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Modelling intra-household interactions in time-use and activity patterns of retired and dual-earner couples

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Abstract

The ageing population has become a global problem in which enhanced understanding on their activity-travel patterns is needed. In this paper, an analysis of retired and dual-earner couples is conducted to investigate how retirement would change their activity time use and patterns. In particular, intra-household interactions are considered, to explore the interdependencies among household members' choices, social-demographics and travel behaviours. Household survey data from Hong Kong are employed.

Results show that retirement would substantially increase joint participations and durations in various out-of-home activities. In addition, the importance of walkability is emphasised for retired couples in a mixed-land-use and transit-dependent city, and a potential social exclusion issue is identified for the low-income retired population. Scenarios analyses including changes of built environment and lifestyles (e.g., telecommuting, online shopping and food delivery) are conducted, to investigate how couples would reallocate the saved travel time. In summary, this paper highlights the importance of considering the group decision mechanism in a household for activity generation and travel demand forecasting. It sheds light on policies to improve quality-of-life for couples before and after the retirement.

Keywords: group decision, activity-based model, ageing population, walkability, online-to-offline services

1. Introduction

1.1. Motivation

The global ageing population is fast-increasing in size. In the United Nations (United Nations, Department of Economic and Social Affairs, Population Division 2013), the share of the population aged 60 years and over was approximately 12% in 2013, whereas in China, this number was greater than 10%

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(China statistical yearbook 2014) and is estimated to reach 30% by 2050 (Strauss et al. 2010). Investigation of the effects of ageing and retirement on activity-travel behaviours is necessary for planners to allocate resources to meet their activity and travel demand.

Since travel behaviours are derivatives of out-of-home activities, activity-based models (ABM) have attracted attention and have been developed for the older population (Habib & Hui 2017; Hahn et al. 2016a; Ravulaparthy et al. 2016), in which their choices of activity types, durations and timing have been studied. Generally, the retired population has more flexible time for discretionary activities without compulsory work tasks. Conversely, their ageing problems and reduced income can discourage them from out-of-home activities and travel behaviours, possibly causing the ”social exclusion” issue, which leads to possible mental and physical health problems for the older population (Ravulaparthy et al. 2016). As the comparison group, the working population is facing a ”time poverty” problem (Bernardo et al. 2015; Kato & Matsumoto 2009), in which they can be too busy to partake in discretionary activities or to spend quality time with their families. Thus, most of the worldwide working population might be experiencing a busy and unsatisfying lifestyle. Working/retirement status can largely change a person's daily activity. In addition, it is unclear how social-demographics and travel behaviours are related to activity patterns. This issue deserves substantial attention to allow the government to improve the quality-of-life for the major groups of the society.

Existing studies have shown that intra-household interaction affects individuals' choice behaviours. There are two seminal special issues on intra-household interaction published by Transportation (Bhat & Pendyala 2005) and in Transportation Research Part B (Timmermans & Zhang 2009). Insightful review papers are published in 2010s, where De Palma et al. (2014) thoroughly discussed the issues of family econometric models, group decision mechanism, and also location and accessibility, and Ho & Mulley (2015) focused more on the intra-household interaction and transportation. Evidences suggest that ignoring the mutual dependence of household members' decisions would induce biased estimation of activity demand. In addition, if an activity is jointly pursued, it also is likely that the related trip is jointly made, leading to different travel patterns in terms of destination, mode, and vehicle choice. Thus, intra-household interaction should be considered when modelling the activity-travel of older people.

Examining a couple's activity participation and time allocation, for example, as illustrated in Figure 1(left), they can choose solo participation for certain activities, e.g., a maintenance activity such as going to the bank or post office, which need to be undertaken only by one member in the household. In addition, household members can coordinate to partake in joint activities in which they enjoy each other's company, e.g., eating-out together in a fine restaurant. Moreover, this couple might prefer more and longer joint activities, which introduces correlation among joint activities. If such intra-household interaction is not

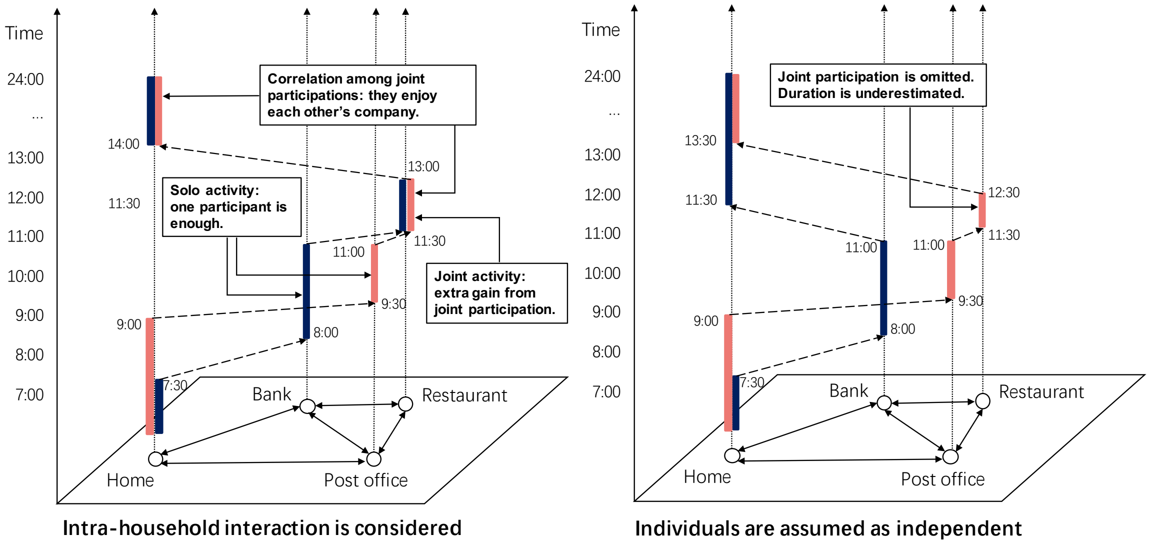

Figure 1: Intra-household interaction in a couple's joint activity participation and time allocation

considered, as illustrated in Figure 1(right), there might be biased estimation of demand forecasting.

This paper is motivated to investigate the intra-household interactions for the retired and working populations. In particular, to investigate how retirement affects intra-household interactions and the activity patterns and time use. A household-level time allocation model is developed, considering the discussed diverse intra-household interactions. The data from the 2011 Hong Kong Travel Characteristic Survey (TCS) are employed in the case study. Because a substantial number of older people lives alone without relatives and friends, retired couples from two-member households are studied and contrastively analysed with dual-earner couples. Based on calibrated models, scenario analyses including changes of built environment and lifestyles (e.g., telecommuting, online shopping and food delivery) are conducted, to investigate how different intra-household interactions cause retired and working couples to reallocate the saved travel time.

1.2. Current work in existing studies

1.2.1. Retired and dual-earner couple activity patterns

Table 1 summarises representative existing literature on retired and dual-couple activity patterns. The purpose of Table 1 is to show the research gap from an empirical analysis perspective, which motivates us for the research in this paper. Further discussion on methodologies and corresponding literature review are shown in the next section rather in Table 1.

There are four features of note in this paper, as summarised in Table 1. First, retired and working couples are contrastively analysed. Recently, several studies have been conducted to investigate the activity patterns of older people (Hahn et al. 2016a; Habib & Hui 2017), workers (Gupta & Vovsha 2013; De Palma et al. 2015) and whole populations (Gliebe & Koppelman 2005; Bhat et al. 2013; Lin & Wang 2014). However, enhanced understanding is required to investigate how retirement changes activity patterns. Though in retired households, the couples obtain more flexible time to schedule, ageing and decreased-income problems might discourage them from participating in out-of-home activities. Thus, a contrastive study should be conducted. As summarised in Table 1, the affecting variables for the workers' activities are working time, commuting time, income, age, and vehicle ownership; affecting variables for older people are economic status, age, health condition, and built environment.

Second, although the activity-based model has been developed and applied in various Western countries such as the USA (Bradley & Vovsha 2005; Bernardo et al. 2015), Australia (Ho & Mulley 2013), France (De Palma et al. 2015), and Canada (Habib 2015), it remains not fully explored in Asia. The built environments and social-demographics in Asia are very different from that of the West, particularly for those cities with high density and transit-oriented development in urban areas. Analysis of activity patterns of the older population in Hong Kong would shed light on the ageing problem in high-density Asian cities. Loo et al. (2017) investigated the neighbourhood environment related to the health of seniors living in Hong Kong, Singapore, and Tokyo, and they ascertained that the proper use of walking aids could allow seniors to be more active. Zhang & Fujiwara (2006) studied elderly people's activity time allocation in a depopulated region of Japan, in which individuals without a driving license are more sensitive to bus travel time. More studies are required to fully depict the activity patterns in Asia.

Third, although the intra-household interactions for activity-travel behaviours have been analysed for more than a decade (Bhat & Pendyala 2005; Timmermans & Zhang 2009; De Palma et al. 2014), examining the intra-household interactions for the older population is not sufficient. Zhang & Fujiwara (2006) investigated diverse group decision mechanisms in a household time allocation model, in which the elderly couples were employed to validate the model's practicality. In their paper, a substantial number of elderly people continued to work. Lai et al. (2018) studied the intra-household interactions in two-member households in Hong Kong, learning that retired people have the least bargaining weight in the group decision for a discrete activity choice. Investigation remains lacking on the interplay within a retired couple for time allocation in activity participation.

Table 1: Summary on the analysis on the retired and workers' activities

Related researches	Region		Activity				Population			Empirical findings related to the studied problems
	Western	Asian	AH*	D	Mai	Man	W	R	N	
Gliebe and Koppelman, 2005	USA					√			√	The retired value joint travel more than the working ones.
Ho and Mulley, 2013	Australia			√	√	√	√			More joint Mai and D activities on weekend.
Habib and Hui, 2017	Canada			√	√	√		√		Older people have less variety in activity-travel behaviours.
Habib et al., 2017	Canada			√	√	√		√		Lower income population is less active.
Zhang and Fujiwara, 2006		Japan	√		√			√		Travel time variation changes the elderly couple's activity.
Kato and Matsumoto, 2009		Japan	√	√			√			Age, income and job affect the leisure activity.
Lin and Wang, 2014		HK		√					√	Working people have fewer joint leisure activities.
Bradley and Vovsha, 2005	USA		√			√			√	Joint Man. has extra gain for working couples, and joint non-Man. has extra gain for retired couples.
Gupta and Vovsha, 2013	USA		√			√	√			Working couples synchronise their departure time for work to stay at home jointly for a longer time.
de Palma et al., 2015	France		√			√	√			
Bhat et al., 2013	USA			√	√	√			√	Senior have more out-of-home activities, while the long-working-time people have less.
Hahn et al., 2016		Korea		√		√		√		Gender, income, driver license and car ownership affects the trip making.
Ravulaparthy et al., 2016	USA			√	√	√		√		Gender, income, driver license and car ownership affects the trip making.
This paper		HK	√	√	√	√	√	√		The retired and working couples are contrastively studied to discover their differences from similarities.

* AH: at-home; D: discretionary; Mai: maintainance; Man: mandatory; W: workers; R: retired; N: not specific.

Fourth, at-home and out-of-home activities throughout the entire day are considered simultaneously. Most the existing studies only consider one or several out-of-home activities. For instance, Gliebe & Koppelman (2005) studied the work, education and discretionary tours in a household; Gupta & Vovsha (2013) analysed the synchronisation behaviours of a working couple's departure time for work in the morning. Ignorance of all-day activity participation and time allocation results in difficulties in understanding the trade-off in time use among different activities within a day. In this paper, the whole-day activities are analysed.

1.2.2. Activity-based models

Figure 2 presents existing models for activity modelling. The following discusses the three streams of modelling.

