THE EFFECTS OF TRAVEL RELATED CHANGES ON HOUSEHOLDS' DYNAMIC BUDGET ALLOCATION DECISIONS

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Abstract

During the last decade, models have been developed to understand how activity-travel patterns are organized in space and time. However, monetary budgets are not included in these models. Yet, the allocation of monetary budgets is important to understand the precedence of activities. In addition to these models of activity-travel demand, several micro-economic models exist which consider the allocation of time and money budgets to activities but these do not consider activity generation at episode level and, hence, direct implications for travel cannot be deduced. Therefore, in this paper, we propose an approach for modeling dynamic time and monetary allocation decisions of households in the context of dynamic activity based models of transport demand. It offers a framework for analyzing and modeling households' responses to changing land use and transport policies and to potential shifts in exogenous factors such as cost and income changes. We introduce the model and discuss the properties of it.

Keywords: time budget, monetary budget, activity based model, dynamics

1. INTRODUCTION

One of the important aspects when evaluating alternative urban plans from the perspective of sustainable development concerns their impact on travel and accessibility. Typically, travel demand models and traffic assignment models are used to evaluate travel and accessibility impacts. Since the mid 1990s, activity-based models have been developed to better represent the decision mechanisms of individuals and households, to understand how time is spent on activities and travel and how activity-travel patterns emerge in time and space. The time constraint is a significant concept in most of these studies such as Albatross (Arentze and Timmermans, 2004) and Tasha (Miller et al., 2003) as their aim is to understand the allocation of time to activities and how this affects the timing and duration of trips. However, these models do not include monetary budgets as an explanatory variable. Yet, many activities require money directly or indirectly and the allocation of monetary budgets is important to understand the occurrence of activities and their associated travel. In this context, the impact of income and monetary budgets on activity participation and travel, in relation to the costs of activities, travel and goods has received limited attention in the urban planning literature and beyond. However, on the longer run, both household incomes as well as prices of petrol, goods and agricultural products may significantly change, due to economic developments, depletion of materials of changes in demand. A striking example is the 2009 financial and economic crisis, which has affected activity patterns, travel decisions and expenditures of households. As a logical consequence, it created a renewed interest in examining household monetary budgets to understand how households allocate their money to activities, travel and goods and how they re-organized their activities in time and space given a more limited budget. These changing budget constraints and varying elasticities will have short-term and long-term effects on activity-travel patterns and may influence the (dis)functioning of our cities.

The importance of monetary constraints in activity participation and time use has been recognized in economic literature since 1965 by Becker. In his time allocation model, income was added as a constraint. Later, De Serpa (1971) and Evans (1972) proposed improvements and modifications of this seminal model. According to these micro-economic theories of time allocation, utility is a function of time spent on different activities and the consumption of goods during the activities. Constraints are derived from limitations in time and money budgets available for activities so that trade-offs have to be made between these budgets. Households are considered as both production and consumption units. They use time and goods to produce more commodities. A limitation of this early work, however, is that these theories do not consider the frequency and duration of activities in each episode. For instance, the utility derived from performing one activity for an hour in a week and for performing the activity three times in a week for 20 minutes is the same, which is not realistic. Moreover, the spatial organization of activities and travel is not considered explicitly in these models although location is important to understand how the activity-travel patterns are organized in space.

To address these issues, several extensions of time allocation models have been proposed (e.g. Jara-Diaz 1994, Kraan 1995, Jara-Diaz and Martinez 1999, Ettema and Timmermans 2007, Anas 2007). These models extended the time allocation models by including spatial aspects and explanatory variables. However, these models have some limitations to predict longer term changes and to explain the dynamic nature of the activities as well.

In our modeling framework, we argue that money, time and location affect the quality of time and quality of commodities. Spending money for increasing quality is not considered in traditional micro-economic formulations. However, it is important in order to understand the income and cost affects on activity patterns. In earlier models, both time and income limitations are considered. Nevertheless, these limitations are not considered within activities as people make trade-offs between time and money and decides the precedence of activities which allows us to understand spatial settings and longer term decisions.

Since Becker (1965), time and money budgets are conceptualized as resources and the decisions of households on allocation of these budgets are modeled to assign the available resources optimally for maximizing the total utility that households derive. However, activities are the result of a continuous decision making process. Thus, this approach is contrary to the dynamic nature of activity and travel because the needs, demands and constraints are not always the same between days for these activities and because the physical and social environment can change over time. In recent years, the first dynamic modeling attempts have been published (e.g. Ettema et al. (2007), Arentze et al. (2009)). These studies showed that it is important to incorporate budget allocation decisions in dynamic activity-travel models to better understand the complex structure of land use and transportation interaction.

