2000, while I_H increased by 45.8% and I_C by 119% in the same period. From 1980 to 2000, although the number of commuters tends to be steady, the commute distance has increased by 26%.

4. THE OVERTIME CHANGES OF THE I_H AND I_C VALUES

The descriptive statistics of second moments are shown in Table 2 by work status and residence area type². It shows that both I_H and I_C have steadily increased from 1980 to 2000,

² The urban area classifications that are adopted in this study are based on the urban area classification scheme by Fukui (2003): *Highly commercial areas* (highest densities of commercial development and a higher daytime

for both workers and non-workers, and simple-trip makers (for whom $I_C \equiv 0$) and complex-trip makers. Likewise the fraction of individuals who engaged in activities outside of their residence zones and the fraction of those who engaged in activities in multiple zones steadily increased. The average I_H and I_C indicate that workers' action spaces are more expansive than non-workers', for both simple-trip makers and complex-trip makers. Average I_H for workers with simple trips increased from 117.2 in 1980 to 162.8 in 2000; corresponding values for non-workers are 16.9 and 30.5. For workers with complex trips, I_H increased from 76.5 to 101.6 and I_C from 4.7 to 9.0. Corresponding values for non-workers are 24.3 and 38.8 for I_H and 1.6 and 3.7 for I_C . Importantly, workers with complex trips have smaller I_H than workers with simple trips. A longer commute does appear to inhibit non-work activity engagement; it consumes time resource and diminishes the time available for non-work activity engagement more than it affords activity engagement by providing access to more opportunities. Non-worker's second moments, on the other hand, suggest that those who travel farther to an opportunity tend to engage in multiple activities; for non-workers, who are subjected to lesser degrees of time constraints than workers, the enabling effect of farther opportunities dominates.

On average, residents of suburbs and un-urbanized area have the most expansive, and those of mixed commercial-residential area have the least expansive action spaces. Consistent with the definition, those residing in autonomous area have smaller rates of activity engagement outside their residence zones. The high accessibility to opportunities, on the other hand, seems to prompt residents of mixed commercial-residential area to engage in activities outside their residence zones

Driver's license holding also almost doubles the values of the second moments. Car availability, on the other hand, does not exhibit as predominant effects (not shown in the table). This may be in part due to the fact that a driver's license holder does not always use the private car in their daily travel; 42.2%, 43.2% and 46.5 % of driver's license holders did not choose private car as their travel mode in 1980, 1990, and 2000, respectively. Furthermore, private car users do not have more expansive action spaces than users of other modes, although their average I_C is larger when they exclusively use private car. Indeed those who use public transit heavily have larger I_H values than private car users, while their I_C values are approximately the same. Individuals who used transit exclusively on a given day have I_H values two to three times larger than individuals who used private car exclusively. These results in part reflect the well-developed railway networks in the study area with high speed rail operation. Interestingly, Individuals with complex trips who used transit for all their trips had widespread activity locations with larger rates of activity engagement outside their residence zones and engagement in multiple zones.

Mixed users of transit and other modes (non-motorized or private car) have action spaces that are substantially more extensive. This is another piece of empirical evidence in addition to that presented is Susilo and Kitamura (2008) which shows the common belief that public transit is not suited for trip chaining does not apply in the Osaka metropolitan area. Dense and well developed transit networks in the Osaka metropolitan areas allow transit users to reach remote locations conveniently while at the same time, they are still able to access

population compared to the nighttime population), *Mixed commercial areas* (a high density of commercial development, though not as high as a commercial area and have residential development as well, often of a high density. Less distinction between day and night populations), *Mixed residential areas* (do not have sufficient work for the population, most residents commute elsewhere. Have a larger night-time than day-time population), *Autonomous areas* (roughly an equal amount of residential and commercial development, allows residents to live and work within the area. No difference in day/night population), *Undeveloped (rural) areas* (low density commercial and residential development. Often represent smaller farming communities).

abundant opportunities surrounding transit terminals. These conditions allow transit users to have more extensive action spaces than users of other modes.

Table 2. Individual Action Space Indices based on Employment and Residential Areas

Employment Status and Residential Area		Simple Trip Makers ³			Complex Trip Makers ⁴		
		1980	1990	2000	1980	1990	2000
Worker ⁵	I_H	117.2	123.5	162.8	76.5	89.5	101.6
	I_C	0.0	0.0	0.0	4.7	6.7	9.0
	N	69,814	80,439	69,640	26,151	24,178	24,322
Non-worker	I_H	16.9	22.2	30.5	24.3	30.6	38.8
	I_C	0.0	0.0	0.0	1.6	2.6	3.7
	N	32,071	27,203	23,154	12,868	13,643	18,065
Highly Commercial	I_H	49.74	56.74	73.85	30.51	39.98	44.16
	I_C	0.00	0.00	0.00	3.51	6.16	7.62
	N	1,950	2,770	2,358	842	1,155	1,287
Mixed Commercial	I_H	44.78	49.29	71.98	32.75	32.51	42.53
	I_C	0.00	0.00	0.00	4.18	4.65	6.86
	N	20,796	24,648	25,400	8,383	9,457	12,441
Autonomous Areas	I_H	51.99	71.31	86.17	30.79	38.99	49.78
	I_C	0.00	0.00	0.00	1.76	3.55	5.35
	N	13,467	15,843	8,368	5,549	5,484	3,698
Mixed Residential	I_H	102.58	120.09	155.35	74.42	88.80	90.65
	I_C	0.00	0.00	0.00	3.93	5.84	7.01
	N	67,879	68,469	61,310	24,943	23,932	29,246
Undeveloped (rural) Area	I_H	112.92	129.47	151.00	54.01	90.48	87.62
	I_C	0.00	0.00	0.00	4.78	13.85	11.23
	N	2,022	430	901	934	114	380
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