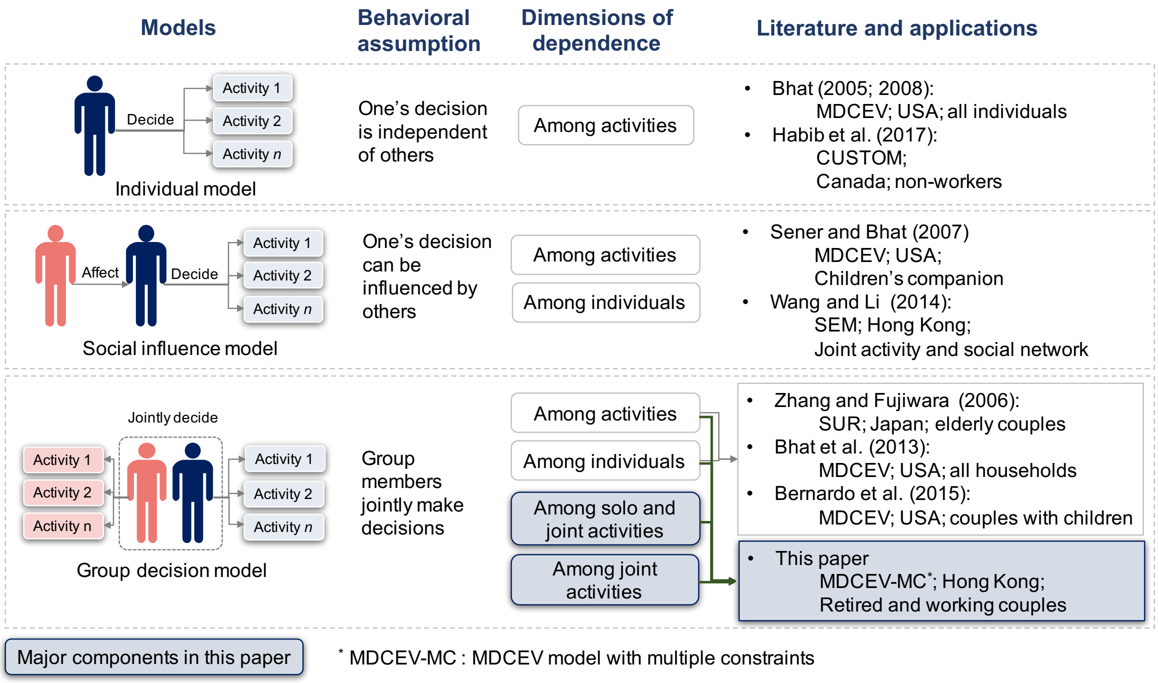

Figure 2: Existing models for activity modelling

The first stream is the individual model an underlying assumption that an individual's choice is independent of other decision makers. Bhat (2005; 2008) proposed a multiple discrete continuous extreme value (MDCEV) model in which activity duration is considered as a time allocation problem. In Habib & Hui (2017), the CUSTOM framework is proposed, which is a combination of a discrete choice model (to determine whether to participate) and a time duration regression model (to determine activity duration).

Individual models assume that decision makers are independent. As discussed in Walker et al. (2011), social influence is significant for individuals' decision making. Therefore, social influence on one's activity choice decision is considered in the second stream of models. For instance, based on a conventional MDCEV model, Sener & Bhat (2007) analysed children's activity with different companions in the USA. Lin & Wang (2014) studied how the social network influenced one's solo and joint discretionary activities in Hong Kong. A structural equation model (SEM) is used to model the interdependencies of activities.

Although the social influence model relaxes the restriction on the independence of decision makers, the individual remains considered the decision maker. Because household members' activities are mutually dependent, the third stream of models introduces the group decision mechanism in household activity modelling.

In the group decision model, household members are assumed to coordinate to maximise the utility of the household. For instance, the collective model (see, Chiappori (1988); Zhang & Fujiwara (2006); Kato & Matsumoto (2009)), in which household members are considered separate decision makers with bargaining weights, and they coordinate their time schedules to achieve the Pareto optimal of the household. Another group decision model, the unitary model, is also frequently employed. For example, the MDCEV model in Bhat et al. (2013) and Bernardo et al. (2015), in which the interaction process of household members is considered implicit, and the household is conceptualised as the decision maker, who allocates time for each activities for each member, to maximise the household's total benefit. In particular, Bhat et al. (2013) discussed the advantages of a household-level MDCEV model over a collective model specification, where the bargaining weights can be represented by the satiation parameters in the MDCEV model. It seems that the MDCEV model is a suitable approach to model the group decision mechanism in joint activity participation and time allocation.

However, there is one limitation in the household-level MDCEV model. Because only one decision maker (the household) is considered in the model, there is only one time constraint - the total available time of the household, which could be impractical when household members have different time constraints, e.g., workers with different working hours have different available time for discretionary activities. Ignoring this fact may cause possible biased outcomes. In this case, a MDCEV model with multiple constraints (MDCEV-MC) (Castro et al. 2012) would be more suitable. However, the model with multiple time constraints is not provided in Castro et al. (2012), neither the estimation method nor the forecasting algorithm. It is unclear how to model the household time allocation problem in the MDCEV-MC framework. More investigation is required.

1.2.3. Dimensions of correlations

Considering the complicated interdependencies in the joint activity choice problem, there also lies multiple dimensions of correlations. In the individual model, only one dimension of correlation can be analysed - the dependence among activities. Concerning the social influence model, one more dimension of correlation can be modelled - the dependence among individuals.

In the group decision model, more dimensions of correlations can be considered. For instance, the unobserved correlations can be modelled by incorporating the non-IID (Independent and identically distributed) normal distributions, similar to conventional tour-based or time allocation models.

In particular, two specific correlations are investigated in this paper:

- Correlations between solo and joint activity.

  Motivations: why are some activities preferred for joint participation and some preferred for solo participation? Is there a net effect from joint participation compared with solo participation? Is the net effect always positive, e.g., extra gain from join participation? Can we discover household members' altruistic behaviours from the group decision based on net effects?

- Correlations among joint activities. Motivations: do some households prefer joint participation for all activities? How can we disentangle such household preferences by observed variables? Are there possibly unobserved correlations among joint activities? Which joint activities are positively correlated, and which are negatively correlated? What are the implications of this evidence?

Concerning these two issues, very few related works have been found. The investigations of these problems are the two features of note of this paper.

2. Research problems and contribution

Summarising the literature review, four research gaps are found and therefore four research problems are investigated in this paper.

- **P1:** to model intra-household interaction in a retired/working couples' joint activity choice problem.
- **P2:** how is the whole-day activity-chains related to retired/working couples' social-demographics, transportation system and built environment, particularly in a transit-dependent city?
- **P3:** Are there net effect (extra gain/loss) from joint activity participation compared with solo? And what is the distribution among populations?

- **P4:** Are there correlations among joint activities participations, in which couples who enjoy each others' accompany would have more joint activities?

Based on the raised research problems and literature review, the contribution of this paper are summarised.

From a methodological point of view: first, a MDCEV-MC model is firstly used in a household activity participation and time allocation problem to consider the heterogenous time constraints of household members. Second, the net effect is firstly proposed to reveal one's extra gain or loss from joint activities participation, to further investigate altruistic behaviours of household members. Third, the correlations among joint activities are firstly reviewed from a household-taste's point of view, to elicit couples' preferences for companionship.

From an empirical point of view: first, the activity-travel behaviours of retired and dual-workers couples are contrastively analysed for the first time. Second, the intra-household interaction is firstly considered in older people's activity participation and time allocation problem, in which whole day activities are all analysed. Third, the effect of mixed land use, high density, and transit-dependent built environment are analysed.

2.1. Structure of this paper

The rest of the paper is described as follows. Section 2 presents the model structure for the household's time allocation problem, in which the activity type, timing, duration, participants, and time constraints of household members are jointly studied. The parameter estimation approach and forecasting algorithm are also presented. The household survey data from Hong Kong will be empirically analysed in section 3, in which two-member households with working or retired couples are contrastively studied. This section reveals the group decision mechanism in the joint activity participation and time allocation problem. In particular, it reveals the nature of net effect from joint participation, and also the correlation among joint activities, to shed light on the individual and household preferences. In section 4, based on calibrated models, two scenarios are analysed to see how the improvement of transportation system and future life style (namely, telecommuting, online shopping and food delivery) change the activity-travel behaviours. The conclusion of the paper is presented in the last section.

3. A group decision model for joint household activity participation and time allocation

3.1. Utility for time allocation

In a household, members are assumed to coordinate to achieve a maximised total utility for the household rather than for individuals. Total household utility can be decomposed into sub-utilities of alternatives, where the sub-utility of allocating time t_k in activity k is

$$u_k(t_k) = \gamma_k \psi_k \ln\left(\frac{t_k}{\gamma_k} + 1\right), \quad (1)$$

where γ_k represents the satiation effect, which reduces the marginal utility with increasing consumption time of activity k. A higher value of γ_k means a lower satiation effect. γ_k also plays the role of the relative weight for each activity. In addition, γ_k introduces corner solutions for k (that is, zero consumption for k). Note that in many existing studies that considered the group decision mechanism in household time allocation (Zhang & Fujiwara 2006; Kato & Matsumoto 2009), this satiation effect is assumed equal to 1. ψ_k is the baseline utility to represent the benefit of one unit of consumed time invested in activity k, or the marginal utility at the point of zero consumption. Let N be the set of members in household g. ψ_k can be specified as a multiplicative combination of baseline utility terms associated with household members,

$$\psi_k = \prod_{n \in N} \psi_k(n), \quad (2)$$

where Eq. (2) is the Nash-type form, which is a specific case of the iso-elastic utility function form for group decision-making (See Zhang & Fujiwara (2006) for more discussion on various group decision-making mechanisms in transportation analysis). In this case, the members identify their baseline utilities for activity k, and then the household baseline utility for activity k is built based on the negotiating result. Eq. (2) can be specified as

$$\psi_k = \prod_{n \in N} \psi_k(n) = \prod_{n \in N} exp(\theta_n x_n + \theta_{ng} x_g + \theta_{nk} x_k + \theta_{ngk} x_{ngk} + \eta_k), \quad (3)$$

where x_n represents member n's individual characteristics, x_g represents household g's characteristics, x_k represents the activity's attributes, x_{ngk} represents the interaction variables, and η_k is an error term. Note that only the baseline utility (as opposed to total utility) takes the Nash-type form. As suggested by Bhat et al. (2013), this specification is consistent with the notion that the intra-household interaction for activity choice involves two parts: (1) a discrete component, which is whether to undertake a specific activity; and (2) a continuous component, which is the amount of time to invest. The discrete choice decision is controlled by the baseline utility, which considers all members baseline utilities. It implies that a household baseline utility should be built initially for each activity, and then the time allocation can be determined.

Eq. (3) can be rewritten as

$$\psi_k = exp(\beta_k z + \eta_k), \quad (4)$$

where z is a vector of exogenous variables (including constants) of activity k, and z includes variables of activity attributes, individuals' and household's characteristics and interaction components; and β_k is a vector of parameters to be estimated. This specification guarantees the positivity of the baseline utility. ψ_k can be considered the expected maximum baseline utility for n to participate in k, and η_k can be considered the residual.

For a couple, n and m are denoted for the husband and wife, respectively. K is denoted as the total number of activities, and each activity can be undertaken independently or jointly. Therefore, the time allocation for n is denoted as $\boldsymbol{t}_n = [t_{n1}, t_{n2}, ..., t_{nK}, t_{J1}, t_{J2}, ..., t_{JK}]$, where is the allocated time by n to pursue the first activity independently, and J is the time spent on the first activity with m jointly. Similarly, the time allocation for m is $\boldsymbol{t}_m = [t_{m1}, t_{m2}, ..., t_{mK}, t_{J1}, t_{J2}, ..., t_{JK}]$. Therefore, the sub-utility functions of activities independently and jointly undertaken by n and m are

$$U_n = \underbrace{\psi_{n1} \ln(t_{n1}+1) + \sum_{k=2}^{K} \gamma_{nk} \psi_{nk} \ln\left(\frac{t_{nk}}{\gamma_{nk}} + 1\right)}_{\text{Time allocation of solo activities undertaken by husband}}, \tag{5}$$

$$U_m = \underbrace{\psi_{m1} \ln(t_{m1}+1) + \sum_{k=2}^{K} \gamma_{mk} \psi_{mk} \ln\left(\frac{t_{mk}}{\gamma_{mk}} + 1\right)}_{\text{Time allocation of solo activities undertaken by wife}}, \tag{6}$$

$$U_j = \underbrace{\sum_{k=1}^{K} \gamma_{Jk} \psi_{Jk} \ln\left(\frac{t_{Jk}}{\gamma_{Jk}} + 1\right)}_{\text{Time allocation of joint activities}}, \tag{7}$$

where activity $n1$ and $m1$ are the non-zero consumption activities (the "outside good") for member n and m. The outside good is represented by an independently undertaken activity, in which each individual would have a certain amount of alone time that, for instance, it could be the alone time during n stays at home. Therefore, the utility of one unit of time to consume this alternative can be considered the numeraire utility for all other activity utilities.