In this paper, therefore we propose an approach for modeling time and money allocation decisions of households including frequency choice of activities. It offers a framework for analyzing and modeling households' responses to changing land use and transport policies and to potential shifts in exogenous factors such as cost and income changes. However, in this paper, we will only discuss travel-related changes such as increases or decreases in travel costs and their effects on activities.

The paper is structured as follows. In Section 2, we continue with the related works that were done before. In Section 3, we first introduce the basic concepts of our model and then we continue with modeling framework. In Section 4, the model is illustrated. Finally, we conclude the paper by discussing major conclusions and possibilities for future research.

2. RELATED WORK

In this section, micro-economic consumer theories of time are discussed as a base to integrate activity based models of transport demand and time and money allocation theory.

Micro-economic theory typically concentrates on describing how individuals decide about which and how much goods to consume for gaining the highest utility, subject to their available budget. Micro-economic theory can also be used for allocating other sources to activities. Therefore, this theory was used to explain the amount of time that is spent on the consumption of goods during activities within the given time and money budgets.

In the economic literature, the role of time started to be discussed in 1965 by Becker. According to Becker, utility is maximized by the time spent on activities and the goods consumed during the activities. He pointed out that market goods are not consumed when they are bought but they are needed to be converted into basic products and this conversion needs time. In his model, income is an endogenous variable as individuals can decide how many hours to work. Therefore, there are two constraints which are money and time and he combined these constraints by suggesting that time can be converted into goods. For instance, by working more hours, you can earn more money to buy goods. After Becker, Johnson (1966) and Oort (1969) used the time constraint to understand the effect of travel time when modeling trip generation. However, they applied a limited formulation by including work time in the utility function.

In De Serpa's model (1971), time and goods are included in the utility function as by Becker, but consumption of each good is considered as an activity. Utility depends on time needed for consumption of goods and the amount of goods consumed. In this model, constraints are derived from available income, available time and time needed for consumption of a good. Time and income constraints are represented as independent equations. He also points out that saving time from an activity creates more time for other activities to increase the utility.

According to Evans (1972), utility is derived from the time spent on activities subject to time and income constraints. In his formulation, activities are the central subject which makes it the first micro-economic model dealing with activities. Type of activity is the main source of utility and the utility can be measured by the amount of time assigned to that activity within a given period. Activities cost money as they need the input of goods to be conducted. In his formulation, cost constraints stem from the amount of goods per unit time which are needed for an activity and the price of one unit of a good. Moreover, time spent on an activity is the source of direct utility. Expenses and income also depend on time spent on consumption and work activities respectively. In addition, the time spent on one activity can be related to the time spent on another activity via the time constraint.

These theories and models point out that individuals do not obtain utility from only one activity but they obtain it from an activity-travel pattern which contains multiple activities. Moreover, these activities are interdependent due to time and money budgets since activities and travel need time and money to be conducted. Therefore, they describe how time and monetary shifts lead to patterns of substitution within the activity-travel pattern. The models mentioned in this section are useful to understand how individuals allocate time and money to activities and goods. As we mentioned above, these works have limitations when applying them to activity-based travel demand models as they do not consider the frequency, and duration of activities in each episode. Moreover, the spatial organization of activities and travel is not considered explicitly in these models.

3. THE MODELING FRAMEWORK

3.1. Basic Concepts

Individuals make decisions for both long and short-term periods. The long-term decisions can be exemplified as the choice of dwelling, work location, employment, etc. These are not made so often but they are important because they determine the constraints for short-term decisions which are made on daily basis such as daily shopping, going out for dinner, etc. We assume that these constraints are temporal and monetary. The most important temporal constraint is the total amount of time that individuals can spend on their activities. During a day, the total available time for daily activity pattern is 24 hours. In addition, individuals have also limited amount of money available, depending on their income.

The time spent on an activity can be defined simply as the duration of an activity plus travel time (if there is travel). If the activity duration is known for each activity episode, then frequency is required to obtain the total amount of time spent on the activity. Money is spent on activities as well as on the dwelling and durable goods which are used during the activities.