5. TOBIT MODEL ESTIMATION RESULTS

Tobit models of I_H and I_C are estimated for workers and non-workers. Results for individuals with simple trips are shown in Table 3 and those for individuals with complex trips in Table 4. Salient results are summarized below.

5.1 Simple-Trip Makers

The result on table 3 shows that workers with simple trips in autonomous area tend to have smaller I_H values presumably he tends to engage commute within the residence zone. On the other hand, those in highly and mixed commercial areas tend to have larger I_H values. The results also show that for workers, the impacts of residential area are weakening overtime whilst the impacts of commute distance to the I_H values are increasing. This is in-line with Susilo and Maat (2007) study in the Netherlands who found that the direct access to activities

³ Simple trip maker is individual who only make two trips/day with one out-of-home activity location. His or her $I_C = 0$ and total second moment value = I_H .

⁴ Complex trip maker is individual who make more than two trips/day with more than one out-of-home activity location. His or her total second moment value = $I_H + I_C$.

⁵ Worker defined as an individual who made at least one work trip on a given day. Worker sample that did not made work trip on a given day are excluded.

locations has weakening the impacts of opportunities at immediate surroundings.

Table 3 also shows that the involvement of non-motorized trips in a non-worker's daily travel negatively affects I_H , while the use of public transit contributes to activity engagement outside the residence zone as well as the value of I_H . Evidently the transit system in the Osaka metropolitan area allows transit travelers to reach farther activity locations opportunities and contributes to an extended action space than does the private car.

Although coefficient estimates are not consistently significant and indications tend to be weak, the results also suggest that non-workers' action spaces vary depending on residence zone type. Finally, for this group of non-workers with simple trips, males tend to larger I_H values than their female counterparts.

5.2 Complex-Trip Makers

Since a worker's action space is delineated by residence and work locations, commute distance has a predominance influence on I_H , which is consistent with the postulated H_4 . Moreover, since the amount of time available for out-of-home activity and travel is more tightly bounded for a worker, a larger commute distance reduces the spread of activity locations and negatively influences I_C . These relationships are confirmed by the Tobit models of I_H and I_C . The result indicates that the constraining effect of commuting is more dominant than its enabling effect; a longer commute takes away time resources more than it provides access to more potential opportunities. A male worker's activity locations, including the workplace, tend to be located farther from home, but are not more dispersed than those of his female counterpart (see Table 4).

As for non-worker, his/her I_H is positive associated with his/her I_C ; the farther a non-worker travels from home, the more dispersed the activity locations will be. The travellers' activity engagement is positively correlated with the distance traveled from home. The result is not consistent with H_6 postulated earlier for non-workers. It also supports the hypothesis of Dijst and Vidakovic (2000) that "given the length of the available interval, individuals try to maximize their reach by increasing travel time given acceptable durations of visit[s]".

Higher residential accessibility to population as well as to the metropolitan center provides workers with more activity opportunities and increases the spread of activity locations, especially for mixed area workers (Table 4b). On the contrary, the residential accessibilities to the population center negatively affect the spread of non-workers' activity locations (see Table 5). Closer distance to the population centers and metropolitan center makes the residential area denser and more opportunities are available. This will allow the non-workers to have more engagement inside residential areas and make their activity locations less spread.

For both workers and non-workers, non-motorized trips tend to make the centroid of activity locations closer to the residence zone and reduce the spread of activity locations. On the contrary, transit trips contribute to a more extensive action space with a longer distance to the activity centroid and more dispersed activity locations. This is presumably due to the high speed of travel offered by railways and the superb access to opportunities provided by transit terminals. This is consistent with postulated H_2 but not H_3 .

Work duration, commuting by auto as well as auto availability do not show consistent signs and are not always significant at the three time points. For individuals with either complex or simple trips, person and household demographic and socioeconomics variables are relatively insignificant; these factors are not primary determinants of the spatial expansion of urban residents' action spaces.