3.2. Choice set composition

The alternatives in the choice set are the same as the "activity purpose - participating individual" combinations in Bhat et al. (2013). Therefore, for a couple n and m, and when there are two activities $A1$ and $A2$ that can be undertaken, then the alternatives in our model are [$A1$ solo-participation by n, $A1$ solo-participation by m, $A2$ solo-participation by n, $A2$ solo-participation by m, $A1$ joint-participation by n and m, $A2$ joint-participation by n and m]. Note that for a household with N members and K activities, the conventional discrete choice analysis (DCA) model has the choice set with $2^{K\times(2^N-1)}-1$ alternatives if we enumerate all possible subsets of household members for joint activity participation, in which the proposed model only has the choice set with only $K\times(2^N-1)$ alternatives. In addition, the utilised specification is extendable for households that are more than two members. Although the number of alternatives would be exploded as the number of household members increases, the employed approach substantially shrinks the choice set size compared with a conventional DCA model. In addition, this specification is still practical as most households have less than five members (e.g. a majority of households in Hong Kong have no more than five members), where the number of alternatives is still not large.

3.3. Model structure

The total household utility function is computed as the summation of sub-utilities, as shown in Eq. (8). All household members are assumed to coordinate to achieve the best time allocations for $\boldsymbol{t}_n$ and $\boldsymbol{t}_m$, so that the household's utility $U_{nm}(\boldsymbol{t}_n, \boldsymbol{t}_m)$ is maximised. Therefore, we have

$$\max \quad U_{nm}(\boldsymbol{t}_n, \boldsymbol{t}_m) = U_n + U_m + U_J \tag{8}$$

$$\text{s.t.} \quad \sum_{k=1}^{K} t_{Jk} + \sum_{k=1}^{K} t_{nk} = T_n, \tag{9}$$

$$\sum_{k=1}^{K} t_{Jk} + \sum_{k=1}^{K} t_{mk} = T_m, \tag{10}$$

where $U_{nm}(\boldsymbol{t}_n, \boldsymbol{t}_m)$ is increasing and continuously differentiable; $\boldsymbol{t}_n, \boldsymbol{t}_m > 0, \forall k \in K$, are the consumed time; and T_n and T_m are time budgets for n and m, respectively.

3.4. Correlations among alternatives

The model specification above assumes an independent and identical distribution (IID) of error terms among alternatives. To relax this assumption and to capture the unobserved correlations among alternatives, we specify a correlated error structure for the model. The utility is a combination of two components, in which the baseline utility decides "whether to participate", and the satiation effect decides "how long to participate". The correlations of activities can exist in both of these components. Therefore, the covariance matrix is specified for both of these components.

First, we investigate whether the participations of activities are correlated. Therefore for the baseline utility, the error term η_k in Eq. can be decomposed into two components, ε_k and ξ_k. ε_k follows an IID type-I extreme value distribution, and ξ_k follows a multivariate normal distribution with zero means and a covariance matrix Σ_k. In particular, ξ_k captures the unobserved correlations among "whether to participate in an activity".

Second, we investigate whether the durations of activities are correlated. Thus, the satiation parameters are specified as $\gamma_k = exp(w_k z + \zeta_k)$, where w_k is a vector of parameters to be estimated. ζ_k follows a multivariate normal distribution with zero means and a covariance matrix Σ_{ζ}. In particular, ζ_k captures the unobserved correlations among the activity durations.

Third, we investigate the net effect from joint activity compared with solo participation. The underlying assumption is that, if the couples would like to participate joint activity, they should obtain more utility (extra gain) compared with solo participation. Similarly, if one activity is preferred to be undertaken as a solo activity, this preference suggests that there is extra loss from joint participation. The model structure facilitates this goal. We perform a pairwise comparison of the sub-utilities, and the net effects are defined as follows.

$$NET_{nk} = U_{Jk}(t) - U_{nk}(t) \text{ for the husband, and} \tag{11}$$

$$NET_{mk} = U_{Jk}(t) - U_{mk}(t) \text{ for the wife.} \tag{12}$$

Thus, we can compute the net effect for a certain population segment, e.g., age or income. Similarly, we can compute the net effect for baseline utility and satiation effect respectively, to investigate the utility difference between the joint and solo activity of "whether to participate" and "how long to participate".

3.5. Model parameter estimation

Eq. (8) has two time constraints that are different from the specifications in Bhat et al. (2013) and Bernardo et al. (2015). Therefore, a MDCEV-MC model is employed. Putting Eq. (5), Eq. (6) and Eq. (7) into Eq. (8), we construct the Lagrangian as

$$\begin{aligned}
\mathscr{L} = & \underbrace{\gamma_{n1}\psi_{n1}\ln\left(\frac{t_{n1}}{\gamma_{n1}}+1\right) + \sum_{k=2}^{K}\left[\gamma_{nk}\psi_{nk}\ln\left(\frac{t_{nk}}{\gamma_{nk}}+1\right)\right]}_{\text{Husband's solo activities}} \\
& + \underbrace{\gamma_{m1}\psi_{m1}\ln\left(\frac{t_{m1}}{\gamma_{m1}}+1\right) + \sum_{k=2}^{K}\left[\gamma_{mk}\psi_{mk}\ln\left(\frac{t_{mk}}{\gamma_{mk}}+1\right)\right]}_{\text{Wife's solo activities}} \\
& + \underbrace{\sum_{k=1}^{K}\left[\gamma_{Jk}\psi_{Jk}\ln\left(\frac{t_{Jk}}{\gamma_{Jk}}+1\right)\right]}_{\text{Joint activities}} - \underbrace{\lambda_n\left[\sum_{k=1}^{K}t_{Jk} + \sum_{k=1}^{K}t_{nk} - T_n\right] - \lambda_m\left[\sum_{k=1}^{K}t_{Jk} + \sum_{k=1}^{K}t_{mk} - T_m\right]}_{\text{Time constraints}}
\end{aligned} \tag{13}$$

where λ_n and λ_n are Lagrangian multipliers corresponding to the time constraints T_n and T_m. By applying the Karush-Kuhn-Tucker (KKT) first-order conditions for the household's optimal time allocations

$\boldsymbol{t^*} = [t^*_{n1}, t^*_{n2}, ..., t^*_{nK}, t^*_{m1}, t^*_{m2}, ..., t^*_{mK}, t^*_{J1}, t^*_{J2}, ..., t^*_{JK}]$, we have

$$\varepsilon_{nk} = W_{nk},\ \text{if}\ t^*_{nk} > 0, k = 2,3,...,K, \tag{14}$$

$$\varepsilon_{nk} < W_{nk},\ \text{if}\ t^*_{nk} = 0, k = 2,3,...,K, \tag{15}$$

$$\begin{aligned} W_{nk} =& z(\beta_{n1} - \beta_{nk}) + \varepsilon_{n1} + \xi_{n1} - \xi_{nk} \\ & + \ln(\gamma_{n1}|\zeta_{n1}) - \ln(\gamma_{nk}|\zeta_{nk}) - \ln(t^*_{n1} + \gamma_{n1}|\zeta_{n1}) + \ln(t^*_{nk} + \gamma_{nk}|\zeta_{nk}), k = 2,3,...,K, \end{aligned} \tag{16}$$

$$\varepsilon_{mk} = W_{mk},\ \text{if}\ t^*_{mk} > 0, k = 2,3,...,K, \tag{17}$$

$$\varepsilon_{mk} < W_{mk},\ \text{if}\ t^*_{mk} = 0, k = 2,3,...,K, \tag{18}$$

$$\begin{aligned} W_{mk} =& z(\beta_{m1} - \beta_{mk}) + \varepsilon_{m1} + \xi_{m1} - \xi_{mk} \\ & + \ln(\gamma_{m1}|\zeta_{m1}) - \ln(\gamma_{mk}|\zeta_{mk}) - \ln(t^*_{m1} + \gamma_{m1}|\zeta_{m1}) + \ln(t^*_{mk} + \gamma_{mk}|\zeta_{mk}), k = 2,3,...,K, \end{aligned} \tag{19}$$

$$\varepsilon_{Jk} = W_{Jk},\ \text{if}\ t^*_{Jk} > 0, k = 1,2,...,K, \tag{20}$$

$$\varepsilon_{Jk} < W_{Jk},\ \text{if}\ t^*_{Jk} = 0, k = 1,2,...,K, \tag{21}$$

$$W_{Jk} = \ln(S) - \ln(L_k), k = 1,2,...,K, \tag{22}$$

$$S = \frac{(\gamma_{n1}|\zeta_{n1})exp(\beta_{n1}z + \varepsilon_{n1} + \xi_{n1})}{t^*_{n1} + \gamma_{n1}|\zeta_{n1}} + \frac{(\gamma_{m1}|\zeta_{m1})exp(\beta_{m1}z + \varepsilon_{m1} + \xi_{m1})}{t^*_{m1} + \gamma_{m1}|\zeta_{m1}}, \tag{23}$$

$$L = \frac{(\gamma_{Jk}|\zeta_{J1})exp(\beta_{Jk}z + \xi_{Jk})}{t^*_{Jk} + \gamma_{Jk}|\zeta_{Jk}}. \tag{24}$$

We do not present the whole derivation of above equations in this paper, since existing literature (see Bhat (2005; 2008), and Castro et al. (2012)) have presented these steps in a similar approach.

Without loss of generality, we assume that the first Q_n and Q_m of the total K activities are *independently* participated in by husband and wife, and the first Q_J of the total K activities are *jointly* undertaken. Under the assumptions that the unobserved terms ε are independently distributed across all alternatives ($k = 1,2,...,K$) and independent of z, and follow a standard extreme value distribution with scale parameter σ, the probability of the optimal time allocation where the household chooses the first Q_n, Q_m and Q_J of the K activities, given $\boldsymbol{\theta} = (\varepsilon_{n1}, \varepsilon_{n2}, \xi_{n1}, \xi_{n2}, ..., \xi_{JK}, \zeta_{n1}, \zeta n2, ...\zeta_{JK})$, is:

$$\begin{aligned} & \Pr(t^*_{n2}, ..., t^*_{nQ_n}, 0, ..., 0, t^*_{m2}, ..., t^*_{mQ_m}, 0, ..., 0, t^*_{J1}, ..., t^*_{JQ_J}, 0, ..., 0|\boldsymbol{\theta}) \\ =& \left[\det(\mathbf{J})|\boldsymbol{\theta} \times \prod_{k=2}^{Q_n} \frac{1}{\sigma} g\left(\frac{W_{nk}|\boldsymbol{\theta}}{\sigma}\right) \times \prod_{k=2}^{Q_m} \frac{1}{\sigma} g\left(\frac{W_{mk}|\boldsymbol{\theta}}{\sigma}\right) \times \prod_{k=1}^{Q_J} \frac{1}{\sigma} g\left(\frac{W_{Jk}|\boldsymbol{\theta}}{\sigma}\right) \right] \\ & \times \left[\prod_{k=Q_n+1}^{K} G\left(\frac{W_{nk}|\boldsymbol{\theta}}{\sigma}\right) \times \prod_{k=Q_m+1}^{K} G\left(\frac{W_{mk}|\boldsymbol{\theta}}{\sigma}\right) \times \prod_{k=Q_J+1}^{K} G\left(\frac{W_{Jk}|\boldsymbol{\theta}}{\sigma}\right) \right] \end{aligned} \tag{25}$$

where g is the standard extreme value density function, G is the standard extreme value cumulative distribution function, and $\det(\mathbf{J})|\boldsymbol{\theta}$ is the determinant of the Jacobian $\mathbf{J}$ conditional on the error terms of the first activity participated by n and m.

The first component on the right side of Equation (25) involves the density of the $(K-2)$ chosen alternatives based on a change-of-variable calculus (the transformation from the random utility errors $(\varepsilon_{ij}, i = n,m,J; j = 2,3,...,K$ for $i = n,m; j = 1,2,...,K$ for $i = J)$ to the activity durations $(t_{ij}, i = n,m,J; j = 2,3,...,K$ for $i = n,m; j = 1,2,...,K$ for $i = J)$ generates the Jacobian $\mathbf{J}$; the first activity that independently participated by n and m do not appear in this term because they can be derived from the consumption of the other activities).

