A Microeconomic Theory–Based Latent Class Multiple Discrete–Continuous Choice Model of Time Use and Goods Consumption

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A microeconomic theory–based multiple discrete–continuous choice model was developed to accommodate (*a*) both time allocation and goods consumption as decision variables in the utility function, (*b*) both time and money budget constraints governing the activity participation and goods consumption decisions, (*c*) a finite probability of zero consumption and zero time allocation (i.e., corner solutions), and (*d*) technical constraints in the form of minimum consumption levels for any good that would be consumed and minimum time allocation for any activity conducted. The proposed model was applied in the form of a latent class model (to consider heterogeneity) on a Dutch data set to understand the determinants of weekly time use and goods consumption behavior.

To explain individuals' activity participation and travel behavior, the traditional, goods consumption–based consumer theory requires the incorporation of time along with goods into the utility functions, their interrelations, and the recognition of constraints on available time and money (*1–3*). These models are able to disentangle different estimates of the value of time: value of time as a resource, value of working time, and value of assigning time to an activity or travel. This capability is important for the evaluation of transportation policies, because the benefits of travel time reductions can be economically measured by using the different estimated values of time.

Although microeconomic time use models have been gaining traction in the recent past, they are still saddled with at least a few limitations. First, traditional microeconomic models were used to analyze consumption among broad consumption categories (housing, education, etc.). In such analyses, allowing zero consumption (or a corner solution) was not necessary; this property was extended when time was included. However, modern activity-based analysis of time use and goods consumption requires a detailed categorization of activities and goods due to which the consideration of corner solutions becomes important. Second, model formulations should allow the presence of minimum necessary amounts of time for taking part in activities (e.g., minimum necessary time for eating). The few microeconomic models that allow minimum time allocations in the form of technical constraints do not simultaneously allow for corner solutions (i.e., nonparticipation in activities); for example, the work by DeSerpa (*2*), Jara-Díaz et al. (*4*), Jara-Díaz and Astroza (*5*), or Jara-Díaz et al. (*6*) should be reviewed.

In the past decade, a separate stream of research has made significant advances in the context of using sophisticated utility functions for modeling individuals' time-use choices while allowing corner solutions. For example, the multiple discrete-continuous extreme value (MDCEV) model proposed by Bhat (*7*) is based on a microeconomic utility maximization formulation with random utility functions that are easy to interpret, accommodates corner solutions, and yields closed-form probability expressions for observed time allocation patterns. Such multiple discrete-continuous (MDC) model formulations have been applied largely in contexts with time allocation to activities as the only decision variable entering the utility function and a single budget constraint associated with time, which leaves goods consumption out of the picture. In the recent literature, however, there is increasing recognition that both time allocation and goods consumption generate utility and that constraints on both time and money budget govern time use and consumption decisions (*5, 8, 9*), although none of these studies recognize corner solutions in time allocation or goods consumption. More generally, there has been limited research on the use of multiple types of decision variables and multiple constraints within the context of MDC models (*9–11*). Castro et al. presented the multiple constraint–MDCEV model structure considering two constraints: a monetary budget constraint and a time constraint (*9*). However, the formulation does not consider both time allocation and goods consumption separately as decision variables in the utility function and does not accommodate technical constraints, such as minimum values for the decision variables.

The aim of this study is to develop a microeconomic theory–based MDC choice model that considers (*a*) both time allocation and goods consumption separately as decision variables in the utility function, (*b*) both time and money constraints as determinants of activity participation and goods consumption decisions, (*c*) a finite probability of zero consumption and zero time allocation (i.e., corner solutions), and (*d*) technical constraints in the form of minimum consumption levels for any good that is consumed and minimum time allocation for any activity pursued. In addition, following work by Jara-Díaz et al. (*6*),

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the utility function here includes time assigned to work as a decision variable (i.e., work duration is endogenously determined) along with the time allocation to nonwork activities. The work activity provides the link between the two constraints (monetary budget and total available time) and represents the trade-offs portrayed in this model; individuals may assign more (less) time to work to generate more (less) money for buying more (less) goods, but less (more) free time to perform nonwork activities. The application of this proposed model to different segments of the population allows the analyst to capture demographic heterogeneity in preferences and to estimate values of time that vary on the basis of observed demographic variables such as gender, age, and income (*8, 5, 6*). In the current study, heterogeneity in preferences is captured by using the latent class model formulation, which allows a discrete-mixture distribution for model parameters based on observed demographic variables and allows the analyst to endogenously segment the population (*12*).