While conducting an activity, individuals obtain a certain amount of satisfaction or utility. Our model assumes that the utility of activities can be explained as the sum of *process utility* and *product utility* (Winston, 1987). Process utility is the utility derived from conducting the activity directly while product utility is the utility derived from postponed consumption of products produced by the activity. For instance, possible pleasure derived directly from cooking is the process utility while utility derived from consumption of the prepared food is the product utility. Thus, in this example an individual receives not only process utility but also product utility. However, some activities do not result in any product. For these activities, individuals only receive the process utility. For instance, one does not get any product at the end of watching TV (except, possibly, information) and therefore the utility derived from this activity is only the process utility. For realizing both process and product utility, time and money are spent.

Money that is spent on activities can be either fixed or variable and discretionary. Fixed expenditures are spent only once in a determined period of time such as rent of the dwelling. Moreover, some activities have fixed costs which can be paid at each occurrence of the activity. For instance, if someone decides to do an activity which has fixed cost, such as going to the cinema, there is no choice to pay less or more than the ticket price as it is fixed. Discretionary expenditures vary from situation to situation and depend on a decision of the person which may be influenced by the activity duration such as the case in going out, leisure shopping etc. If the duration of the activity is longer, the amount of expenditure made will be higher. Also, there are travel-related expenditures in the longer term such as the purchase of a car or purchase of a season train ticket and expenditures that are made in the shorter term such as the running costs of a car each time when one travels. In addition, individuals spend money to conduct activities by buying necessary input goods. These goods can be split into durable and non-durable goods. For instance, for a washing activity one needs to purchase a washing machine which is a durable good and one needs to purchase detergent for washing to get clean clothes which is a non-durable good. Or, in another example, one needs to purchase a stove to cook which is a durable good and needs to purchase food to prepare the meal which is a non-durable good.

The important question is how the available amounts of time and money are allocated to activities. It should be noted that utility is affected by both the input of time and money, implying that at least for some activities time and money can be substitutes for each other. For example, people make trade-offs between time gained by using a washing machine for a washing activity and money saved by washing by hand instead of buying a washing machine. Thus, an important observation is that people make trade-offs between time and money budgets. As time and money are both limited resources, "utility of an additional unit time spent", which expresses the quality of time, and "utility of an additional unit good bought", which expresses the quality of goods, determine how time and money are allocated.

The dwelling and durable goods, which are the outcome of long-term decisions of individuals are used during the activities and affect both process and product utility for the activities that they are used for. Individuals do not buy these for each episode, but they have secondary effects as well as they put time and money constraints on activities. Therefore, people make trade-offs between long term investments in facilities and daily time and money expenditures. We deal with this by using a scenario based approach. For instance, if one considers moving, there will be two scenarios: a new house and a scenario of the existing house. The net utility of moving then is determined as the difference in utility between the scenarios under best time and money allocations to activities under each scenario. For instance; buying a more expensive house would cause more expenditure for the house. Thus, more expenditure for a house would increase the utility per unit time for at home activities which means that moving has an influence on the function for utility of time. For instance, a more expensive house may have a garden and one can enjoy spending time at the garden which would increase the utility of time that is spent at-home. However, the increase in the money spent on a dwelling might involve a decrease in the expenditure to activities and to durable goods if budgets stay the same. Furthermore, location of the dwelling may change the activity pattern. If one moves to a house closer to the working place, less time will be spent for travel between home and work. Thus, time available for other activities will increase. Moreover, it would cause a decrease in travel expenditure so that more money can be allocated to other activities. Furthermore, choosing a house in a more attractive district would also cause an increase in utility of living.

Therefore, the trade-offs between time and money can be used to examine the behavioral dimensions such as long-term and short-term decisions such as buying a car, choosing work location, etc. (Jara-Diaz and Martinez, 1999).

The location of an activity is also important to understand the expenditures of time and money allocated to activities. It has a two-way effect on activity-travel choices. First, by spending more time or money on traveling one could reach a more attractive location (process or product utility), while the location of an activity may also affect the amount of time and money one wishes to spend during the activity. For instance, if a location is attractive such as going to a restaurant in an exclusive area then one might wish to spend more money and/or time there. Secondly, the location can influence time and money spent directly if locations differ in terms of price levels (e.g. an expensive shopping center) or speed of service (queues) in addition of that the location of activity affects expenditures of time and money to travel. These amounts of travel time and expenditures cannot be spent on other activities and decrease the available budget for other activities.