The second component on the right side of Equation (25) involves the probability of the activities that are not participated $(Q_n+1, Q_n+2, ..., K, Q_m+1, Q_m+2, ..., K, Q_J+1, Q_J+2, ..., K)$. This is obtained by integrating $(\varepsilon^*_{nQ_n+1}, ..., \varepsilon^*_{nK}, \varepsilon^*_{mQ_m+1}, ..., \varepsilon^*_{mK}, \varepsilon^*_{JQ_J+1}, ..., \varepsilon^*_{JK})$ over the region consistent with no-participation, based on the KKT inequalities in Equation (14-24) in the manuscript.

Integrating out the error terms ε_{n1} and ε_{m1} from Equation (25), and also consider the error terms of $\xi_{n1}, \xi_{n2}, ..., \xi_{JK}, \zeta_{n1}, \zeta n2, ...\zeta_{JK}$, the unconditional probability can be computed as

$$\begin{aligned} &\Pr(t^*_{n2}, ..., t^*_{nQ_n}, 0, ..., 0, t^*_{m2}, ..., t^*_{mQ_m}, 0, ..., 0, t^*_{J1}, ..., t^*_{JQ_J}, 0, ..., 0) \\ &= \int_{\varepsilon_{n1}=-\infty}^{\infty} \int_{\varepsilon_{m1}=-\infty}^{\infty} \int_{\xi_{n1}=-\infty}^{\infty} \cdots \int_{\xi_{JK}=-\infty}^{\infty} \int_{\zeta_{n1}=-\infty}^{\infty} \cdots \int_{\zeta_{JK}=-\infty}^{\infty} \Lambda \mathrm{d}\varepsilon_{n1} \mathrm{d}\varepsilon_{m1} \mathrm{d}\xi_{n1} ... \mathrm{d}\xi_{JK} \mathrm{d}\zeta_{n1} ... \mathrm{d}\zeta_{JK} \end{aligned} \tag{26}$$

where

$$\begin{aligned} \Lambda = \det(\mathbf{J}) \times &\left[\prod_{k=2}^{Q_n} \frac{1}{\sigma} g\left(\frac{W_{nk}}{\sigma}\right) \times \prod_{k=2}^{Q_m} \frac{1}{\sigma} g\left(\frac{W_{mk}}{\sigma}\right) \times \prod_{k=1}^{Q_J} \frac{1}{\sigma} g\left(\frac{W_{Jk}}{\sigma}\right) \right] \\ &\times \left[\prod_{k=Q_n+1}^{K} G\left(\frac{W_{nk}}{\sigma}\right) \times \prod_{k=Q_m+1}^{K} G\left(\frac{W_{mk}}{\sigma}\right) \times \prod_{k=Q_J+1}^{K} G\left(\frac{W_{Jk}}{\sigma}\right) \right] \\ &\times f(\varepsilon_{n1}) f(\varepsilon_{m1}) f(\xi_{n1}) ... f(\xi_{JK}) f(\zeta_{n1}) ... f(\zeta_{JK}) \end{aligned} \tag{27}$$

$\mathbf{J}$ results from a change-of-variable technique to obtain the density of $\varepsilon = (\varepsilon_{n2}, ..., \varepsilon_{nK}, \varepsilon_{m2}, ..., \varepsilon_{mK}, \varepsilon_{J1}, \varepsilon_{J2}, ..., \varepsilon_{JK})$ from $\boldsymbol{t^*} = [t^*_{n2}, ..., t^*_{nK}, t^*_{m2}, ..., t^*_{mK}, t^*_{J1}, t^*_{J2}, ..., t^*_{JK}]$. Therefore, $\mathbf{J}$ is a $(Q_n + Q_m + Q_J - 2) \times (Q_n + Q_m + Q_J - 2)$ matrix, in which the element is

$$\mathbf{J}_{ij} = \frac{\partial \varepsilon_i}{\partial t_j}, i, j = n2, ..., nQ_n, m2, ..., mQ_m, J1, ..., JQ_J. \tag{28}$$

We use simulation-based maximum likelihood estimation. O is the number of observations. Drawing R sets of $(\varepsilon_{n1}\varepsilon_{m1}\xi_{n1}...\xi_{JK}\zeta_{n1}...\zeta_{JK})$ for each observation o, the log-likelihood function is

$$LL = \sum_{o=1}^{O} \left[\frac{1}{R} \sum_{r=1}^{R} \Pr_r(\varepsilon_{n1}\varepsilon_{m1}\xi_{n1}...\xi_{JK}\zeta_{n1}...\zeta_{JK}) \right]. \tag{29}$$

Readers are referred to (Train 2009) for more details of the simulation-based maximum likelihood estimation.

3.6. *Forecasting*

Based on Pinjari & Bhat (2010), the forecasting algorithm is reformulated and presented. The algorithm is an incremental enumeration method. It includes three basic steps, as shown in Algorithm 1.

Algorithm 1: Forecasting algorithm for the household-level MDCEV-MC model

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Input: Exogenous variables z and estimates φ_{nk}, φ_{mk}, φ_{Jk}, γ_{nk}, γ_{mk}, γ_{Jk}, and the simulated error terms $\varepsilon_{nk}, \varepsilon_{mk}, \varepsilon_{Jk}, \xi_{nk}, \xi_{mk}, \xi_{Jk}, \zeta_{nk}, \zeta_{mk}, \zeta_{Jk}, k = 1,2,..,K$.

Output: Lagrange multipliers λ_n and λ_m; the numbers of consumed activities Q_n, Q_m, and Q_J; and optimal time allocations of t^*_{nk}, t^*_{mk}, and t^*_{Jk}, $k = 1,2,..,K$.

Step 1: Initiation. Assume that only the outside goods for members n and m are consumed, denote $Q_n = 1$, $Q_m = 1$, and $Q_J = 0$.

Arrange $\varphi_{nk}(k = 2,...,K)$ of K solo activities in the descending order, with φ_{n1} in the first place.

Arrange $\varphi_{mk}(k = 2,...,K)$ of K solo activities in the descending order, with φ_{m1} in the first place.

Arrange $\varphi_{Jk}(k = 1,...,K)$ of K joint activities in the descending order.

Step 2: Lagrange multipliers and consumption of outside goods. Compute the values of λ_n, λ_m, t^*_{n1}, and t^*_{m1} using the methods above.

Step 3: Consumptions of activities (inside goods).

for $i = 1 : K$ **do**

  if $i > 1$ *and* $(\lambda_n > \varphi_{ni}$ *or* $i = K)$ **then**

    The first i solo activities are consumed by member n.

    Compute the optimal consumptions using $t^*_{nk} = \gamma_{nk}\varphi_{nk}/\lambda_n - \gamma_{nk}$.

    Return $Q_n = i$, and t^*_{nk}, $k = 2,..,i$.

  end

  if $i > 1$ *and* $(\lambda_m > \varphi_{mi}$ *or* $i = K)$ **then**

    The first i solo activities are consumed by member m.

    Compute the optimal consumptions using $t^*_{mk} = \gamma_{mk}\varphi_{mk}/\lambda_m - \gamma_{mk}$.

    Return $Q_m = i$, and t^*_{mk}, $k = 2,..,i$.

  end

  if $\lambda_n + \lambda_m > \varphi_{Ji}$ *or* $i = K$ **then**

    The first i joint activities are consumed.

    Compute the optimal consumptions using $t^*_{Jk} = \gamma_{Jk}\varphi_{Jk}/(\lambda_n + \lambda_m) - \gamma_{Jk}$.

    Return $Q_J = i$, and t^*_{Jk}, $k = 1,2,..,i$.

  end

end

As discussed by Pinjari & Bhat (2010), we can start from the assumption that only the outside goods are consumed, and then verify this assumption by examining the KKT conditions for other (assumed to be) non-chosen activities step by step. The algorithm stops until either the KKT conditions are met, or the assumed number of chosen activities reaches the maximum number K.

4. Empirical analysis

4.1. Data description

A sample from the 2011 Hong Kong Travel Characteristic Survey (TCS) is used for the model calibration. The survey includes the daily activity diaries of 101,384 individuals, which covers approximately 1.5% of the total population in Hong Kong. In total, 35,401 households were surveyed, and 122,237 trips were recorded. Based on the reported trips, activities[3] were derived between trips. Only activity chains that meet the following conditions are analysed in this paper: (1) Out-of-home activities were conducted; (2) It started from home; and (3) It ended at home.

Table 2: Description of activities of the working and retired couples on weekdays.

		Working couples	Retired couples
	#Couples (observations)	1571 (3142)	290 (580)
#Observations	#Out-of-home activities (non-mandatory)	193 (36 joint*)	610 (396 joint)
	#Shopping	-	274 (166 joint)
	#Eat-out	-	150 (100 joint)
	#Leisure	-	128 (90 joint)
	#Maintenance	-	58 (40 joint)
	%Joint out-of-home activities	18.7%	64.9%
Average duration (h)	Working time †		
	Workers who had out-of-home activities	8.08	
	Workers who did not have out-of-home activities	9.42	
	At-home activities		
	Evening at-home joint‡	6.52	8.60
	Evening at-home solo	1.76	2.09
	Out-of-home activities (non-mandatory)	1.79	2.28
	Shopping	-	2.21
	Eat-out	-	1.78
	Leisure	-	3.52
	Maintenance	-	1.60

* 38 out of 162 out-of-home activities are jointly participated.

[3] The activity type was inferred from the destination of the trip, for example, the activity was identified as "shopping" if the destination of the trip is "Market/shopping arcade/shops/supermarket", and the purpose of the trip is not work-related. Outliers, e.g., 8 hours for shopping, were excluded.

† With possible lunch break. The ”out-of-home activities” are non-mandatory.

‡ ”Evening at-home” indicates the at-home activity after the last out-of-home activity. The reference day (24 hours) was from 3am of the day before the interview to 3am of the day of interview.

Households with members who are couples are selected for analysis, because they are mostly the decision makers in a household. In addition, we are motivated to study the senior's activity patterns because of the ageing population issue in Hong Kong. In our sample, a substantial number of the retired couples live alone without relatives or friends. Therefore, for a contrastive analysis, we selected the households with only two members who are working couples for the comparison. Doing so simplifies our study, in which the social influence from the spouse and the net effects from the joint activities are easily disentangled. Moreover, the factors affecting both the working and retired populations are identified, making it easier to identify the factors that only affect the retired population. Based on the results, it is easier to study more intra-household interactions in which more household members are considered. Finally, a total of 1861 two-member households were selected, including 1571 working couples and 290 retired[4] couples.

The description of the dataset is presented in Table 2. The mandatory activity is not studied in this paper, because it has relatively less flexibility for scheduling. The first part of Table 2 reports the number of observations for non-mandatory out-of-home activities[5]. Among the 1571 working couples, there are only 162 observations of out-of-home activities after work, and only 23.5% of these activities were jointly participated in[6]. The last point suggests that on a weekday, joint out-of-home activities after work might not be preferred for the workers. Conversely, the number of out-of-home activities is much greater for the retired; therefore, we further classified them into four subgroups: shopping, eating-out, leisure, and maintenance. Moreover, more than 70% of their out-of-home activities were participated in jointly, suggesting that the availability of more flexible time for retired couples than for working couples offers the former more oppotunities for out-of-home activities.

The second part of Table 2 reports the average durations of activities. Workers with out-of-home

[4]The official retirement age in Hong Kong is 60 for government-related sectors, and 65 for private-enterprise sectors. The ”retired” status is reported by the respondent when the respondent did not participate in any part-time or full-time jobs in previous or next 7 days in relation to the survey day.

[5]For simplicity, the ”out-of-home activities” in the rest of this paper are all non-mandatory.