The proposed model is applied to a 2012 Dutch data set on weekly time use and goods consumption. The empirical model is used to understand the sociodemographic determinants of time allocation and goods consumptions as well as to derive different values of time: value of work time and value of leisure (nonwork) time. These values of time are compared with those from other time use models in the literature that ignore (*a*) corner solutions and minimum consumption or time allocation and (*b*) the entrance of goods consumption to the utility functions along with time allocation. It is also demonstrated that the latent class model helps identify different segments of the population, each with distinct preferences and values of time. To the authors' knowledge, this effort is the first that brings together a multitude of recent advances in microeconomic time use modeling and MDC choice modeling: (*a*) utility specified as a function of both time allocation to activities and consumption of goods, (*b*) explicit recognition of both time and money constraints, (*c*) inclusion of work time in the utility function as well as a generator of income needed for consumption, (*d*) corner solutions in both time allocation and goods consumption, (*e*) technical constraints in the form of minimum time allocation and minimum goods consumption, and (*f*) endogenous market segmentation to capture heterogeneity in a unified framework that is behaviorally more realistic than earlier models and offers useful empirical insights into the determinants of the values of leisure and work time.

METHODOLOGY

An individual q ($q = 1, 2, \ldots, Q$) belonging to a segment g ($g = 1, 2, \ldots, G$) maximizes his or her utility of consuming different goods k ($k = 1, 2, \ldots, K$) and time allocations to different nonwork activities n ($n = 1, 2, \ldots, N$) and work activity w subject to two binding constraints:

$$\max\left(U_q\left(\boldsymbol{x}_q, \boldsymbol{t}_q, t_{qw}\right) \middle| \left(q \in g\right)\right) = \sum_{k=1}^{K} u_{gk}\left(x_{qk}\right) + \sum_{n=1}^{N} \tilde{u}_{gn}\left(t_{qn}\right) + \tilde{u}_{gw}\left(t_{qw}\right) \quad (1)$$

$$\sum_{k=1}^{K} p_{qk} x_{qk} = E_q + \omega_q t_{qw} \quad (2)$$

$$\sum_{n=1}^{N} t_{qn} + t_{qw} = T_q \quad (3)$$

where $U_q(\boldsymbol{x}_q, \boldsymbol{t}_q, t_{qw})|(q \in g)$ is a quasi-concave, increasing and continuously differentiable utility function with respect to consumption of goods and time allocation to activities, given that individual q belongs to market segment g. Specifically, $\boldsymbol{x}_q$ $(= x_{q1}, x_{q2}, \ldots, x_{qk}, \ldots, x_{qK}; x_{qk} \geq 0, \forall k = 1, 2, \ldots, K)$ is the vector of consumption of different goods, $\boldsymbol{t}_q$ $(= t_{q1}, t_{q2}, \ldots, t_{qn}, \ldots, t_{qN}; t_{qn} \geq 0, \forall n = 1, 2, \ldots, N)$ is the vector of time allocation to different nonwork activities, and t_{qw} is the time allocation to work. Equation 2 is the money budget constraint,

where

p_{qk} = unit price of consuming good k for individual q,
E_q = nonwork income of individual q minus fixed expenses such as housing and utilities, and
ω_q = individual's wage rate.

Equation 3 is the time budget constraint, where T_q is the total available time for individual q. This model is implemented for individuals from single-worker households.