Table 3. Tobit Model for I_H Values of Simple Trip Workers and Non-Workers

Explanatory Variables	Worker						Non-worker					
	1980		1990		2000		1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-255.48	-7.17	-229.13	-5.67	-290.86	-9.39	-359.97	-3.78	-98.41	-0.54	-191.01	-1.47
Male [D]	8.43	0.83	22.38	3.8	17.19	2.61	72.68	2.13	23.32	0.57	131.79	3.58
20 - 24 Years Old [D]	12.3	0.74	-13.33	-1.43	-11.97	-1.04	69.44	1.7	-14.65	-0.27	-132.33	-1.53
25 - 34 Years Old [D]	12.77	0.85	-11.28	-1.32	-7	-0.78	30.33	1.16	-74.47	-2.21	-25.88	-0.65
35 - 44 Years Old [D]	30.25	1.9	-5.41	-0.62	-5.45	-0.54	15.63	0.54	45.93	1.4	-53.93	-1.22
45 - 54 Years Old [D]	18.44	1.19	-4.36	-0.52	-9.36	-1	30.13	1.13	49.38	1.76	-75.35	-2.16
Number of Household Members	-3.18	-0.93	0.65	0.3	-2.35	-0.93	10.13	1.33	2.39	0.25	7.02	0.57
Parent with Dependent Child [D]	-6.15	-0.58	-12.48	-1.92	1.39	0.18	-8.9	-0.41	-45.84	-1.6	-84.52	-2.19
Number of Cars per Adult Household Member	-18.15	-1.34	-5.73	-0.65	-8.56	-0.81	-21.77	-0.83	21.82	0.62	116.57	2.48
Driver's License Holding [D]	-14.82	-1.43	2.32	0.34	1.76	0.2	22.31	1.05	35.89	1.53	-12.22	-0.39
Resides in Commercial Area [D]	115.61	2.83	28.41	0.83	118.53	3.8	229.35	2.32	-193.36	-1.19	75.12	0.53
Resides in Mixed Commercial/Residential Area [D]	132.13	4.16	-10.23	-0.33	72.86	2.7	153.01	1.71	-206.6	-1.36	38.99	0.33
Resides in Autonomous Area [D]	-64.95	-2.17	-65.2	-2.12	-28.4	-1.02	29.85	0.34	-326.58	-2.15	-82.77	-0.67
Resides in Suburbs Area [D]	43.64	1.52	-71.91	-2.38	-0.8	-0.03	107.24	1.26	-222.27	-1.49	23.16	0.21
Residence Zone Accessibility to Population	19.74	4.69	2.28	0.47	-4.32	-3.93	6.6	0.79	12.33	0.67	-11.67	-2.43
Work Zone Accessibility to Population	-42.47	-68.23	-0.81	-0.26	0.02	0.56						
One-way Commute Distance	42.51	74.55	36.75	101.65	40.16	110.5						
Distance to Metropolitan Center	0.01	0.2	0.84	3.43	0.56	2.5	0.18	1.57	0.89	0.89	-1.19	-1.16
Fraction of Transit Trips in Given Day Trips Pattern	-0.24	-0.02	8.36	1.3	-4.76	-0.67	152.64	5.61	284.74	9.92	321.65	8.67
Fraction of Non-motorized Trips in Given Day Trips Pattern	-140.76	-9.02	-45.84	-4.61	-30.49	-2.8	-257.63	-9.5	-272.13	-9.68	-357.43	-10.48
σ	269.4	92.64	175.81	102.34	198.37	99.49	248.23	26.85	302.06	28.14	389.91	29.53
N	6987		7987		7082		3196		2707		2284	
LM test [df] for tobit	5969.130[20]		6007.019[20]		5986.355[20]		149.948[18]		258.604[18]		379.300[18]	
L (β)	-28998		-32256		-30910		-3472		-3717		-4036	

Table 4. Tobit Model for I_H and I_C Values of Complex Trip Workers

a. I_H Values

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-185.83	-5.76	-60.74	-0.80	-300.56	-6.01
Male [D]	45.60	5.11	28.90	3.38	14.29	1.26
Resides in Highly Commercial Area [D]	126.56	2.97	-35.56	-0.51	153.02	2.81
Resides in Mixed Commercial Area [D]	82.23	2.34	-71.90	-1.10	135.97	2.80
Resides in Autonomous Area [D]	-19.77	-0.59	-109.55	-1.69	-27.32	-0.53
Resides in Mixed Residential Area [D]	53.67	1.64	-75.17	-1.17	51.40	1.11
Residence Zone Accessibility to Population	19.04	4.45	-18.33	-2.03	-3.01	-1.39
Zone Accessibility to Population	-26.56	-40.51	18.18	2.71	0.14	1.99
Work One-way Commute Distance	26.63	42.05	25.91	35.96	35.94	49.67
Distance to Metropolitan Center	0.03	0.89	-0.09	-0.20	1.33	3.04
Fraction of Transit Trips in Given Day Trips Pattern	75.56	5.12	23.58	1.62	-12.73	-0.67
Fraction of Non-Motorized Trips in Given Day Trips Pattern	-76.85	-6.06	-77.77	-5.97	-67.20	-3.97
σ	171.01	51.98	170.12	52.87	219.99	53.49
N	2681		2456		2347	
LM test [df] for tobit	1138.424[12]		1353.977[12]		1916.534[12]	
L (β)	-9176		-9297		-9548	