[6]This percentage is due to the design of the survey: only the mechanised trips and the walking trips (more than 10 minutes) are recorded. Therefore, some out-of-home activities are not available to us, such as fast-food trips or grocery shopping downstairs. In other words, the survey captures the relatively important out-of-home events: the worker must take a ride (or walk more than 10 minutes) for the out-of-home activity after work. Thereafter, the workers must take a ride (or walk more than 10 minutes) for the next destination.

activities had relatively shorter working times, because their post-work time is less squeezed. Concerning out-of-home activities, the average durations are all longer than one hour[4], and the retired spent more time on out-of-home activities than working couples did. Specifically, the average time spent on leisure activities is the largest, which includes for example fishing, camping, and visiting tourist attractions. Shopping activity ranks second, possibly due to the multifunctional shopping malls in Hong Kong, at which seniors can achieve various tasks (Lord et al. 2011).

4.2. Model specification and parameter estimation

Considering the different activity patterns of working and retired couples, different models are specified for them. Various exogenous variables were considered in the model, and the specifications with the best goodness-of-fit are presented in Table 3, Table 4 , Table 5 and Table 6.

In each model, the ”staying at home” time is decomposed into two parts: AM (from 3:00 to the first out-of-home activity) and PM (from the end of the last out-of-home activity to 3:00 of the next day). From a modelling point of view, the very long staying at home time (as compared to out-of-home activities) would make the estimation difficult. Therefore, it would be easier to estimate parameters if this long period is broken into two parts. From a behaviour point of view, people have different feelings for the AM and PM at home time: the former one would be more tense, e.g. for a worker who should mind whether he/she would be late for work; while the latter one would be more relaxed, since it represents the end of day, and he/she can relax and spend time with household members. In this regard, the AM at-home time is used as the outside good, where we do not further specify whether this period is alone or with the spouse, since this time slot is more tense, and do not have much flexibility to schedule. As for the PM at-home time, which is more flexible for scheduling, we further specify it as ”PM at-home solo” and ”PM at-home joint”, where the person can decide whether he/she would spend this at-home time alone, with the spouse, or participate out-of-home activities.

Only approximately 10% of the working couples had out-of-home activities, and the number of joint activities is small. Therefore, their out-of-home activities were not further classified into subgroups. In addition, on weekdays, the time for at-home activities before work (when to get up and when to depart for work) and mandatory activities are mostly fixed for each worker. Therefore, we only analyse the workers' after-work time allocation problem. Because the retired couples do not have mandatory activities, all of their time is available for scheduling. In addition, it is important to analyse their out-of-home activities because of the ”social exclusion” issue, which would largely decrease their quality-of-life (Habib & Hui 2017). For instance, they might reduce the frequency of out-of-home activities due to disabilities, poverty, or lack of convenient transportation modes. Therefore, we focus on the retired couples' out-of-home activities, which were further classified into four subgroups: shopping (non-maintenance purpose), eating out, leisure (e.g., recreation and family visit) and maintenance (e.g., hospital).

Travel time is specified in two parts. First, the travel time to one activity is attached to that activity as a whole component in time allocation. Second, unlike the spent time into activity which is specified as utility, travel time is mostly considered as disutility. Therefore, the longer travel time and the more inconvenient of the transportation mode to participate an activity, the less attractive of that activity. As such, the travel time of all transportation modes are specified as Zhang & Fujiwara (2006), where the travel time of the trip to the activity is specified in the baseline utility function. As for unchosen activities, travel time is approximated from similar sample (respondent of similar social-demographics that lives in similar neighbourhood).

4.2.1. Results for working couples

Results presented in Table 3 suggest that, the non-working time slot and Friday would increase the couples' willingness to participate in out-of-home activities, as expected. Concerning age, being young would lead to a lower baseline utility for the out-of-home activity, possibly because workers younger than 50 years old are the major labour force in their work places and consequently have longer working days. Similarly, working couples with a higher income would have a lower baseline utility for out-of-home activities after work. In addition, those who have private houses, which also indicate a wealthy status[7], would be less likely to pursue out-of-home activities, possibly because high-income couples can have longer working days; thus, their post-work time and energy are squeezed (Bhat et al. 2013). Therefore, there will be less participation time for out-of-home activities for this population. As shown in Table 3, their willingness for out-of-home activities decreases because of long work days or commuting time. This is an intuitive inference because working and travelling are time and energy consuming; thus, their post-work time and energy for out-of-home activities are reduced.

Concerning out-of-home activities after work, results from Table 5 suggest that, although being younger, high income and a private household would decrease the working couples' participation time in out-of-home activities, but these attributes would increase the durations of their out-of-home activities. This is an intuitive inference because being younger, they would be more energetic and thus would spend more time at out-of-home activities. In addition, out-of-home activities in the urban area usually require monetary expenses, such as eating-out in restaurants and shopping. Therefore, have a relatively wealthy status, such as having a high income and living in a private house, would encourage the couple to spend

[7] House prices in Hong Kong are high compared with household income; the median of monthly household income in 2011 was 21,000 HKD, but the average price for a private house was approximately 7,000 HKD per square foot in 2011.

more time in these out-of-home activities. Combining the results with baseline utility, we can conclude that although this population has relatively fewer out-of-home activities, once they decide to participate, they would spend more time than others would.

Table 3: Parameters estimation for the baseline utility of working couples.

Variables		Estimates (significant at the 0.05 level)	
		Out-of-home	PM[*] at-home
Friday	Husband solo	0.15	
	Wife solo	0.14	
	Joint	0.12	-0.39
Young[†]	Husband solo		
	Wife solo	-0.11	
	Joint	-0.12 (either)	0.06 (husband) 0.34 (wife)
Housing is private[‡]	Husband solo	-0.10	
	Wife solo		
	Joint	-0.35	0.58
High household income[§]	Husband solo	0.07	
	Wife solo	-0.05	
	Joint	-0.06	0.58
Long working time[**]	Husband solo		0.16
	Wife solo	-1.28	0.50
	Joint	-0.29	0.07 (husband) 0.28 (wife)
Long commute time[††]	Joint		0.08 (husband) 0.10 (wife)
Constant	Husband solo	0.11	0.94
	Wife solo	0.15	0.51
	Joint	0.10	1.45
log(travel time (min))	Transit-rail	-0.21	
	Transit-road	-0.26	
	Private cat / Taxi	-0.17	
σ (scale parameter of EV-distributed errors)		0.43	
Non-working hours	Husband solo	1.87	
	Wife solo	1.90	
	Joint	1.86	-0.05

[*] ”PM at-home” is the at-home activity after the last out-of-home activity.

[†] Those who are not older that of 50 years old is defined as ”young”. 50 years old is set as the cut-off based on the frequency of out-of-home activities.

‡ The housing types of "public rental" and "subsidised sale" are set as the base.

§ The monthly household income that higher than 40,000 HKD (1.00 USD = 7.8 HKD), which was the 75% percentile of the population.

** Working time more than 12 hours, which takes up 16% of the workers in the dual-workers' families.

†† commute time to/from work was more than 1 hour, which takes up 13.7% of the workers in the dual-workers' families.

Table 4: Parameters estimation for the satiation of working couples.

Variables		Estimates (significant at the 0.05 level)	
		Out-of-home	PM* at-home
Young	Husband solo	-3.73	
	Wife solo	0.66	
	Joint	0.70	0.19 (husband)
Housing is private	Husband solo	-2.75	
	Wife solo	0.93	
	Joint	1.12	-4.20
High household income	Husband solo	1.72	
	Wife solo	0.93	
	Joint	1.12	-4.20
Short working time*	Joint		-0.43 (husband)
			-0.10 (wife)
Constant	Husband solo	3.00	4.90
	Wife solo	4.96	5.01
	Joint	4.99	9.91

* 35% of the workers in the dual-workers' families worked less than 9.2 hours (550 min.).

Concerning the transportation mode, transit (road) has the largest absolute value, suggesting the most importance. The second one is transit (rail), followed by private car/taxi. The weight for walking is not significant. This is an intuitive inference because the shared rate of transit in Hong Kong is over 90%, and workers feel that transit would be the most important mode. The reduced travel time of the public transport system would have more effect than other modes would.

4.2.2. Results for retired couples

Estimation results of baseline utility are shown in Table 5. Concerning the timing, only the estimates of the shopping activity are significant. The estimates for hours after 17:00 have the smallest value, suggesting that retired couples prefer to avoid the congestion of the evening peak for out-of-home activities. A similar result was discovered by Shoval et al. (2010); they found that most seniors would avoid the evening peak for out-of-home activities. Another finding is from Habib & Hui (2017), who found that seniors prefer certain activities in the suburban area. Although the variables and experiments are not identical, we consider it intuitive that seniors have a tendency to avoid spatial and temporal congestion when activity scheduling.

Table 5: Parameters estimation for the baseline utility of retired couples.

Variables		Estimates (significant at the 0.05 level)				
		Shop	Eat-out	Leisure	Maintenance	PM at-home
Time of day	7:30-9:30	3.58				
	9:30-11:00	3.46				
	11:00-14:00	3.18				
	14:00-17:00	3.02				
Age $<$ 75 yr.*	Husband solo	0.10		0.12		
	Wife solo	0.09				
	Joint (both)	0.11	0.08	0.13	0.08	0.29 (husband) 0.08 (wife)
Housing is private	Husband solo					
	Wife solo	0.10				
	Joint	0.11	0.28			
Constant	Solo	3.29	3.52	4.76	3.70	4.80 (husband) 4.38 (wife)
	Joint	3.39	5.01	5.10	4.49	7.64
log(travel time (min))	Transit-rail	-0.232 (for all out-of-home and PM at-home activities)				
	Transit-road	-0.215 (for all out-of-home and PM at-home activities)				
	Private cat / Taxi	-0.246 (for all out-of-home and PM at-home activities)				
	Walk	-0.259 (for all out-of-home and PM at-home activities)				
σ (scale parameter of EV-distributed errors)		0.69				

* 75 years old is set as the cut-off based on the frequency of out-of-home activities.

Table 6: Parameters estimation for the satiation of retired couples.

Variables		Estimates (significant at the 0.05 level)				
		Shop	Eat-out	Leisure	Maintenance	PM at-home
Private house	Joint	0.11	0.08	0.13	0.08	0.29 (husband) 0.08 (wife)
Housing is private	Joint	0.28				-0.27
Constant	Solo	4.54	5.29	5.99	5.63	4.62
	Joint	4.63		5.80		5.62
Age $<$ 75 yr.	Joint (both)					-0.66

For those whose housing type is private[8], the retired would have a higher baseline utility for shopping and eating-out activity participation. Intuitively, that being relatively financially independent would encourage them to undertake more out-of-home activities, which mostly require spending money. Conversely, this point reveals that there might be a "social exclusion" issue for the retired in a poor economic condition, in which they engage in out-of-home activities with a lower frequency. Similar implications were uncovered by Moniruzzaman et al. (2015) and Hahn et al. (2016b); being poor would substantially decrease seniors' number of trips. Moreover, the low frequency of out-of-home activities might decrease the seniors' quality-of-life, because their physical and mental health can be affected (Choi & Dinitto 2015; Loo et al. 2017).

The scale parameter σ of the retired couples is larger than that of the working couples, suggesting less variance in the baseline utility. Possibly, the retired population seeks less variety in their time allocation than the workers do because their habits are more stable.

Among all transportation modes, the absolute value of walking is the largest, suggesting that it is the most important mode for the retired population. Note that this result is different from our "control group", the working couples, for whom the transit is the most important. Many studies have emphasised the importance of walkability on senior mobility, health, and quality-of-life (Su & Bell 2009; Choi & Dinitto 2015; Loo et al. 2017). In addition, we found that retired couples spent approximately twice as much time walking as did the working couples in our sample. This finding resembles those from previous studies, in which the seniors walked more than did other age groups (Rosenbloom 2001; Pucher & Renne 2005). Followed by walking, private car/taxi is the second important mode. A possible reason is the high expense of this mode: the retired couples are sensitive to monetary cost because their income is less than the workers.

Based on the contrastive analysis, we thus conclude that the retired in Hong Kong have the largest demand for travel by walking. As shown in Table 7, walking was found to have a large efect on people's daily activities in Hong Kong. In addition, when they become old and retired their need for better a walking environment thus increases (Schmcker et al. 2008; Moniruzzaman et al. 2013). Moreover, senior people were found to walk more in the urban area, with the mixed land use, compact community, good transit system, and low ownership of private cars (Rosenbloom 2001; Pucher & Renne 2005; Cao et al.