Travel has indirect utility on activities. For instance, a faster transport mode allows one to reach a chosen location quicker. Therefore, the duration of the travel will decrease and time will be saved for spending on other activities. In turn, spending more time on other activities can bring process utility and product utility, since products are the function of time spent during the activity. Moreover, one can go to further locations by car since a wider radius brings better locations in reach, which will make them gain more process and product utility. Travel may also have process utility itself. For instance one may like riding a bicycle and consequently derive process utility from it. However, we assume that people spend time and money for travel for the utility of activities it brings within reach even though it has a negative effect on total utility of activities because these travel time and expenditures cannot be spent on other activities.

Another issue in the model is the role of shopping activity. A shopping activity has only process utility and indirect utility gained from other activities that use the goods bought during shopping. For these other activities, we consider how much money is spent for the goods that are used. However, people buy the goods that are used in activities during the shopping activity. This might cause double counting for the money spent to buy goods. Therefore, we assume that what is spent on shopping is counted in the activity where it is used. Thus, shopping activity enables households to get the goods. In each good requiring activity, the stocks of goods are consumed and as a result utility is gained. For instance, soap used during the washing activity is bought at the shopping activity but it is counted as expenses during the washing activity. Moreover, for semi- durable goods, utility is gained from the activities where those durable goods are used. For instance, if one buys a nice dress for going out, the utility is not gained from the shopping activity but gained from the activities that are conducted while this dress is worn for going out. The expenditure that is spent on the dress is considered as an "expenditure" made for the going out activity. If one wears the dress several times for going out then it affects the process utility of going out.

3.2. Utility Function

Given the above considerations, we assume that total utility of an activity is the overall sum of utility across activities, as follows:.

$$U_h^{ATOT}(l, m, f, T^A, E^{pr}, l^{\oplus}, p, T^S) = \sum_{i \in J_h} U_i^A(l_i, f_i, T_i^A, E_i^{pr}, l^{\oplus}, p_i, T_i^S) \quad (1)$$

where,

1. duration of activity, T^A;
2. frequency of activity, *f;*
3. location of the activity, *l;*
4. time spent for searching the goods to buy, T^S;
5. money spent each episode for process utility, E^{pr};
6. price per unit good, *p,* which determines the amount of money spent each episode for product utility;
7. location of the shopping activity, $l^{\oplus}$;
8. mode of transport, *m*

and J_h is a set of activities that contains personal activities and household activities. Personal activities are conducted by individuals for personal needs while household activities can be conducted by both (or multiple) persons and serve household needs. Thus, *h* can be a person doing a personal activity *i* from a set of personal activities J_h for personal needs and it can also be the household doing a household activity *i* from a set of household activities J_h for household needs.

The total utility of activity per episode that individuals gain is the sum of the utility of travel and the utility of the activity as in the following equation:

$$U_i^A(l, m, f, T^A, E^{pr}, l^{\oplus}, p, T^S) = U^M(l, m) + U_i^A(l, f, T^A, E^{pr}, l^{\oplus}, p, T^S) \quad (2)$$

where U_i^A is the utility of activity *i* per episode and U^M is the utility of travel per episode.

The utility of activity per episode is the sum of *process utility* and *product utility.* Process utility is derived from the duration, T^A, frequency of activity, *f*, and the (average) utility of per unit time spent for the activity, u_{ti}. Utility per unit time spent depends on the location of activity, *l*, and money spent each episode for process utility, E^{pr}. Product utility is derived from frequency, *f*, amount of products obtained in each episode for product utility, G_i and utility per unit goods bought for the activity u_{gi}. Amount of products obtained in each episode for product utility of the activity depends on the duration of the activity, T^A, whereas utility per unit goods bought for the activity depends on the location of the shopping activity, $l^{\oplus}$, as the goods are bought during shopping but used during the activities that they are bought for, price per unit goods bought, *p*, and the time spent for searching the goods, T^S, to use during the activity to produce products. The following utility function captures these notions:

$$U_i{}^A(l, f, T^A, E^{pr}, l^{\oplus}, T^S, p) = \frac{1}{f}\left[\ln(f \times T^A) \times u_{ti}(l, E^{pr}) + \ln(f \times G_i(T^A)) \times u_{gi}(l^{\oplus}, p, T^S)\right] \quad (3)$$

Utility derived from activities depends on the frequency. One can choose to conduct an activity with higher frequency to gain more utility, even if the total time stays the same. For instance, one can choose to go to a sport centre for an hour/week or can choose to go there 3 times for 20 minutes each. Individuals decide on frequency of activities to maximize utility. For instance, one can go to the beach and eat ice cream every day. However; the same amount of utility will not be obtained every day. Therefore, one can derive more utility from each episode by reducing the frequency of the activity. Furthermore, mandatory activities such as work have fixed frequencies that are decided in the context of long term decisions. The function above (eqn.3) calculates the utility of an activity per episode as an average across episodes by multiplying with 1/f which allows us to apply this model to describe repetitive behavior. In this function, also the logarithmic function is applied to total time and total products obtained for each activity to satisfy the assumption that process utility and product utility increases with diminishing marginal utility as the time allocated to activity and products obtained for each episode increases.