b. I_C Values

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-242.37	-17.01	-255.64	-16.54	-221.66	-17.00
Male [D]	-0.154	-2.64	-0.100	-1.65	-0.0002	-0.01
20 - 24 Years Old [D]	-0.327	-3.03	0.036	0.35	0.062	0.73
25 - 34 Years Old [D]	-0.258	-3.01	-0.019	-0.21	-0.003	-0.06
35 - 44 Years Old [D]	-0.225	-2.30	0.080	0.86	0.046	0.76
45 - 54 Years Old [D]	-0.231	-2.35	-0.136	-1.34	0.013	0.22
Number of Household Members	0.021	1.00	0.011	0.41	0.024	1.58
Parent with Dependent Child [D]	-0.011	-0.15	-0.028	-0.37	-0.042	-0.80
Number of Cars per Adult Household Member	-0.064	-0.84	0.216	2.32	0.012	0.18
Resides in Highly Commercial Area [D]	0.217	1.33	0.498	1.31	0.008	0.07
Resides in Mixed Commercial Area [D]	0.556	4.09	0.622	2.03	0.084	0.93
Resides in Autonomous Area [D]	0.124	0.69	0.361	1.20	0.025	0.21
Resides in Mixed Residential Area [D]	0.377	3.04	0.293	1.00	-0.081	-0.96
Residence Zone Accessibility to Population	0.070	2.68	0.096	2.01	0.010	1.62
Work Zone Accessibility to Population	0.041	1.94	0.015	0.52	0.006	0.83
One-way Commute Distance	-0.020	-6.57	-0.031	-5.82	-0.017	-6.19
Distance to Metropolitan Center	0.006	3.78	0.003	0.96	0.003	2.49
Fraction of Transit Trips in Given Day Trips Pattern	0.256	2.41	0.079	0.70	0.210	2.26
Fraction of Non-Motorized Trips in Given Day Trips Pattern	-0.908	-6.72	-1.177	-8.00	-0.640	-5.68
Commute with Car [D]	0.267	2.78	0.054	0.55	-0.019	-0.23
Work Duration [minutes]	-0.0001	-0.59	0.0001	0.89	0.0005	4.18
Number of Work Trips	0.139	3.53	0.208	5.46	0.156	5.47
σ	132.13	20.82	141.73	21.35	140.58	21.82
N	2681		2456		2347	
LM test [df] for tobit	169.083[22]		125.073[22]		110.427[22]	
L (β)	-2072		-2242		-2353	

Table 5. Tobit Model for I_H and I_C Values of Complex Non-Workers

Explanatory Variables	I_H						I_C					
	1980		1990		2000		1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-35.54	-0.46	-332.81	-2.03	25.24	0.39	-386.39	-0.06	-131.19	-1.37	-548.28	-7.54
Male [D]	57.42	1.7	47.85	1.05	15.86	0.71	-56.63	-1.63	-59.29	-2.08	12.01	0.49
20 - 24 Years Old [D]	-20.23	-0.51	-100.65	-1.45	6.45	0.16	66.1	2.1	64.37	1.67	-52.4	-0.95
25 - 34 Years Old [D]	-7.36	-0.33	-26.87	-0.84	-1.04	-0.04	42.81	1.64	15.89	0.79	-18.88	-0.68
35 - 44 Years Old [D]	-0.48	-0.02	7.98	0.23	41.09	1.65	46.48	1.66	-9.28	-0.41	-84.86	-2.81
45 - 54 Years Old [D]	-2.35	-0.1	17.33	0.55	22.65	1.16	50.01	1.92	-24.87	-1.22	-52.39	-2.32
Number of Household Members	20.19	3.21	-9.6	-0.98	-0.44	-0.07	-10.12	-1.69	4.98	0.76	12.94	1.69
Parent with Dependent Child [D]	-20.77	-1.18	-33.92	-1.23	-47.03	-2.21	-0.82	-0.05	20.1	1.12	41.8	1.62
Number of Cars per Adult Household Member	-32.05	-1.5	10.73	0.3	-13.25	-0.53	41.36	2.21	-24.2	-1.02	31.51	1.04
Driver's License Holding [D]	29.46	1.83	-23.86	-1	-12.42	-0.74	-14.95	-1.06	12.2	0.82	11	0.53
Resides in Highly Commercial Area [D]	-37.5	-0.45	-135.73	-0.98	-63.08	-0.9	-86.73	-0.01	66.86	0.88	150.45	2.15
Resides in Mixed Commercial Area [D]	-32.98	-0.45	-42.74	-0.34	-15.54	-0.27	302.63	0.05	18.55	0.29	13.78	0.23
Resides in Autonomous Area [D]	-119.84	-1.65	-111.24	-0.9	-127.4	-2.08	305.42	0.05	51.16	0.81	121.02	1.84
Resides in Mixed Residential Area [D]	-61.64	-0.88	-25.67	-0.21	-25.6	-0.46	309.84	0.05	-9.29	-0.15	8.88	0.16
Residence Zone Accessibility to Population	-2.8	-0.44	70.31	3.71	-7.58	-2.72	-16.5	-2.83	-23.93	-1.86	12	3.7
Distance to Metropolitan Center	-0.01	-0.17	3.56	3.69	0.38	0.76	-1.56	-7.61	-1.9	-2.77	-0.82	-1.35
Fraction of Transit Trips in Given Day Trips Pattern	212.16	7.87	244.78	6.44	286.98	10.56	-84.55	-2.87	-252.59	-6.41	-570.57	-11.15
Fraction of Non-Motorized Trips in Given Day Trips Pattern	-140.25	-6.11	-281.83	-9.15	-177.84	-9.13	-11.34	-0.53	13.56	0.56	52.42	1.83
Spreadness of Activity Locations (\bar{I}_C)	0.7	2.26	0.7	2.18	0.27	3.26						
Activity Centroid Distance from Home Location (\bar{I}_H)							1.5	7.52	2.12	9.45	4.19	16.86
σ	153.6	23.26	251.07	25.39	208.61	31.8	61.44	8.7	84.81	9.77	143.78	13.41
N	1267		1351		1711		1267		1351		1711	
LM test [df] for tobit	145.755[19]		306.486[19]		346.275[19]		71.808[19]		55.483[19]		97.458[19]	
L (β)	-2389		-2848		-4382		-331		-468		-888	