[8]We observe that one-half of the retired couples' monthly household income were less than 10,000 HKD, which is below the 25th percentile of the population. This percentage might be due to the pension system in Hong Kong, in which the pension is generally not paid monthly. Therefore, we use the variable of "type of housing" as the proxy for "income" to represent the economic status of the household.

2008; Moniruzzaman et al. 2013, 2015). These characteristics are typical in Hong Kong. Therefore, we suggest that proper attention should be paid given to walking accessibility and the environment for the senior in Hong Kong.

Table 7: Variables correlated with more walk trips and longer walking time.

	Senior	Urban area	Mixed land use	Transit dependent	Without private vehicle	Non-work purpose
Rosenbloom, 2001	✓		✓	✓		
Pucher and Renne, 2005	✓	✓				✓
Schmcker et al., 2008	✓	✓	✓	✓		✓
Cao et al., 2010	✓	✓	✓	✓	✓	✓
Moniruzzaman et al., 2013	✓					✓
Moniruzzaman et al., 2015	✓	✓	✓		✓	
Retired population in Hong Kong	✓	✓	✓	✓	✓	✓

4.2.3. Net effect from joint activities compared with solo participation

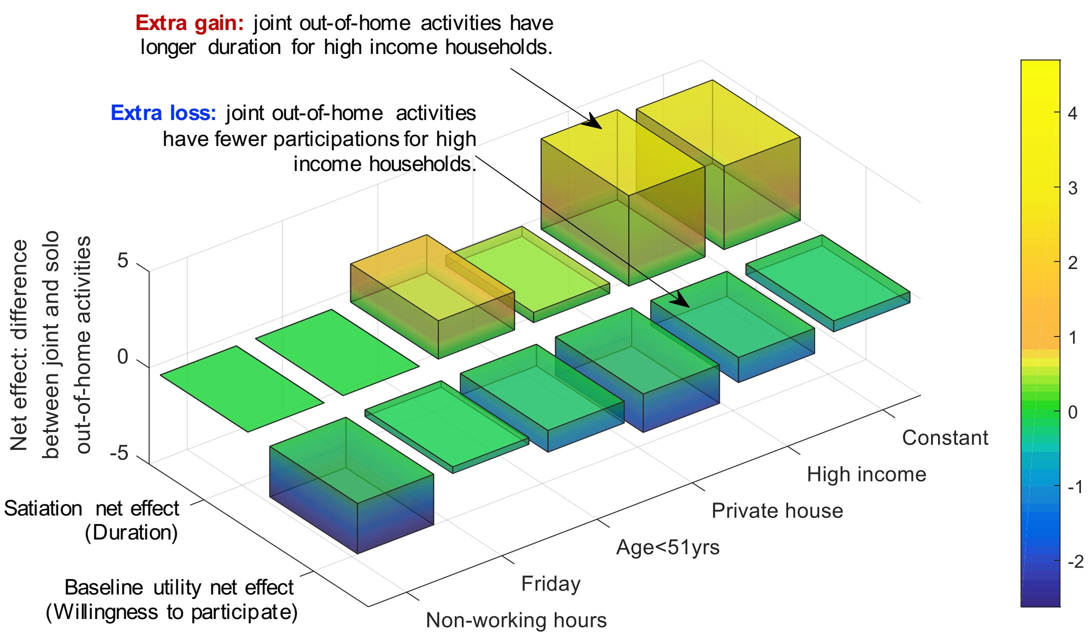

Figure 3: Working couples' net effect from joint out-of-home activities compared with solo participation.

Figure 3 presents working couples' net effect from joint out-of-home activities compared with solo participation. The net effects of baseline utility and satiation are both presented, using the deterministic parts of the utility that are presented in Table 3 and Table 4. The purpose of Figure 3 is to present the utility difference (net effect) of different exogenous variables. Taking the baseline utility for example, the net effect of "Friday" is computed as $\exp(\beta_{Jk,Friday}) - \exp(\beta_{nk,Friday})$ for household member n and activity k. In Figure 3, the y-axis is the utility difference. To clearly show the difference of each variables, the error terms are not considered in the utility function, just the deterministic parts are compared. In Figure 3, we do not differentiate husband and wife, and the average value is presented.

Net effects of baseline utilities are all negative, suggesting that working couples have less willingness to participate in joint than in solo activities. However, the net effects of satiation are all positive, suggesting that joint activities would have longer durations than would solo activities. This point implies that, although working couples lack many opportunities for joint activities during the work days, once they decide to partake in joint activities, they enjoy each other's company and spend a longer time compared with solo participation.

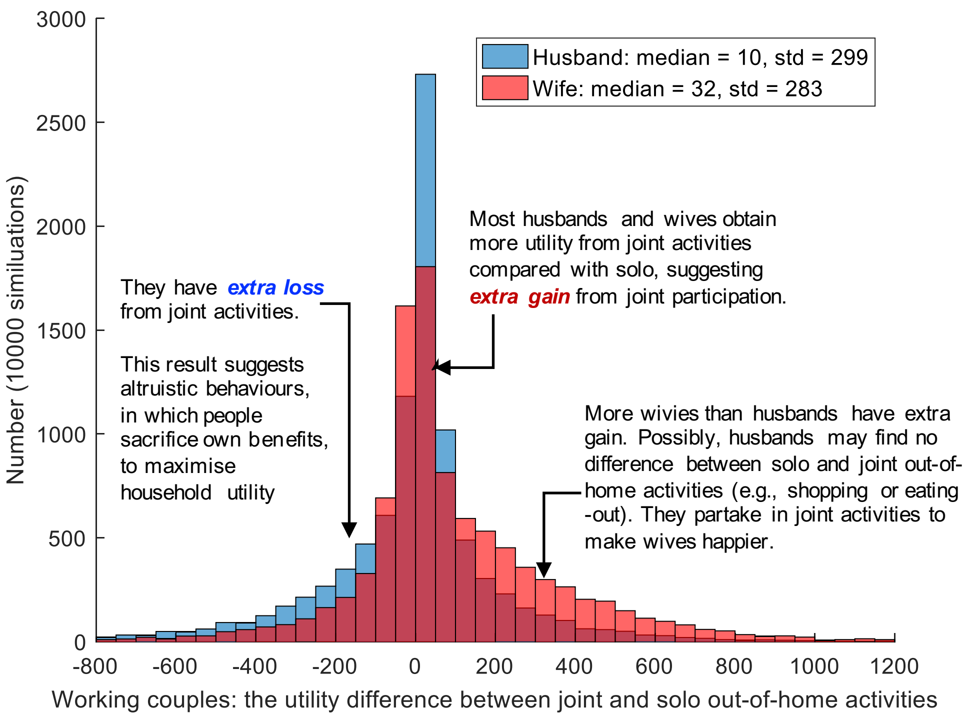

Figure 4: Working couples' utility difference (net effect) between joint and solo out-of-home activities.

The values of the baseline utility and satiation effect cannot alone reveal the actual net effect, because the overall utility of investing a certain amount of time into an activity is a combination of these two components. Therefore, Figure 4 presents the utility difference between joint and solo out-of-home activities. In addition, we focus on husband and wife (gender) instead of other exogenous variables.

Subjects with out-of-home activities are selected, and we compare their utilities if they invest the same amount of time into solo and joint activities. The utility differences of husband and wife are both presented. The error terms are added into the baseline utilities and satiation parameters. The results are therefore distributions. In Figure 4, the *y*-axis is the number of individuals (we simulate 10000 couples), and the *x*-axis is the utility difference. The blue colour is the husband, and the red colour is the wife. The colour of bars are semi-transparent, so that the overlapped parts of the bars can be seen.

The median values are all positive. Results suggest that husband and wife both obtain more utility if they invest the time into joint out-of-home activities compared with solo participation. Note that for some husbands/wives they have extra loss from the joint activities, but they still partake in joint activities because the households have greater utilities. This result suggests altruistic behaviours, in which one might sacrifice own benefits to partake in joint activities to make the spouse happy, and eventually to maximise the household total utility. In addition, it is found that more husbands have extra loss from joint out-of-home activities than wives do. For instance, husband might accompany wife for shopping or eating-out, in which the husband might feel no difference between solo and joint participation, but the companionship would make the wife happier.

Retired couples' net effects for the baseline utility and the satiation are all positive (computed based on the results in Table 5 and Table 6), suggesting that they have more joint activities, and that they have longer durations in joint activities, compared with solo activities. We combine the baseline utility and satiation effect as the overall utility, and we add the error components in the model. The resulting distributions of husband's and wife's net effects are presented in Figure 5. The median values of all out-of-home activities are all positive, suggesting that both husband and wife generally obtain more utility from joint out-of-home activities.

Altruistic behaviours are also found in the retired couples, in which husbands/wives are found to have extra loss from joint activities. As compared with working couples, the distributions for retired couples are skewed. There are fewer retired people have extra loss than extra gain. Possibly, time is a very limited resource for workers, but more sufficient for the retired. Thus, the worker might need to sacrifice own time to schedule for joint activities; conversely, the retired do not need to do so.

Generally, the median value of the distributions is not large (e.g. 10 for husband, and 32 for the wife, for the working couples), which are of the same magnitude in Figure 3. In addition, the utility difference in Figure 3 is just for one variables, but Figure 4 and 5 present the overall utility difference of

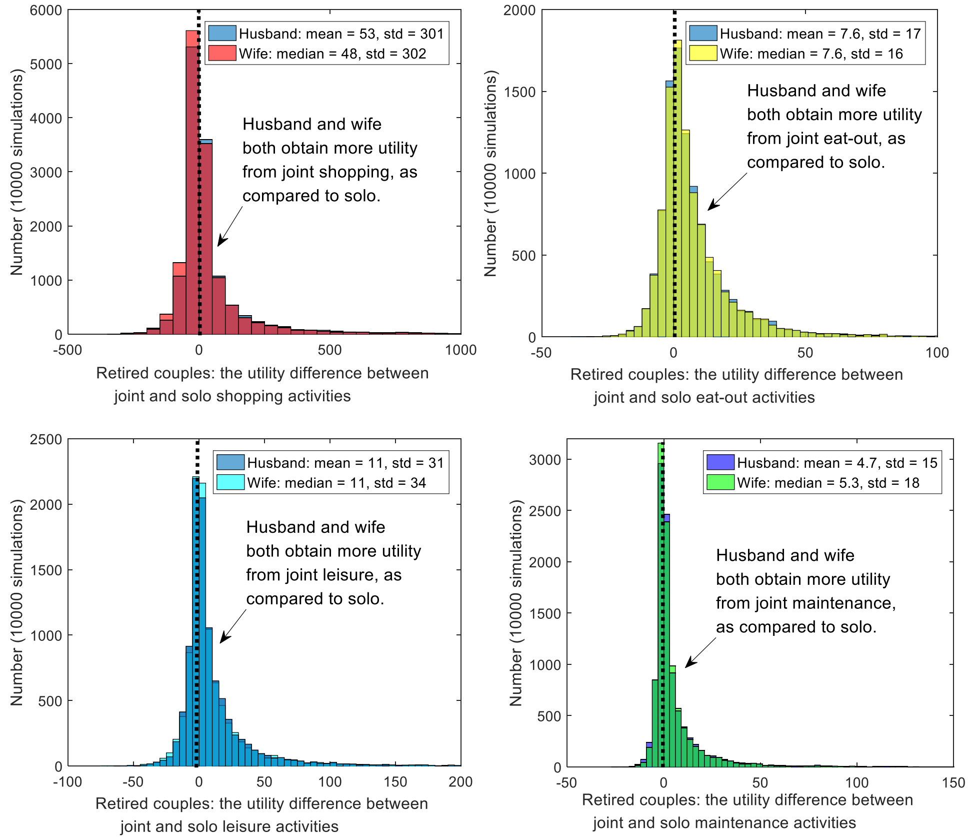

Figure 5: Retired couples' utility difference (net effect) between joint and solo out-of-home activities.

all variables, so that the range of Figure 4 and 5 should be wider than Figure 3. However, the standard deviations of the distributions in Figure 4 and 5 are very large. It suggests the observed variables have very limited explanatory power on some populations, even though we specify a complex error structure to narrow down this gap. To further improve the explanatory power of the model, analyst should identify which unobserved variables are of most importance to explain the behaviours of those populations.