The duration of the activity in each episode also determines the utility, given the levels of the other input variables. For process utility, over the range of duration the utility one gets increases but with decreasing marginal utility due to saturation. Thus, starting a new activity brings more utility then spending more time on an ongoing activity, but at the same time requires that more time needs to be invested at least for the extra travel and possibly also for the activity (as it may take time before an activity in an episode becomes effective). In addition, for product utility, the products obtained are the result of time spent on the activity ($G_i(T^A)$): the longer the duration, the more products are produced. With more products produced, the production increases but with diminishing marginal rate due to saturation. For instance, if one spends more time on shopping then the products that are obtained increase but after a while, one does not need more products. These assumptions are satisfied by using logarithmic functions for total time and total products obtained for each activity.

Utility per unit time spent (u_{ti}) for an activity increases with the money spent during each episode, E^{pr}, to improve the conditions for the activity and with the attractiveness of the location *l*. For instance, one can go out and spend more money on eating /drinking in a café and thus enjoy the time spent on going out more which increases the utility per unit time. Moreover, one can spend the same amount of money for an activity but the utility per unit time increases or decreases according to the location preference. For instance, one can spend the same amount of money for dinner at two different locations but the more attractive location will generate more utility per unit time spent. Utility can also be represented with a logarithmic function of time spent since it increases with decreasing marginal utility if time spent increases.

Utility per unit good bought, u_{gi}, for an activity increases with the quality of the chosen location of the shopping activity, $l^{\oplus}$, price per unit good, *p*, and time spent for searching the goods, T^S. Since goods can be bought at different locations, and at potentially different prices the time needed for searching the goods is different from the total time spent for shopping itself. For instance, the soap to be used in washing activity can be bought in a short time period and in the closest store regardless of the price, or one can choose to save money and spend time for searching cheaper soap of the same quality. The quality of goods is assumed to positively affect the product utility.

As mentioned above, individuals maximize the utility of their activity patterns under time and money constraints. The expenditure that is spent for the process utility in each episode is E^{pr} while the expenditure that is spent for the product utility is the multiplication of price per unit good, *p,* and the amount of products obtained, G_i, in each episode for product utility. Therefore, the total expenditure of an activity per episode, E_i^A, is defined as:

$$E_i^A(E^{pr}, T^A, p) = E^{pr} + p \times G_i(T^A) \qquad (4)$$

Total expenditure that is spent on activity and travel, E_h^{TOT}, is the sum of total expenditure across activities *i* from a set of personal activities J_h of person *h* and travel expenditures, E^M. The latter is a function of mode and location for each activity *i* as follows:

$$E_h^{TOT} = \sum_{i \in J_h} f_i [E_i^A + E^M(m_i, l_i)] \qquad (5)$$

The total time spent is an individual expenditure. It is the sum of total time spent on each activity, total time spent for searching the goods for each activity and the total travel time which is a function of mode and location for each activity and total time spent on working:

$$T_h^{TOT} = T_h^W + \sum_{i \in J_h} f_i [T_i^A + T_i^S + T^M (m_i, l_i)] \qquad (6)$$

Total time, T^{TOT} should be less than or equal to the available time for each person: $T^{TOT} \leq$ available time. In equation 6, total time spent on working is considered as a component of the time constraint since work activity is assumed as a different activity from all other activities, i.e. it does not produce direct utility (only indirect through income) and is fixed in terms of time spent. It may generate process utility as someone likes or dislikes working, but this is disregarded in the model. Income is a function of the time spent on the work activity as seen in the following equation:

$$I = \sum_h (T_h^w \times w_h) + I_h^o \qquad (7)$$

As implied by this equation, total income of the household is the sum of the individual incomes, which depend on total time spent on working, T^W, and wage rate of the workers, w_h, in the household and extra, not-work related income I^o for each of the workers in the household.
The income constraint should be equal by definition to the sum of budget constraints, B_h, of individuals sharing a household and total savings, S, as follows:

$$I = \sum_h B_h + S \qquad (8)$$

Savings S are added to the equation 8 because people may not spend all the income and can save some money at the end of the month, but they can also exceed the budget by spending from existing savings. In addition, individuals in one household spend the income to household/shared needs but also to their personal needs. If there are two persons in the household then there will be three budgets which are personal budgets of each person as shown in equation 9 and the household budget as shown in equation 10.