6. THE STABILITY AND THE CHANGES IN ACTION SPACE

Stability of urban residents' action spaces over time is examined in this section using the Tobit models estimated above. The following four methods are used:

1. testing the hypothesis that the model coefficients have not changed over the years as by applying likelihood ratio test,
2. testing the hypothesis that the model coefficients have not changed over the years by applying pair-wise comparison
3. predicting the values of the endogenous variables using the coefficient estimates from 1980, 1990 and 2000, on data from 1980, 1990 and 2000, and
4. predicting the values of the endogenous variables on the data from 1980, 1990 and 2000, using the coefficient estimates from 1980, 1990, and 2000.

The first and second methods offer statistical indications of behavioral stability as represented by the model coefficients. The third method indicates structural change in the action space indices over time; it shows how I_H and I_C of an individual with certain attributes, living in a certain area and having a certain level of accessibility, have changed over time. The fourth method, on the other hand, indicates how changes in the characteristics of individuals have prompted changes in I_H and I_C (see Kitamura and Susilo, 2005, for more explanation of the methods).

Table 6. Stability of Action Space Indices for Simple and Complex Trip Makers

a. Stability of Simple Trip Makers

Year Data	Worker's I_H		Non-Worker's I_H	
	χ^2	Df	χ^2	df
1980 vs 1990	1011	20	53.9	18
1980 vs 2000	8789	20	132	18
1990 vs 2000	125	20	67.4	18
1980 vs 1990 vs 2000	12980	40	171	36

The critical values of χ^2 at $\alpha = 0.05$ is 28.9 (df = 18), 31.4 (df = 20), 51 (df = 36) and 55.8 (df = 40)

b. Stability of Complex Trip Makers

Year Data	Worker				Non-Worker			
	I_H		I_C		I_H		I_C	
	χ^2	Df	χ^2	df	χ^2	df	χ^2	df
1980 vs 1990	68.5	12	38.7	22	109	19	42	19
1980 vs 2000	3049	12	-	22	69.4	19	119	19
1990 vs 2000	178	12	51.1	22	50.2	19	65	19
1980 vs 1990 vs 2000	4215	24	-	44	139	38	189	38

The critical values of χ^2 at $\alpha = 0.05$ is 21 (df = 12), 30.1 (df=19), 33.9 (df = 22), 36.4 (df =24), 53.4 (df = 38) and 60.5 (df = 44)

- : because of the indices are calculated based on zones, I_C values are not performing well. No proper likelihood test value was obtained

The results of likelihood ratio tests (Table 6) indicate that the model coefficients are not stable between any pairs of years, prompting a conclusion that individuals' action spaces, as represented by I_H and I_C , have not been stable between 1980 and 2000 in the Osaka metropolitan area. Pair-wise tests of individual coefficients (not shown in here) also indicate that the models are not stable between any combinations of years for both simple and

complex trip makers, which are not consistent with postulated H₅.

To separate the effects of variations in coefficient vectors and those in explanatory variable values on the action space indices, the 1980, 1990 and 2000 mean explanatory variable values are input to the respective model to compute index values with the estimated 1980, 1990 and 2000 coefficient vectors. The results are summarized in Figure 2.