4.2.4. Correlations among joint activities

In this section, the correlations among joint activities are investigated. The assumption is that if a couple enjoys each other's company, they would partake in joint activities all of the time. This preference introduces the correlations among joint activities. In particular, the durations of staying at-home jointly are investigated. If a couple likes to partake in joint out-of-home activities, they might coordinate to stay at home jointly for longer periods, compared with remaining at-home independently.

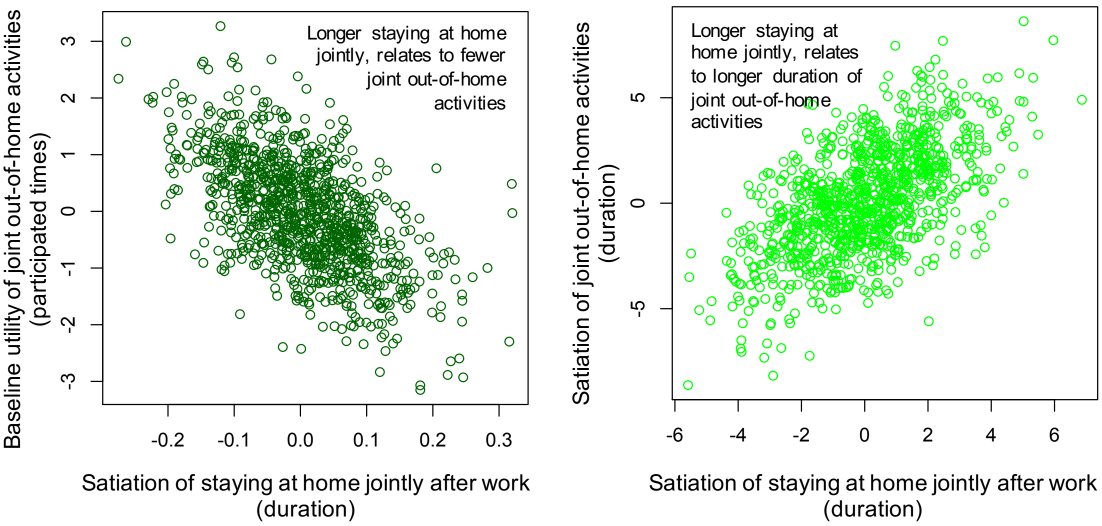

Figure 6: Correlations in utility of working couples' joint at-home after work and out-of-home activities. Left: Correlation of participations; right: correlation of duration. "Maint." is short for maintenance.

One thousand utilities are drawn from the covariance matrix of working couples. The results in Figure 6 show that the duration of joint at-home time after work is negatively correlated with the participations of out-of-home activities (Figure 6(left)), but positively correlated with the duration of out-of-home activities (Figure 6(right)). Working couples, who spend a longer time at home after work, have few out-of-home activities, which is consistent with all working couples. However, once they decide to go out together, they also spend more time. Possibly, they enjoy the companionship and thus spend more time both staying at home and on out-of-home activities.

Another one thousand utilities are drawn from the covariance matrix of retired couples. Figure 7(left) shows that a longer duration of jointly staying at home links to more participations in joint eating-out activities. Possibly, the Chinese culture prefers a lively eating environment in which the more participants the merrier. In addition, there is a strong positive correlation between joint shopping and joint eating-out activities. It is possible that in a dense city such as Hong Kong, restaurants and shopping malls are adjacent, so couples schedule shopping activity with an eating-out activity in one tour. However, the durations of joint shopping and eating-out are negatively correlated, as shown in Figure 7(right). The duration for shopping or eating-out is squeezed because they are mostly scheduled into one tour.

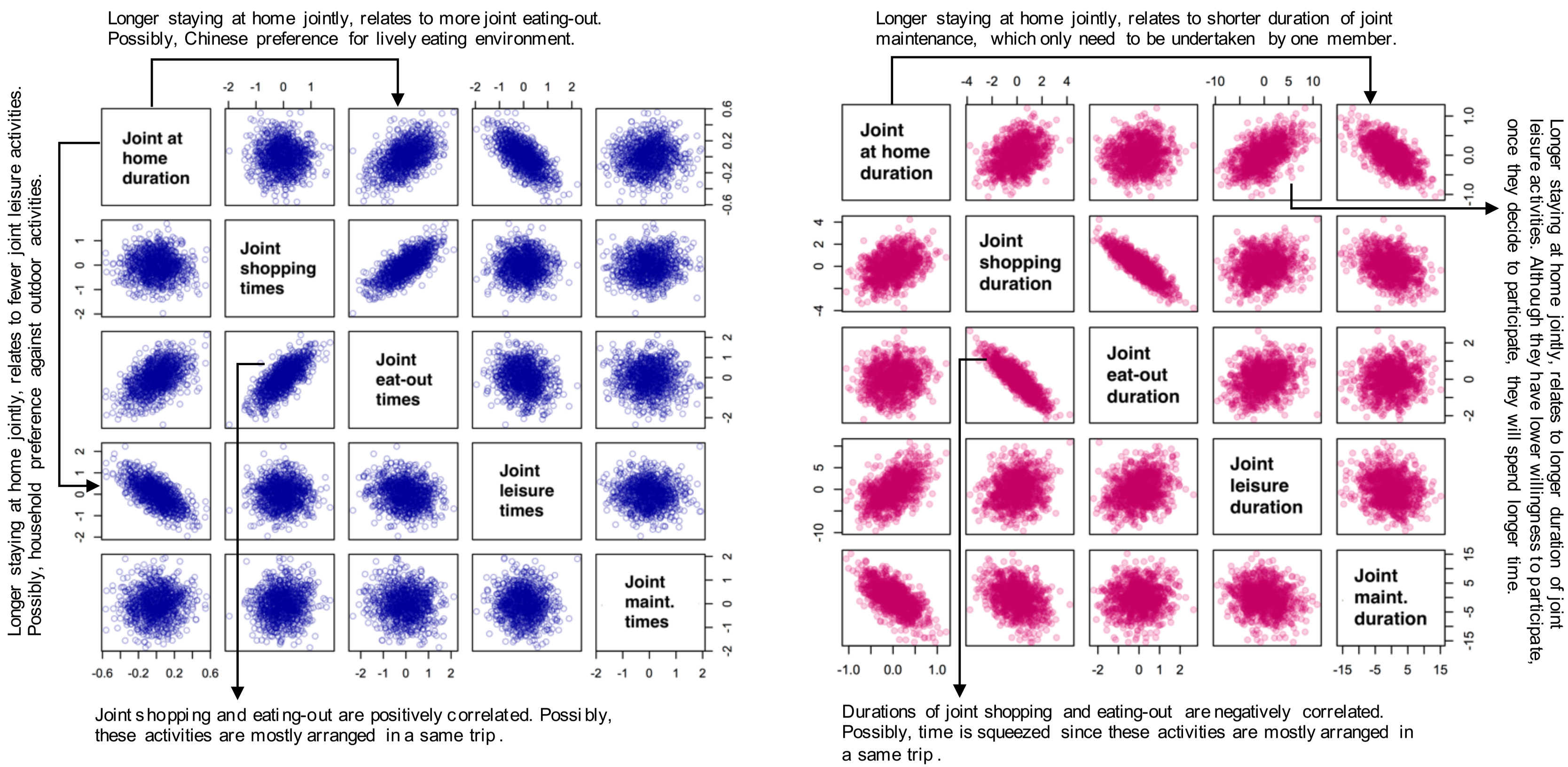

Figure 7: Correlation in utility of retired couples' joint activities (stay at-home (AH) in the evening, shopping, eating-out, leisure and maintenance (maint.)). Left: correlations of joint at-home satiation (duration) and joint out-of-home baseline utility (participations). Right: Correlations of baseline utilities (duration) of joint at-home satiation (duration) and joint out-of-home activities.

The participations in joint leisure activities, such as fishing and hiking, are negatively correlated with the joint at-home duration. This finding might reveal a household preference against outdoor activities, so they stay at home for a longer time. However, once they decide to jointly participate in these leisure activities, they also spend more time, as shown in Figure 7(right).

One interesting point is found - the joint maintenance duration is negatively correlated with the duration of jointly staying at home. It is possible that maintenance activities only need to be undertaken by any one household member, so the couples who like to spend long periods at-home prefer to send only one member for this activity.

4.2.5. Summary of the empirical analysis

Table 8 summarises key findings from the empirical study. More discussions are presented in section 6, after the scenario analysis.

Table 8: Summary of the empirical study.

	Worker	Reitred	Policy implications
Social-demographics	Young, high income, long working/commuting workers have low willingness for out-of -home activities. Once they participate, they have long durations.	Poor and old retired couples have low willingness and short duration for out-of -home activities.	For discretionary activities, workers require more flexible time, and the retired require subsidies and elderly-friendly environment.
Travel time	Most sensitive to transit.	Most sensitive to walking.	Transportation policies for high-density, mixed land use and transit dependent city should be different from car-dependent cities.
Net effect	Most of them have extra gain from joint activity compared with solo activity; some obtain extra loss.		Generally, couples prefer joint activities. However, dual-earner couples may be too busy for joint activities. Altruistic behaviours are found in the household: people might sacrifice the own benefit to maximise the household total utility.
Correlation among joint participations	Stay at home is correlated with out-of-home activities	Shopping and eating-out are correlated. Stay at home and leisure and maintenance activities are correlated.	Generally, couples enjoy each other's company, and they participate more joint activities. Ignoring the correlations may result in biased estimation.

5. Scenario analysis

Two scenarios are analysed. The first one is to investigate how the improvement of transportation system would change people's activity patterns. The second one is to find out how future lifestyles, such as online shopping, food delivery and telecommuting, would change people's activity-travel behaviours.

5.1. Improvement of transportation system

The of investment on transportation infrastructure, such a new subway or a BRT system, can be tens of billions. Thus, the decision on such investment is very critical, and it usually should consider how the investment stimulates the local economic, and how it saves the travel time of all populations. However, so far very little has been discussed on how the improvement of the transportation system changes people's activity patterns, in particular, how the changed travel time improve the quality-of-life and social welfare from an activity-based perspective. For instance, a worker can arrive home earlier so that he/she can have more time to spend with the spouse. So that not only the travellers are benefited, but also the household members.

Similar approach from Zhang & Fujiwara (2006) is applied, to investigate the increased utility of household members when travel time is saved. In addition, to discover the importance of intra-household interactions for policy evaluation, the developed group decision model is compared with a MDCEV model in which each household member is assumed as independent (the independent model).

First, we applied both models to evaluate a hypothesised policy, in which travel time is reduced by 20%. Both models show that all households' utilities are increased. However, the estimated improvements are different: for more than half of the working and retired couples, the improvements are underestimated by the independent model. This point suggests that if all household members are assumed independent without intra-household interactions, their utilities and the improved degrees of quality-of-life would be underestimated. It is likely that a different policy would be chosen if the wrong model is applied.

Second, the developed model has better goodness-of-fit than the independent model does. It reinforces our understanding that it is important to consider intra-household interactions in transportation investment.

5.2. Change of life style

The development of internet technology has substantially changed the daily life of all populations. Concerning the retired couples, a recent report[9] shows that half of the older population in China is familiar

[9]"Research report on the internet usage of middle-age and older population in China", jointly issued by the Chinese Academic of Social Science and Tencent Co., who owns the largest online social network and mobile payment platform in China. The report

with mobile payment for all types of internet-based services, such as online shopping and food delivery services, in which the travel time between locations can be saved. We investigate how the retired couples would reallocate the saved travel time. The dual-earner couples are also compared. However, the data on their specific non-mandatory out-of-home activity types are too few. Thus, we test how the telecommuting policy, which also saves travel time, would change the working couples' activities. Based on the calibrated models, the forecasting algorithms are used for these scenario analyses.

5.2.1. Online shopping

The report of "Trends in China's online consuming"[10] reveals that the elderly in China are a rapidly increasing population for online shopping and constitute an approximately 30% market share. In addition, online shopping behaviours are becoming common for the young and middle-aged population, and such a habit is likely to be retained as this generation retires. Therefore, it would not be unusual that the retired population frequently shop online in the near future. This observation remains absent in the existing studies, and how online shopping services will reshape retired people's daily activity remains unknown.