From Equation 1, the utility function is defined as an additively separable function of subutilities derived from consuming goods, $u_{gk}(x_{qk})$; subutilities derived from allocating time to nonwork activities, $\tilde{u}_{gn}(t_{qn})$; and a subutility from the time allocated to work, $\tilde{u}_{gw}(t_{qw})$. The functional form of the subutilities follows the linear expenditure system utility form originally proposed by Bhat (*7*), which was extended by Van Nostrand et al. (*13*) to accommodate minimum required consumption and time allocation:

$$u_{gk}\left(x_{qk}\right) = \begin{cases} \psi_{qgk} x_{qk} & \text{if } x_{qk} \leq x_{qk}^0 \\ \psi_{qgk} x_{qk}^0 + \gamma_{qgk} \psi_{qgk} \ln\left(\dfrac{x_{qk} - x_{qk}^0}{\gamma_{qgk}} + 1\right) & \\ & \text{otherwise } x_{qk} > x_{qk}^0 \end{cases}$$

$$\tilde{u}_{gn}\left(t_{qn}\right) = \begin{cases} \tilde{\psi}_{qgn} t_{qn} & \text{if } t_{qn} \leq t_{qn}^0 \\ \tilde{\psi}_{qgn} t_{qn}^0 + \tilde{\gamma}_{qgn} \tilde{\psi}_{qgn} \ln\left(\dfrac{t_{qn} - t_{qn}^0}{\tilde{\gamma}_{qgn}} + 1\right) & \\ & \text{otherwise } t_{qn} > t_{qn}^0 \end{cases}$$

$$\tilde{u}_{gw}\left(t_{qw}\right) = \begin{cases} \tilde{\psi}_{qgw} t_{qw}^0 & \text{if } t_{qw} \leq t_{qw}^0 \\ \tilde{\psi}_{qgw} t_{qw}^0 + \tilde{\psi}_{qgw} \ln\left(t_{qw} - t_{qw}^0\right) & \text{otherwise } t_{qw} > t_{qw}^0 \end{cases} \quad (4)$$

where

ψ_{qgk}, $\tilde{\psi}_{qgn}$, and $\tilde{\psi}_{qgw}$ = baseline marginal utility parameters associated with good k, nonwork activity type n, and work activity, respectively;
x_{qk}^0 = minimum required consumption of good k (if it is consumed);
t_{qn}^0 = minimum amount of time required to conduct activity n (if that activity is conducted); and
t_{qw}^0 = minimum required duration for work.

As with many previous studies, exogenously given minimum levels of goods consumption and time allocation were considered in the current study (*4, 14*). Endogenously determining the minimum levels is beyond the scope of this study. Specifically, x_{qk}^0 is set as the observed minimum level of consumption of good k in the data set, t_{qn}^0 is set as the observed minimum level of time allocation to activity n, and

t^0_{qw} is set as the observed minimum work duration minus 1. The minus 1 in the utility function of work activity ensures that the function is defined and continuously differentiable for all values of t_{qw}. Although this assumption is made for algebraic convenience, it is innocuous because one can interpret t^0_{qw} as one unit less than the minimum required work duration (as opposed to the minimum work duration). As discussed by Van Nostrand et al., the utility derived from consuming a good (time allocation to a nonwork activity) increases linearly until the minimum required amount of consumption (time) is allocated to that good (activity), after which the functional form takes a nonlinear shape to allow diminishing marginal utility (*13*). Because of this functional form, if a good is consumed (time is allocated to an activity), the consumption (time allocation) has to be greater than the minimum values defined earlier. Also, the functional form for $\tilde{u}_{gw}$ implies that work plays the role of an essential alternative that is always allocated a positive amount of time by all workers. For all goods and nonwork activities, the functional form allows corner solutions (i.e., zero consumption or time allocation) because of the presence of +1 in the utility form (*7*).

For an individual q who belongs to segment g, ψ_{qgk}, $\tilde{\psi}_{qgn}$, and $\tilde{\psi}_{qgw}$ are the baseline marginal utility parameters associated with good k, nonwork activity type n, and work activity, respectively, representing marginal utilities at zero values of the corresponding consumption or time allocation. A greater value of the baseline marginal utility parameter for an alternative good or nonwork activity suggests a greater likelihood of choice and a greater amount of consumption of that alternative. Satiation parameters for good k and nonwork activity n are γ_{qgk} and $\tilde{\gamma}_{qgn}$, respectively; a greater value of the satiation parameter suggests a greater amount of consumption of that alternative.