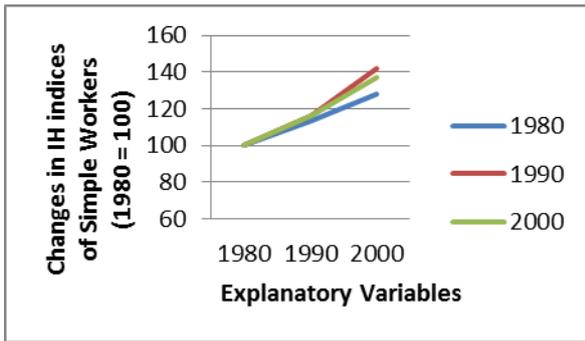
Section a, c, e, and g of Figure 2 show the impact of changes in mean explanatory variable values under the three coefficient vectors (1980, 1990 and 2000). In other words, it shows the impact of changes in the demographic, socio-economic and accessibility variables by themselves, without any changes in the structural relationships underlying I_H and I_C . Section b, d, and f of the Figure 2 show the impact of changes in coefficient vectors, i.e., it shows the impact of changes in the structural relationships, without any changes in the demographic, socio-economic and accessibility variables. The test results show that:

- All action space indices of both simple and complex trip makers have been continuously expanding between 1980 and 2000, which is consistent with postulated H₁.
- The simple workers' I_H has steadily increased from 1980 to 2000 by about 30 to 40% due to changes in mean explanatory variable values, under any of the three coefficient vectors. It may be inferred that changes in demographics, socio-economics and accessibility between 1980 and 2000 have by themselves induced about 30 to 40% increases in workers' commute distances. The simple non-workers' I_H tended to increase as well, but the patterns are not consistent.
- Non-workers' I_H steadily and substantially increased with structural changes. On the other hand, workers' I_H decreased in 1990 and increased slightly in 2000. Structural changes underlying commute distance produced contraction. Combined effects of the changes in demographics, socio-economics and accessibility and changes in structural relationships have produced the expansion of I_H shown in Figure 2c.
- As for complex trip makers, the changes of demographic, socio-economic and accessibilities indices between 1980 and 2000 have by themselves induced over 17 - 38% increase of I_H value of complex trip workers. However, the trends are not clear from the I_C indices, presumably caused by roughness of zoning system (based on districts or municipalities) that used in the data collection. Most of the sample does not engage in across-municipalities activity (only 12% among workers and 5% among non-workers who have $I_C > 0$ and 80% of non-worker travelers have $I_H = 0$). The intra zone trip as well as its expansion over period is imperceptible. However, the workers' I_C value as well as non-workers' indices still show an expansion trend.

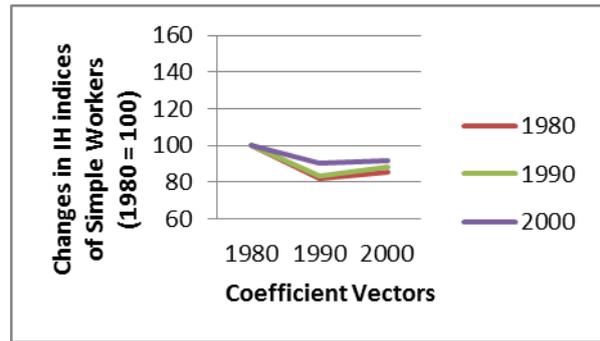
Overall, despite some unclear patterns due to the roughness of zoning system, the statistical analyses have showed that the changing of socio-economic and demographic conditions from 1980 to 2000, as well as the changing of actions space indices relationship themselves have encourage the individual to constantly expand their spatial movement in space.

7. CONCLUSION

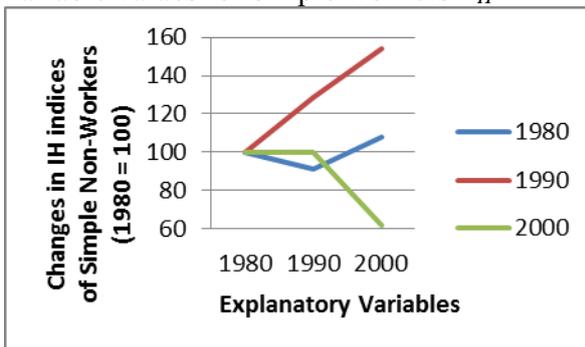
Using the results of household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, supplemented with demographic, land use, and network data, this study has attempted to examine how changes in the travel environment and demographic and socio-economic characteristics of the area have impacted area residents' action spaces over time. It shows that action space, as represented by the second moments about the residence zone of activity locations, has steadily expanded from 1980 to 2000, as well as the fraction of individuals who engage their activity to outside their residence zone.