$$B_h = E_h^{TOT} + E_h^D \quad \text{where } B_h \text{ is a personal budget} \qquad (9)$$

$$B_h = E_h^{TOT} + E_h^H + E_h^D \quad \text{where } B_h \text{ is a household budget} \qquad (10)$$

The household budget constraint is the sum of three components: total expenditure to activities and travel E_h^{TOT}, expenditure to dwelling E^H and expenditure to durable goods E^D as shown in equation 10. The personal budget constraint is the sum of two components as total expenditure to activities and travel E_h^{TOT} and expenditure to durable goods E^D as shown in equation 9.

3.3. Model Specification

In this sub-section, we propose further specifications of the functions involved in the above framework. First, regarding the costs of travelling we propose the following function:

$$E^M(m_i,l_i) = \left(c^M(m_i) \times d^M(m_i,l_i)\right) + C^M(m_i) \tag{11}$$

where $d^M(m_i,l_i)$ is travelled distance given mode choice *m* and location choice *l* of activity *i*, $c^M(m_i)$ is per unit travel cost for using mode *m* and $C^M(m_i)$ is fixed travel cost for using mode *m*. Travel time is calculated as:

$$T^M(m_i,l_i) = d^M(m_i,l_i) / S^M(m_i) \tag{12}$$

where $d^M(m_i,l_i)$ is travelled distance given mode choice *m* and location choice *l* of activity *i*, $S^M(m_i)$ is the average speed of using mode *m*.

With regard to the product utility of activities, we assume that products obtained G_i are an increasing function of the time spent on the activity *i* with a decreasing rate, which is expressed with a logarithmic function given by:

$$G_i(T^A) = \alpha_i \ln\left(T^A\right) \tag{13}$$

α_i represents a productivity which we model as a function of characteristics of individuals:

$$\alpha_i = f\left(X_h\right) \tag{14}$$

where *h* is the person conducting activity *i* and X_h is a vector of characteristics of person *h* such as socio-demographics.

In addition, we assume that the money spent on each activity increases the average utility per unit time for activity *i* with diminishing marginal utility in interaction with the attractiveness of the location where the activity is conducted. However, in the general case, without spending money on an activity, the activity has a base utility at the location of the activity. The proposed function is defined as;

$$u_{ti}(l, E^{pr}) = \beta_l^0 + \beta_l \ln\left(E^{pr}\right) \tag{15}$$

where β_l^0 is the base utility per unit time spent of activity *i* at location *l* and $\beta_l \ln\left(E^{pr}\right)$ is the increase of utility of activity *i* at location *l* when money is spent on each episode of activity *i*. The base utility is further specified as:

$$\beta_l^0 = \sum_s \beta_s^0 X_{ls} \tag{16}$$

where β_s^0 are parameters and X_{ls} values of attributes *s* of location *l* of activity *i*. The expenditure related term is, similarly, specified as:

$$\beta_l = \sum_m \beta_m^0 X_{lm} \tag{17}$$

where β_m^0 are parameters and X_{lm} values of attributes *m* of location *l* of activity *i*.

Furthermore, we assume that utility per unit good bought for an activity *i* increases with the quality of chosen location of the shopping activity, price per unit good and time spent for searching the goods. Price per unit good and time spent for searching the goods increases the utility per unit goods bought with diminishing marginal utility. In the general case, the activity itself has a base utility per unit goods bought without spending time for searching the goods and money for the goods that are given by the equation:

$$u_{gi}(l^{\oplus}, T^s, p) = \beta_{l^{\oplus}}^0 + \beta_{l^{\oplus}} \ln\left(T^s\right)\ln(p) \tag{18}$$

where $\beta_{l^{\oplus}}^0$ is the base utility per unit good bought of activity *i* at location of the shopping activity $l^{\oplus}$ and $\beta_{l^{\oplus}} \ln\left(T^s\right)\ln(p)$ is the increase of utility of activity *i* at location $l^{\oplus}$ when time for searching the goods and money is spent on activity *i*. We further parameterize these terms as:

$$\beta_{l^{\oplus}}^0 = \sum_s \beta_s^0 X_{l^{\otimes}s} \tag{19}$$

$$\beta_{l^{\oplus}} = \sum_m \beta_n^0 X_{l^{\otimes}n} \tag{20}$$

where β_s^0 and β_n^0 are parameters and $X_{l^{\oplus}s}$ and $X_{l^{\oplus}n}$ are attributes of the location of the shopping activity $l^{\oplus}$ for activity *i*.