The optimal values of goods consumption, nonwork time allocation, and work time allocation may be solved by the following Lagrangian function for the optimization problem in Equations 1 to 3 and deriving the Karush–Kuhn–Tucker (KKT) conditions of optimality. The Lagrangian function for the individual q given that he or she belongs to segment g corresponds to

$$l_{qg}(\boldsymbol{x}_q, \boldsymbol{t}_q, t_{qw}, \lambda_{qg}, \mu_{qg}) = U_q(\boldsymbol{x}_q, \boldsymbol{t}_q, t_{qw}) + \lambda_{qg}\left(E_q + \omega_q t_{qw} - \sum_{k=1}^{K} p_{qk}x_{qk}\right) + \mu_{qg}\left(T_q - t_{qw} - \sum_{n=1}^{N} t_{qn}\right) \tag{5}$$

where λ_{qg} and μ_{qg} are segment g–specific Lagrangian multipliers for the budget and time constraints; they represent the marginal utilities of expenditure and time, respectively (i.e., the marginal utilities due to a marginal relaxation of the time and budget constraints, respectively). The KKT conditions for optimal consumption and time allocation (x^*_{qk}, t^*_{qn}, and t^*_{qw}) are as follows:

$$\begin{aligned}
&u'_{gk}(x^*_{qk}) - \lambda_{qg}p_{qk} = 0 && \text{if } x^*_{qk} > 0, k = 1, 2, \dots, K\\
&u'_{gk}(x^*_{qk}) - \lambda_{qg}p_{qk} < 0 && \text{if } x^*_{qk} = 0, k = 1, 2, \dots, K\\
&\tilde{u}'_{gn}(t^*_{qn}) - \mu_{qg} = 0 && \text{if } t^*_{qn} > 0, n = 1, 2, \dots, N\\
&\tilde{u}'_{gn}(t^*_{qn}) - \mu_{qg} < 0 && \text{if } t^*_{qn} = 0, n = 1, 2, \dots, N\\
&\tilde{u}'_{gw}(t^*_{qw}) + \omega_q\lambda_{qg} - \mu_{qg} = 0 &&
\end{aligned} \tag{6}$$

where $u'_{gk}(x^*_{qk})$, $\tilde{u}'_{gn}(t^*_{qn})$, and $\tilde{u}'_{gw}(t^*_{qw})$ are the marginal utility functions, defined as follows:

$$u'_{gk}(x^*_{qk}) = \begin{cases} \psi_{qgk} & \text{if } x^*_{qk} \le x^0_{qk} \\ \psi_{qgk}\left(\dfrac{x^*_{qk} - x^0_{qk}}{\gamma_{qgk}} + 1\right)^{-1} & \text{otherwise } x^*_{qk} \ge x^0_{qk} \end{cases}$$

$$\tilde{u}'_{gn}(t^*_{qn}) = \begin{cases} \tilde{\psi}_{qgn} & \text{if } t^*_{qn} \le t^0_{qn} \\ \tilde{\psi}_{qgn}\left(\dfrac{t^*_{qn} - t^0_{qn}}{\gamma_{qgn}} + 1\right)^{-1} & \text{otherwise } t^*_{qn} \ge t^0_{qn} \end{cases}$$

and

$$\tilde{u}'_{gw}(t^*_{qw}) = \begin{cases} \tilde{\psi}_{qgw} & \text{if } t^*_{qw} \le t^0_{qw} \\ \tilde{\psi}_{qgw}\left(t^*_{qw} - t^0_{qw}\right)^{-1} & \text{otherwise } t^*_{qw} > t^0_{qw} \end{cases} \tag{7}$$

The optimal consumption (of goods) and time allocation (to activities) satisfies the KKT conditions in Equation 6 and the money budget and time constraints (Equations 2 and 3), respectively. Good 1 is denoted as the good to which the individual allocates nonzero consumption (the individual has to participate in at least one of the K purposes). The corresponding KKT condition is

$$\psi_{qg1}\left(\frac{x^*_{q1} - x^0_{q1}}{\gamma_{qg1}} + 1\right)^{-1} - \lambda_{qg}p_{q1} = 0$$

in which λ_{qg} may be expressed as follows:

$$\lambda_{qg} = \frac{\psi_{qg1}}{p_{q1}}\left(\frac{x^*_{q1} - x^0_{q1}}{\gamma_{qg1}} + 1\right)^{-1} = \frac{u'_{g1}(x^*_{q1})}{p_{q1}} \tag{8}$$