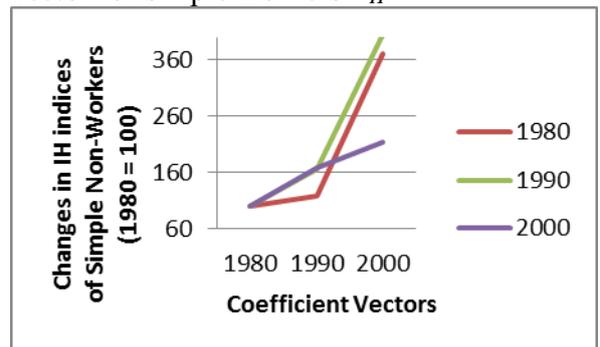
a. Changes due to changes in explanatory variable values for simple workers' I_H



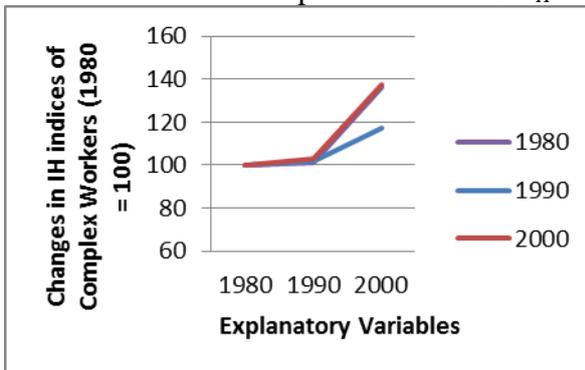
b. Changes due to changes in coefficient vector for simple workers' I_H



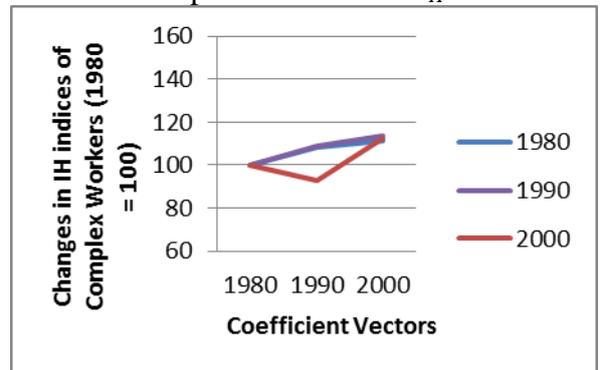
c. Changes due to changes in explanatory variable values for simple non-workers' I_H



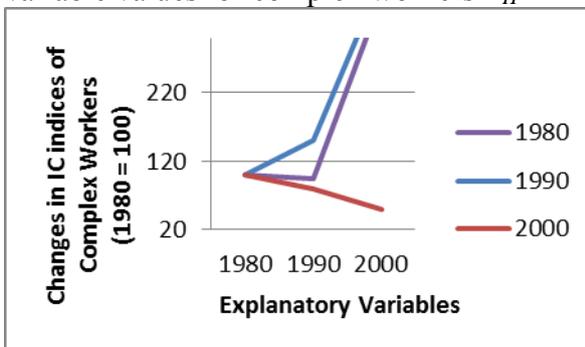
d. Changes due to changes in coefficient vector for simple non-workers' I_H



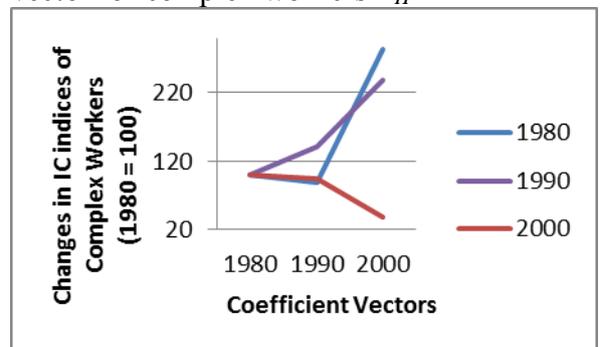
e. Changes due to changes in explanatory variable values for complex workers' I_H



f. Changes due to changes in coefficient vector for complex workers' I_H



g. Changes due to changes in explanatory variable values for complex workers' I_C



h. Changes due to changes in coefficient vector for complex workers' I_C

Figure 2. Action Space Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for both Simple and Complex Trip Makers

The statistical analysis has further shown that workers' commute distance negatively influences the spread of activity locations, while in case of non-workers, activity locations tend to be more dispersed when activities are pursued away from home. Overtime, male worker's activity locations, including the workplace, tend to be located farther from home, but are not more dispersed than those of his female counterpart. Further examination also shows that non-workers' action spaces evolve differently depending on their residence zone type. Due to the limitation of the data, whether the expansion has been contributing to the individual's welfare is hard to be answered accurately. However some previous studies (e.g. Axhausen, 2005) highlighted the likely impact of action space expansion with the growth of social network geographies over longer periods and, thus, also travellers' social capita.

The study also shows that the common belief that public transit is not suited for trip chaining does not apply to the study area where public transit provides superb access to numerous opportunities around transit terminals and stops. As a result, transit users tend to have more extensive action spaces as well as are more likely to chain trips. The results also show that for workers, the impacts of residential area in influencing action space indices are weakening overtime whilst the impacts of commute distance to the I_H values are increasing. This highlights the benefits but also the dangerous of providing (too) high accessibility to distance activity locations in undermining the policy encourages individual to work and live locally by providing a mixed commercial/residential land use configuration.

It is also worth to be noted here that this study is only discuss the phenomenon until year 2000. Since then the socio-demographic of the society has continuously changing and so as the behaviour of the population. Recently there has been a sign of 'peak car' phenomenon in various developed countries where the younger generation starts to prioritise other travel modes than car. This will remains as one of possible the future directions of this study.