4. Illustration

In this section, we describe some results of simulations conducted to illustrate the model. As an illustration, we consider a scenario where travel costs of a hypothetical household increase. The focus is on activity-travel patterns and how monthly expenditures period of two hypothetic persons in this household are allocated before and after the travel costs increase. We assumed a limited number of activity categories, which however suffices to evaluate the effects of travel costs on personal and household budget changes and its outcomes. Here we only illustrate the changes in money allocation within a household although assuming that time allocation remains unchanged.

The activity list contains at home and out-of-home activities. The out-of-home activities are: work, shopping (daily and non-daily), service-related activities, medical activities and leisure-out-of-home. In addition, the activity list includes the following in-home activities: housekeeping, leisure at home and sleep. Transport modes are subdivided into two categories slow (walking or using bike) and fast modes (car or public transport).

We assume a one-to-one correspondence between some activities and expenditure categories. Goods bought during daily shopping supposedly are consumed during housekeeping activity, so that daily shopping (apart from a possible process utility) has only an indirect (product) utility, namely through the housekeeping activity. On the other hand, non-daily shopping corresponds to the need of durable goods and, hence, also produces only an indirect utility, this time through the consumption of durable goods, which is considered a separate category. Finally, services correspond to personal care and business and this is treated in the same way as non-daily shopping for durable goods. Consumption of durable goods and personal care/business generates utility according to the flowing basic function:

$$U = \alpha_i \ln\left(E^{pr}\right) \tag{21}$$

where E^{pr} is the total expenditure in the context of non-daily shopping (for durables) and services (for personal care/business). The two persons in the household which are referred to as Person 1 (P1) and Person 2 (P2) have the same activity list. Furthermore, they both use fast and slow mode for traveling. Housekeeping and daily shopping are considered as household activities, which can be conducted by both persons and brings shared utility. Therefore, these household activities affect the expenditure of each person in the household that they spend to other activities. Housekeeping activity has both process and product utility. Process utility of housekeeping activity is negative, given the effort it involves, while the product utility of it is positive since at the end persons benefit from its product (tidy and clean house).

Table 1 shows the assumed parameter settings, budgets and travel attributes. P1 is a fulltime worker and has a work activity of 8 hours on each weekday. P2 is also a fulltime worker but has a work activity of 7 hours a day. Therefore, P2 has more available time for non-work activities. P1 earns 1021 Euro per month while P2 earns 893 Euro per month. Each of them pays 250 Euro per month for the housing. There are 7 zones in the hypothetical area which correspond to neighborhoods. For each activity, a probable location was identified for each transport mode as regular locations for that activity by that mode. Due to the location of activities and mode choices P1 pays more for travel expenditures. The cost per unit time for a private car is assumed as 0,5 Euro. Fix travel cost for bus is 1,3 Euro while fix cost for parking fee of a car is 1,4 Euro.

Table 1. Assumed Settings

Activity	Money Budget (Euro)		Time Budget (Minutes)		Location (Beta)	Mode	
	P1	P2	P1	P2		P1	P2
Daily Shopping	0	0	180	315	0.045	1	1
Non-Daily Shopping	0	0	270	140	0.350	2	2
Services	0	0	40	50	0.250	2	2
Medical	20	18	25	20	0.620	1	1
Leisure out of home	112	108	720	630	0.212	2	1
Housekeeping	300	253	600	1125	-	-	-
Leisure at home	60	90	9000	9900	-	-	-
Sleep	0	0	13200	13200	-	-	-
Work	0	0	10560	9240	-	2	2
Expenditure					**Consumption (Alpha)**		
Durable Goods	60	58	-	-	6.1		
Personal Care/Business	40	48	-	-	4.1		

*1 corresponds to slow mode, 2 corresponds to fast mode

For this illustration, a basic goal finding algorithm was used to find the optimal allocation of time and money according to the model. In the optimum, the budgets are fully used and marginal utilities are equal across activities for each constrained resource (money and time). Table 2 shows the results under the base scenario. As it is seen in Table 2, P2 spends more time on housekeeping than P1. This reflects the fact that negative process utility of housekeeping activity is higher for P2. To reduce the effect of process utility of housekeeping activity for P2, P1 pays more in total to raise the product utility of housekeeping.