Because of the form of Equation 8, the subsequent expressions in which λ_{qg} is involved will also be also expressed in reference to Activity 1. Now, because all individuals assign a nonzero amount of time to work (and at least 1 unit above the minimum work duration), the KKT condition for working time is

$$\tilde{\psi}_{qgw}\left(t^*_{qw} - t^0_{qw}\right)^{-1} + \omega_q\lambda_{qg} - \mu_{qg} = 0 \tag{9}$$

Replacing λ_{qg} from Equation 8 in Equation 9, the expression for μ_{qg} may be written as follows:

$$\begin{aligned}
\mu_{qg} &= \tilde{\psi}_{qgw}\left(t^*_{qw} - t^0_{qw}\right)^{-1} + \omega_q\frac{\psi_{qg1}}{p_{q1}}\left(\frac{x^*_{q1} - x^0_{q1}}{\gamma_{qg1}} + 1\right)^{-1}\\
&= \tilde{u}'_{gw}(t^*_{qw}) + \omega_q\frac{u'_{g1}(x^*_{q1})}{p_{q1}}
\end{aligned} \tag{10}$$

Substituting λ_{qg} and μ_{qg} into Equation 6, the KKT conditions may be rewritten as

$$\begin{aligned}
&\frac{u'_{gk}(x^*_{qk})}{p_{qk}} = \frac{u'_{g1}(x^*_{q1})}{p_{q1}} && \text{if } x^*_{qk} > 0, k = 2, \dots, K\\
&\frac{u'_{gk}(x^*_{qk})}{p_{qk}} < \frac{u'_{g1}(x^*_{q1})}{p_{q1}} && \text{otherwise } x^*_{qk} = 0, k = 2, \dots, K
\end{aligned}$$

$$\tilde{u}'_{gn}\left(t^*_{qn}\right) = \tilde{u}'_{gw}\left(t^*_{qw}\right) + \omega_q \frac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}} \qquad \text{if } t^*_{qn} > 0, n = 1, 2, \ldots, N$$

$$\tilde{u}'_{gn}\left(t^*_{qn}\right) < \tilde{u}'_{gw}\left(t^*_{qw}\right) + \omega_q \frac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}} \qquad \text{otherwise } t^*_{qn} = 0, n = 1, 2, \ldots, N \tag{11}$$

The foregoing KKT conditions have an intuitive interpretation. For any good k, its optimal consumption will either be (*a*) positive such that its price-normalized marginal utility at optimal consumption is equal to the price-normalized marginal utility of good 1 (or any other consumed good) at its optimal consumption point or (*b*) zero if the price-normalized marginal utility at zero consumption for good k is less than the price-normalized marginal utility of good 1 or any other consumed good. The case of time allocation is similar, where all the activities that are performed have the same marginal utility following a common result in time use models since DeSerpa (*2*), who proposed that all the freely chosen activities (activities that are assigned more time than the necessary minimum) have the same marginal utility. In the context of work, as in Equation 9, the marginal utility of time allocated to work plus the wage rate multiplied by the marginal utility associated with relaxing the budget constraint should be equal to the marginal utility of activities that are assigned more time than the minimum necessary.

The most interesting property of this model is the ability to calculate the value of time as a resource, or value of leisure (VL), and the value of allocating time assigned to work (VW):

$$\text{VL} = \frac{\mu_{qg}}{\lambda_{qg}} = \frac{\tilde{u}'_{gw}\left(t^*_{qw}\right) + \omega_q \dfrac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}}{\dfrac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}} = \frac{\tilde{u}'_{gw}\left(t^*_{qw}\right)}{\dfrac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}} + \omega_q \tag{12}$$

$$\text{VW} = \frac{\mu_{qg}}{\lambda_{qg}} - \omega_q = \frac{\tilde{u}'_{gw}\left(t^*_{qw}\right)}{\dfrac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}} \tag{13}$$

The VL is equal to the total value of work, that is, the value of time assigned to work plus the wage rate, a common result for time use models in which work duration enters the utility function (*2, 4*).