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REFERENCES

- Adiv, A, 1983, The structure of the work-trip based on analysis of trip diaries in the San Francisco Bay Area. In S. Carpenter and P. Jones (eds.) *Recent Advances in Travel Demand Analysis*, Gower Publishing, Aldershot, England, pp. 117-36.
- Axhausen, KW, 2005, Activity spaces, biographies, social networks and their welfare gains and externalities: Some hypotheses and empirical results, *Arbeitsbericht Verkehrs- und Raumplanung*, 290, IVT, ETH Zürich, Zürich.
- Cao, X, Mokhtarian, PL, Handy, SL, 2007, Do Changes in Neighborhood Characteristics Lead to Changes in Travel Behavior? A Structural Equations Modeling Approach. *Transportation*, 34 (5), 535-556
- Cullen I., V. Godson, 1975, Urban networks: the structure of activity patterns. *Progress in Planning*, 4 (1). 1 – 96.
- Dijst, M, 1999, Two-earner families and their action spaces: A case study of two Dutch communities, *GeoJournal*, 4(3), 195-206.
- Dijst, M., V. Vidakovic, 2000, Travel time ratio: The key factor of spatial research, *Transportation*, 27, 179-199.
- Dijst, M., V. Vidakovic, 1997, Individual action space in the city. In D.F. Ettema and H.J.P. Timmermans (eds) *Activity-based Approaches to Travel Analysis*, Pergamon

- Press, Oxford, pp. 117-134.
- Fujii, S, Kitamura, R, Kishizawa, K, 1999, An analysis of individuals' joint activity engagement using a model system of activity-travel behavior and time use. *Transportation Research Record*, 1676, 11-19.
- Fukui, K., 2003, Longitudinal Analysis of Travel Behavior Change Using Dynamic Urban Area Classification. MS thesis, Department of Civil Engineering Systems, Kyoto University, Kyoto, February (in Japanese).
- Golledge, R.G., R.J. Stimson, 1997, *Spatial Behavior*, The Guilford Press, New York and London.
- Horton, F.E., W.E. Wagner, 1969, A Markovian analysis of urban travel behavior: Pattern response by socioeconomic-occupational groups. *Highway Research Record*, 283, 19-29.
- Kei-Han-Shin Metropolitan Area Transportation Planning Commission (undated) Current State of Osaka Metropolitan Area as Indicated by Its Residents' Movement. Osaka.
- Kinki Regional Development Bureau's Websites (<http://www.kkr.mlit.go.jp>)
- Kitamura, R., Y.O. Susilo, 2005, Is travel demand insatiable? A study of changes in structural relationships underlying travel. *Transportmetrica*, 1(1), 23 - 45.
- Kitamura, R., Y.O. Susilo, K. Fukui, J. Murakami, K. Kishino, 2003, The invariants of travel behavior: the case of Kyoto-Osaka-Kobe metropolitan area of Japan, 1970-2000. Paper presented at the 10th Conference of the International Association for Travel Behaviour Research, Lucerne, August.
- McCray, T, N. Brais, 2007, Exploring the Role of Transportation in Fostering Social Exclusion: The Use of GIS to Support Qualitative Data. *Networks and Spatial Economics*, Vol. 7, pp. 397-412.
- Oster, C.V., 1979, The second role of the work trip: visiting non-work destination. *Transportation Research Record*, 728, 79-81.
- Pred, A., 1977, The choreography of existence: Comments on Hagerstrand's time-geography and its usefulness. *Economic Geography*, 53, 207-21.
- Schönfelder, S, K.W. Axhausen, 2002, On the variability of human activity spaces, *Arbeitsberichte Verkehr- und Raumplanung*, 151, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
- Schönfelder, S., K.W. Axhausen, 2003, Activity spaces: Measures of social exclusion?, *Transport Policy*, 10 (4), 273 - 286.
- Srivastava G., S. Schönfelder, 2003, On the temporal variation of human activity spaces, *Arbeitsberichte Verkehr- und Raumplanung*, 196, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
- Susilo, Y.O., M. Dijst, 2010, Behavioural decisions of travel-time ratio for work, maintenance and leisure activities in the Netherlands. *Journal of Transportation Planning and Technology*, Vol. 33, pp. 19 - 34.
- Susilo, Y.O., Kitamura, R, 2005, On an analysis of the day-to-day variability in the individual's action space: an exploration of the six-week Mobidrive travel diary data. *Transport Research Record*, 1902, 124 - 133.
- Susilo, Y.O., Kitamura, R, 2008, Structural changes in commuters' daily travel: The case of auto and transit commuters in the Osaka metropolitan area of Japan, 1980 through 2000. *Transportation Research A*, Vol. 42, pp. 95 - 115.
- Zahavi, Y, 1979, The UMOB Project report DOT-RSPA-DPB-20-79-3, US Department of Transportation, Washington, D.C.