Table 2. Allocation of money and time for the base scenario

Activity	**P1** (f, T^A, E^{pr})	**P2** (f, T^A, E^{pr})
Daily Shopping	(6,30,0)	(9,35,0)
Non-Daily Shopping	(3,90,0)	(2,70,0)
Services	(2,20,0)	(2,25,0)
Medical	(1,25,20)	(1,20,18)
Leisure out of home	(8,90,14)	(9,70,12)
Leisure at home	(30,300,2)	(30,330,3)
Sleep	(30,440,0)	(30,440,0)
Work	(22,480,0)	(22,420,0)
	P1 $(f_i, T_i^A, E_i^A, T_i^S)$	**P2** $(f_i, T_i^A, E_i^A, T_i^S)$
Housekeeping	(10,60,30,15)	(15,75,16.8,15)

Apart from housekeeping, all other activities are personal. P1 and P2 differ regarding their schedule of activities. As a scenario, we assume an increase in travel costs of 50% for the fast transport mode and consider a case where the individuals only reconsider the allocation of monetary expenditures. Given that destination, transport mode, frequency choices for activities stay the same, the available budget for expenditures decreases. Thus, P1 and P2 should reallocate their monetary budgets to their personal and household activities for the new situation. The reallocation of the budgets is made by keeping the marginal utilities the same at higher levels since less expenditure has higher marginal utility.

Table 3. Expenditure categories and budget (Euro / month)

	Base		**Travel Cost %50 increase**	
Expenditure Categories	**P1**	**P2**	**P1**	**P2**
Medical	20	18	16	17
Housekeeping	300	253	270	237
Leisure out of home	112	108	88	99
Leisure at home	60	90	58	89
Durable Goods	60	58	47	55
Personal Care/Business	40	48	32	45
Travel	179	68	260	101
Housing	250	250	250	250
Total	1021	893	1021	893

As can be seen in Table 3, due to the increase in travel costs the expenditures for activities decrease. It affects the expenditure of P1 more than P2 as P1 has more travel costs. It should be noted that although travel costs (per unit) increase by 50%, travel expenditures increase by less. This implies that travel will be reduced to save budget for maintaining the process and product utility of activities. As a consequence, not only monetary budgets but also time allocations (and frequencies) will be affected.

Table 4. Expenditure categories and utility

	Base		Travel Cost %50 increase	
Expenditure Categories	**P1**	**P2**	**P1**	**P2**
Medical	5,99	4,33	5,54	4,24
Housekeeping	9,57	9,23	9,24	8,99
Leisure out of home	3,69	2,42	3,34	2,34
Leisure at home	1,38	2,23	1,31	2,2
Durable Goods	24,97	20,09	23,48	19,8
Personal Care/Business	15,12	15,6	14,2	15,34
Total	60,72	53,9	57,12	52,91

Table 4 explains that increase in travel expenditures decreases the utility of other activities since the expenditure that is spent for travel cannot be spent on other activities.

5. Conclusion

The anticipated depletion of fossil fuels leading to increased fuel costs have triggered the need to elaborate current activity-based models of transport demand by including explicitly budget allocation. Although theories on budget and time allocation are not new as summarized in this paper, they are limited in scope and therefore need further elaboration.

In this paper, we described how time and money budgets can be integrated in an episode based activity-based model of travel demand. The proposed model enables exchange between time and money budget of individuals and households within their activities. The framework also includes the savings and the expenditure to durable goods and housing. A distinctive characteristic of the model is that it can evaluate policy scenarios in terms of time and monetary budget effects, thus it allows better understanding the impact of income and cost changes on activities and travel. A crucial element of the model to achieve this is the distinction between process and product utility of activities, which allows for an intuitively and theoretically plausible linkage between expenditures, investments, activity engagement and utility.

We have illustrated the model in a simple example. The results of this exercise demonstrate the potential of the model and its underlying concepts and mechanisms. However, for the application of the model, several problems remain for future research. First, to our knowledge, there are no readily available data sets that include sufficient information on both activity patterns and expenditures. This implies that dedicated data need to be collected. Data on existing activity and expenditure patterns may be useful, but in addition consumer responses to dramatically changing situations are crucial for developing dynamic models. We expect that stated adaptation experiments may be useful in this context. Secondly, the model is quite complex. It implies that its operationalisation and estimation presents a challenge and requires additional thought and experimentation. The authors hope to report on these issues in their future publications.

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