MODEL ESTIMATION

Observed heterogeneity across individuals within segment g and stochasticity through the baseline marginal utility functions are introduced:

$$\psi_{qgk} = \exp\left(\beta'_{qg} z_{qk} + \varepsilon_{qgk}\right)$$

$$\tilde{\psi}_{qgn} = \exp\left(\tilde{\beta}'_{qg} \tilde{z}_{qn} + \tilde{\varepsilon}_{qgn}\right)$$

$$\tilde{\psi}_{qgw} = \exp\left(\tilde{\varepsilon}_{qgw}\right) \tag{14}$$

where

z_{qk} = D-dimensional vector of observed attributes characterizing good k and individual q;

β_{qg} = corresponding vector of coefficients (of dimension $D \times 1$), including alternative-specific constants to capture intrinsic preferences for each good;

$\tilde{z}_{qn}$ = $\tilde{D}$-dimensional vector of observed attributes characterizing individual q; and

$\tilde{\beta}_{qg}$ = corresponding vector of coefficients, including alternative-specific constants to capture intrinsic preferences for each activity.

For identification purposes, for each individual attribute entering z_{qk} in the goods consumption utility function, the coefficient for one good is normalized to zero. Similarly, the alternative-specific constant for one good is normalized to zero (i.e., one good is treated as the base alternative). The time allocation utility function is normalized by treating the work activity as the base alternative (with no observed variables or a constant entering the utility function).

Use of the stochastic baseline marginal utility expressions from Equation 14 in the KKT conditions of Equation 11 leads to the following stochastic KKT conditions:

$$\ln\left(\frac{V_{qgk}}{p_{qk}}\right) + \beta'_{qg} z_{qk} + \varepsilon_{qgk} = -\ln\left(\frac{1}{p_{q1}}\left(\frac{x^*_{q1} - x^0_{q1}}{\gamma_{qg1}} + 1\right)\right) + \beta'_{qg} z_{q1} + \varepsilon_{qg1}$$
$$\text{if } x^*_{qk} > 0, k = 2, \ldots, K$$

$$\ln\left(\frac{V_{qgk}}{p_{gk}}\right) + \beta'_{qg} z_{qk} + \varepsilon_{qgk} < -\ln\left(\frac{1}{p_{q1}}\left(\frac{x^*_{q1} - x^0_{q1}}{\gamma_{qg1}} + 1\right)\right) + \beta'_{qg} z_{q1} + \varepsilon_{qg1}$$
$$\text{otherwise } x^*_{qk} = 0, k = 2, \ldots, K$$

$$\ln\left(\tilde{V}_{qgn}\right) + \tilde{\beta}'_{qg} \tilde{z}_{qn} + \tilde{\varepsilon}_{qgn} = \ln\left(\tilde{u}'_{gw}\left(t^*_{qw}\right) + \omega_q \frac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}\right)$$
$$\text{if } t^*_{qn} > 0, n = 1, 2, \ldots, N$$

$$\ln\left(\tilde{V}_{qgn}\right) + \tilde{\beta}'_{qg} \tilde{z}_{qn} + \tilde{\varepsilon}_{qgn} < \ln\left(\tilde{u}'_{gw}\left(t^*_{qw}\right) + \omega_q \frac{u'_{g1}\left(x^*_{q1}\right)}{p_{q1}}\right)$$
$$\text{otherwise } t^*_{qn} = 0, n = 1, 2, \ldots, N \tag{15}$$

where

$$V_{qgk} = \begin{cases} 1 & \text{if } x^*_{qk} \le x^0_{qk} \\ \left(\dfrac{x^*_{qk} - x^0_{qk}}{\gamma_{qgk}} + 1\right)^{-1} & \text{otherwise } x^*_{qk} \ge x^0_{qk} \end{cases}$$

$$\tilde{V}_{qgn} = \begin{cases} 1 & \text{if } t^*_{qn} \le t^0_{qn} \\ \left(\dfrac{t^*_{qn} - t^0_{qn}}{\gamma_{qgn}} + 1\right)^{-1} & \text{otherwise } t^*_{qn} \ge t^0_{qn} \end{cases}$$