In our experiment, the online shopping duration is assumed the same as the actual one. Therefore, only travel time to and from the shopping mall is saved. In particular, we target the population whose travel time to the shopping mall is more than thirty minutes, which includes 31% of the retired population in our sample. For these populations, online shopping would be the most convenient because substantial travel time can be saved. In addition, substantial of energy will be saved, considering that long trips might be too energy-consuming for the retired population.

Results suggest that the participations of eating-out activities are slightly increased by 10% for the target population. The durations and participations of other out-of-home activities are not substantially changed. It appears that retired couples would spend the saved travel time at-home rather than participating another out-of-home activity. Combining the analysis above, we know that retired couples mostly arrange only one out-of-home activity for one day. If the retired couples rearrange their shopping activities to be done online, they would remain at home the whole day. Another issue might arise in which the retired couple would face a potential self-social-exclusion problem because they will not go out-of-home. Currently, this is not uncommon for the younger generation. It appears that the retired population would also face such a problem because online-to-offline (O2O) service is too convenient.

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is issued in 2017, and written in Chinese.

[10]Jointly issued by Taobao from the Alibaba Co. and the data centre of China Business News (CBNData). The report used the 2011-2015 online shopping data from the largest online shopping platform (www.taobao.com) in China. The report is written in Chinese.

5.2.2. *Food delivery*

We continue to study the O2O scenario of food delivery for retired couples, which is not fully discussed in existing studies. In China, there are several large food-delivery internet platforms, e.g., Meituan and Eleme. Not only fast food is delivered, but also quality food from fine restaurants can be ordered. Such service largely saves the travel time to the restaurant and the waiting time at hot restaurants, which can be more than one hour. Evidence[11] shows that the number of users for such food delivery service in China has reached 150 million, by which people's lifestyles are considerably reshaped.

The retired population is a particularly suitable population for such services because such services substantially increase their accessibility to all types of food and at the same time saves travel and waiting time and energy. Therefore, we select those couples whose travel time to a restaurant is more than thirty minutes as the research population, a portion that includes 22% of the retired population in our sample. We assume that their eating time remained the same. Therefore, only travel time to and from the restaurant is saved. We investigate how these couples reschedule the saved travel time for their daily activities.

Results suggest that the participations of all out-of-home activities are not substantially changed. However, the durations of leisure activities are slightly increased by approximately 5%. Similar to online shopping, most couples would spend the saved travel time only to remain at home. The convenient service appears to encourage people to partake in fewer out-of-home activities.

Note that the simulations are based on assumptions that the durations of online shopping and eating delivered food are the same as are actual out-of-home participations. In reality, the online shopping duration can be longer because online shopping is not as energy-consuming as shopping in a mall, and the duration of eating at-home can be shorter because the waiting time at the restaurant can be saved. In addition, the social-demographic might be different as the internet generation retires. Longitudinal studies are required to fine-tune the model and update the experiments.

5.2.3. *Telecommuting*

Although Hong Kong is a very dense city, more than 13% of workers in our sample have commuting times of more than 1 hour per trip. We investigate how a telecommuting policy changes their daily activities. In particular, would they reschedule more time for out-of-home activities, such as eating-out and leisure, to improve their quality of life.

However, we are unsure whether the long-commute workers are the most suitable population for the

[11] From the 38th "Survey on Chinese internet development" by China Internet Network Information Centre (CNNIC). The report is issued in 2016, and written in Chinese.

telecommuting policy. Therefore, we conducted another experiment for the workers whose working time is longer than 12 hours. These workers include 16% of the working population in our sample.

Results show that the telecommuting policy significantly changes the long-commute workers' daily activities. The participations of non-mandatory out-of-home activities double, and the durations are slightly increased. Concerning the long-workday workers, the telecommuting policy is not as effective as the one for long-commute workers. The reason is that the policy does not substantially reduce their mandatory time, and they therefore lack sufficient time for out-of-home activities after work. In all, the long-commute workers would be the most suitable population for the telecommuting policy.

5.3. Summary of the scenario analyses

In all, Table 9 summaries the scenario analyses and the implications from four scenario analyses. Results emphasises the importance of considering intra-household interactions for policy evaluation. In particular, it sheds light on how future built environment and lifestyles reshape our activity patterns, and how eventually change the travel behaviours. It appears that dual-earner workers lack sufficient time for non-mandatory out-of-home activities, so the saved travel time significantly change their activities and time allocation. However, those who are retired have sufficient time; the benefit of saved travel time appears marginal.

Table 9: Results of scenarios analysis.

<table>
<tr><th>Scenarios</th><th colspan="2">Population</th><th>Result</th><th>Implications</th></tr>
<tr><td>Improved transportation system</td><td colspan="2">All populations</td><td>All households' utilities are increased</td><td>(1) The traveller and the spouse are all benefited.
(2) Considering intra-household interaction is critical for investment.</td></tr>
<tr><td>Online shopping</td><td>Retired couples</td><td>Travel time to shopping mall > 30 minutes</td><td>Not significantly changed</td><td rowspan="2">(1) The saved travel time is not reallocated to other out-of-home activities.
(2) The convenient O2O services may discourage people from partaking in out-of-home activities</td></tr>
<tr><td>Food delivery</td><td>Retired couples</td><td>Travel time to restaurant > 30 minutes</td><td>Not significantly changed</td></tr>
<tr><td rowspan="2">Telecommuting</td><td rowspan="2">Working couples</td><td>Commuting time > 1 hour</td><td>More out-of-home activities</td><td rowspan="2">(1) The policy is not equally effective for all workers.
(2) Telecommuting is suitable for the long-commuting population</td></tr>
<tr><td>Working time > 12 hours</td><td>Not significantly changed</td></tr>
</table>

The purpose of the scenario analysis is to show that our model can be applied for policy evaluation and future scenarios analysis. It shows that our model is practical and easy to use. In addition, although some settings of the scenarios are based on other materials other than survey, results still shed light on how improvement of the transportation system will benefit the whole society, and how would a completely different policy might be chosen if we do not consider the intra-household interaction in activity-travel behaviours modelling. However, readers should note that and the results might be not applicable if the actual situations are different or changed. More detailed settings and more sophisticated approaches to generate the missing data would help to achieve a better analysis result.

6. Discussions and implications

6.1. Walkability and social exclusion of the retired population

Walking is found to be the most important transportation mode for retired couples, which is different from working couples and is consistent with the findings from existing studies, in which the older population has a strong need for a fine walking environment in the urban area with mixed land use and in a transit-dependent city such as Hong Kong.

Our results reveal that there might be a ”social exclusion” issue for the retired population in poor economic condition, in which they might engage in out-of-home activities with a lower frequency. This finding resembles the results of many previous studies. However, this issue could be more severe, because the pension in Hong Kong is paid at once instead of monthly. It is possible that the retired would face even more severe poverty and social exclusion issues as they become older.

6.2. Intra-household interactions

Empirical analysis shows that the developed model considering intra-household interactions outperforms the independent model in terms of goodness-of-fit. It sheds light on research and application, in which the development and analysis of activity-based models should fully consider the group decision mechanism. Otherwise, transportation policies such as new rail construction and transit optimisation would be wrongly evaluated, and the improvement might be underestimated. The cost-benefit of investment in rail construction, transit subsidies, and walking environment improvement would be inaccurate.

6.3. Net effect from joint activity compared with solo participation

The intra-household interactions naturally imply the net effect from joint activities compared with solo participation. The net effect can be positive, negative or even neutral, suggesting that the individual considers the joint activity better than, worse than, or the same as solo participation. The net effect can be decomposed into several dimensions in terms of baseline utility and satiation effect, social-demographics, and alternatives.

Results from working couples show that the net effects of baseline utility are all negative, suggesting that the couples would have fewer joint activities compared with solo participation on work days. However, the net effects of satiation are all positive, suggesting that the joint activities have longer durations than solo ones do and implying that working couples might be too busy to participate in joint activities after work; however, once they decide to partake in joint activities, they would spend more time on them compared with solo participation. Concerning retired couples, the net effects of baseline utility and satiation are all positive. It appears that the working and retired couples all enjoy each other's company to make such a time allocation decision. The contrastive study reveals that the very few participations of workers' joint out-of-home activities can be due to the limited available time. When the workers retired, the number of joint activities would substantially increase.

A considerable number of household members obtain negative net effect from the joint activities, revealing the altruistic behaviours of household members in a group decision mechanism. One might sacrifice one's own benefit to maximise the household's overall benefit because the companionship would make the spouse happier (e.g., leisure activity) or more convenient (e.g., maintenance activity such as going to hospital).

6.4. Correlations among joint activities

All joint activities are found significantly correlated, suggesting unobserved household tastes indeed affect household activity decision behaviours. Working couples, who have longer durations in joint out-of-home activities, would also jointly stay at home for a longer time. Retired couples appear to prefer arranging joint shopping and eating out in one trip, but the durations are negatively correlated.

Couples need not like partaking in all activities jointly. For maintenance activities, such as going to the bank or post office, joint participation is generally negatively correlated with other joint activities. This result suggests that, for maintenance activities that can be undertaken by any one household member, joint participation would be less preferred for couples who have more joint "fun" activities (e.g., shopping, eating out and leisure).

Such analysis sheds light on the household activity participation and time allocation analysis from additional perspectives. First, the independency assumptions of activities or alternatives would ignore the unobserved tastes of a household, which would cause inaccuracies in forecasting. Second, not necessarily all joint activities are positively correlated. We decomposed the correlation analysis into baseline utility and satiation effects and discovered interesting results. It is not unusual to specify error terms for components that decide participations and durations (Srinivasan and Bhat, 2006). However, it is the first time with specified error terms in the satiation in an MDCEV structure. Third, it sheds light on policy evaluation, in which a policy target to change one activity would also affect other activities because the household would schedule all activities simultaneously.

6.5. How internet-based services reshape working and retired couples' lifestyles

The development of internet and O2O services has significantly reshaped people's lifestyles. An analysis of these effects is needed. Thus, we perform simulations with the calibrated models for hypothesised scenarios. First, the telecommuting policy is not equally effective for all populations. Our results show that workers who are long-time commuters would benefit more than would long-workday workers. Second, we assume that in the near future, retired couples would be familiar with O2O services such as online shopping and food delivery. Results show that retired couples do not allocate the saved travel time to other activities. Instead, they would stay at home for a longer time. It appears that convenient O2O services discourage couples from partaking in out-of-home activities. A natural concern would be the possible self-social-exclusion problem for the retired population, because out-of-home activities such as shopping and eating out would include more direct and indirect social interactions. How this change of lifestyle affects their physical and mental health remains unknown. Fine-tuned models with fine-grained data and experimental design are required to further evaluate this problem.

7. Conclusions

This paper investigates diverse interactions and correlations in the joint household activity schedule problem. The retired population is studied. In comparison, the working population is analysed for a contrastive study. In particular, couples from two-member households are selected, considering most retired couples live alone without relatives or friends.

A household-level multiple discrete continuous extreme value (MDCEV) model with multiple constraints is developed. A forecasting algorithm is provided. Several interesting results are discovered. First, the group decision mechanism is incorporated to consider intra-household interactions among household members. The developed model outperforms the conventional model in which individuals are considered independent decision makers. Future research and applications should consider using the household rather than the individual as the basic unit. Second, this paper analyses the net effects from joint activity compared with solo participation. Results from our contrastive analysis suggest that the small number of workers' joint out-of-home activities is due to limited available time. Policies such as telecommuting would substantially improve their quality-of-life. Third, the correlations among joint activities are analysed. We discover that couples, who have longer durations for joint non-mandatory out-of-home activities, also would remain at home jointly for longer periods. However, for maintenance activities that can be undertaken by any one person in the household, joint participation is negatively correlated with other joint activities. Finally, results from the contrastive analysis show that walkability is important for the older population in the urban area of a mixed-land-use and transit-dependent city such as Hong Kong.

Based on calibrated models, three scenarios are analysed to investigate how internet technology and online-to-offline services would reshape the households' lifestyles. Telecommuting policy, online shopping and food delivery services are analysed for working and retired couples. Implications are discussed.

This paper only analysed couples in two-member households. Concerning households with more members, and as more activities are analysed, the number of dimensions of correlation becomes large. It would be time-consuming and difficult to successfully estimate all parameters in the model. An efficient approach for model estimation should be further considered (Bhat 2011). In addition, the large number of error terms can be difficult to interpret. The latent variable method would be a possible approach to resolve this problem.

8. Acknowledgements

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