Assuming that the stochastic terms are independent and identically distributed Type-1 extreme value distributed, the probability that an individual q (who belongs to segment g) consumes M of the K goods and assigns time to $\tilde{M}$ of the N nonwork activities is

$$P_{qg}\left(x_{q1}^*, x_{q2}^*, \ldots, x_{qM}^*, 0, \ldots, 0, t_{q1}^*, t_{q2}^*, \ldots, t_{q\tilde{M}}^*, 0, \ldots, 0, t_{qw}^*\right)$$
$$= \frac{1}{\sigma_g^{M-1}}\left[\prod_{k=2}^{M} c_{qgk}\right]\left[\prod_{n=2}^{\tilde{M}} \tilde{c}_{qgn}\right] \int_{\varepsilon_{qg1}=-\infty}^{\infty} \int_{\tilde{\varepsilon}_{qgw}=-\infty}^{\infty} \prod_{k=2}^{M} h\left(\frac{W_k\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right.}{\sigma_g}\right)$$
$$\times \prod_{n=1}^{\tilde{M}} h\left(\frac{W_n\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right.}{\sigma_g}\right) \times \left\{\begin{array}{l} \prod_{l=M+1}^{K} H\left(\frac{W_l\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right.}{\sigma_g}\right) \\ \times \prod_{r=\tilde{M}+1}^{N} H\left(\frac{W_r\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right.}{\sigma_g}\right) \end{array}\right\}$$
$$\times f_g\left(\varepsilon_{qg1}\right) f_g\left(\tilde{\varepsilon}_{qgw}\right) d\varepsilon_{qg1} d\tilde{\varepsilon}_{qgw} \tag{16}$$

where

$$c_{qgk} = \frac{1}{x_{qgk}^* - x_{qg0}^* + \gamma_{qgk}}$$

$$\tilde{c}_{qgn} = \frac{1}{t_{qgn}^* - t_{qg0}^* + \tilde{\gamma}_{qgk}}$$

$$W_k\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right. = -\ln\left(\frac{1}{p_{q1}}\left(\frac{x_{q1}^* - x_{q1}^0}{\gamma_{qg1}} + 1\right)\right) + \boldsymbol{\beta}'_{qg} \boldsymbol{z}_{q1} + \varepsilon_{qg1}$$
$$- \ln\left(\frac{V_{qgk}}{p_{qk}}\right) - \boldsymbol{\beta}'_{qg} \boldsymbol{z}_{qk}$$

$$W_n\left|\left(\varepsilon_{qg1}, \tilde{\varepsilon}_{qgw}\right)\right. = \ln\left(\tilde{u}'_{gw}\left(t_{qw}^*\right) + \omega_q \frac{u'_{g1}\left(x_{q1}^*\right)}{p_{q1}}\right) - \ln\left(\tilde{V}_{qgn}\right) - \tilde{\boldsymbol{\beta}}'_{qg} \tilde{\boldsymbol{z}}_{qn}$$

h = standard extreme value density function,
H = standard extreme value cumulative distribution function, and
$f_g(\varepsilon)$ = probability density function of the extreme value distributed ε-term with scale parameter σ_g.

The scale parameter σ_g is estimable if there is price variation across different goods; its value needs to be normalized (typically to 1) if there is no price variation.

The derivation thus far was based on the assumption that individual q belongs to a single segment g. Now, the case when individual q belongs to a finite mixture of segments is considered. That is, the actual assignment of individual q to a specific segment is not observed, but one is able to attribute different probabilities π_{qg} ($g = 1, 2, \ldots, G$) that the individual belongs to different latent segments. It is required that $0 \le \pi_{qg} \le 1$, and $\sum_{g=1}^{G} \pi_{qg} = 1$ using the logit link function:

$$\pi_{qg} = \frac{\exp\left(\boldsymbol{\delta}'_g \boldsymbol{w}_q\right)}{\sum_{g'=1}^{G} \exp\left(\boldsymbol{\delta}'_{g'} \boldsymbol{w}_q\right)} \tag{17}$$

where $\boldsymbol{w}_q$ is a vector of individual exogenous variables and $\boldsymbol{\delta}_g$ is the vector of coefficients determining the influence of $\boldsymbol{w}_q$ on the membership of individual q in segment g, with all the elements in $\boldsymbol{\delta}_1$ set to zero for identification purposes. With these latent segmentation probabilities, the overall likelihood for observation q may be written as follows:

$$P_q = \sum_{g=1}^{G} \pi_{qg} P_{qg} \tag{18}$$

and the likelihood function for the entire data set may be written as

$$P = \prod_q P_q \tag{19}$$

The use of latent classes requires labeling restrictions for identifiability. In particular, the parameter space includes $G!$ subspaces, each associated with a different way of labeling the mixture components. To prevent the interchange of the mixture components, a restriction is imposed that the constants specific to the second alternative (good) are increasing across the segments. Such a labeling restriction is needed because the same model specification results simply by interchanging the sequence in which the segments are numbered, so multiple sets of parameters result in the same likelihood function. The second alternative is used for labeling restrictions because all parameters for the first alternative are fixed to zero.

EMPIRICAL APPLICATION

The modeling methodology presented earlier is applied by using a Dutch data set drawn from the Longitudinal Internet Studies for the Social Sciences (LISS) panel. Survey data sets of the type needed for analysis in this study, with both time use and goods consumption (and expenditures) information, are rare. Therefore, previous studies had to resort to alternative approaches to impute data or to merge data from separate time use surveys and consumer expenditure surveys [e.g., the study by Konduri et al. (*8*)].

Data Description and Sample Selection

The LISS panel is based on a probability sample of Dutch households drawn from the country's population register. Administered over the Internet in the form of monthly surveys in 2009, 2010, and 2012, the LISS panel included a survey of time use and expenditures; details may be found elsewhere (*15*). In the current work, the focus will be on the data from the latest wave (October 2012). In this survey, respondents reported (*a*) their time allocation to various activities (including work) during 7 days before the survey and (*b*) their average monthly monetary expenditure (in euros) in 30 expense categories for 12 months before the survey. In this analysis, the monetary expenditures were considered as a proxy for goods consumption because the survey information did not include the amount of goods consumed. To achieve consistency between activity durations and expenditures, monthly expenditures and monthly income were divided by four to obtain weekly expenditures and weekly income, respectively. After sample cleaning, the final estimation sample had 1,193 workers. A detailed description of the sample selection can be found in the online supplement, available at http://www.caee.utexas.edu/prof/bhat/ABSTRACTS/ITM/Online Supplement.pdf. Of these individuals, 48% were women; 20% were 18 to 34 years old, 37% were 35 to 49 years old, and 43% were 50 years old or older. Twenty-nine percent had at least a graduate degree, 28% lived alone, 39% lived in households with children, and 84% lived in an urban area.

Variable Specification and Model Formulation

From the various activities reported in the LISS panel, the following 11 categories of activities were constructed for the analysis:

1. Work,
2. Travel,
3. Household chores,
4. Personal care,
5. Education,
6. Activities with children,
7. Entertainment,
8. Assisting friends and family,
9. Administrative chores and family finances,
10. Sleeping and relaxing, and
11. Going to church and other activities.

A detailed description of the activity categories can be found in the online supplement mentioned earlier. There are activities that individuals must perform despite their preference to avoid them (e.g., commuting and other travel that must be undertaken to get to different activity locations). (Arguably, other activities such as household chores and personal care might be considered as mere maintenance tasks. However, individuals can derive utility from household chores such as cooking, gardening, and shopping. Similarly, personal care activities such as visiting the beauty salon may also provide utility. Therefore, such activities might be allocated more than the minimum necessary time and therefore are part of the decision variables.) Such activities are assigned the minimum necessary time and therefore can be left out of the decision variables in the empirical model. Because the time frame of the analysis was a week, the total weekly time available for any individual was 168 h (24×7 h), from which the total time assigned to commute and other travel should be subtracted. Three of the 10 activities entering the utility function—work, sleeping and relaxing, and personal care—are treated as essential alternatives in that all working individuals participate and spend time in these activities (i.e., the corresponding utility functions were specified not to allow corner solutions).

As indicated earlier, because information about expenditures was only available in composite categories, it was assumed that the expenditures entered the utility functions as a proxy for consumption of goods. Therefore, the same expenditures enter the money budget constraint with unit prices. To do so, the 30 categories of expenses recorded in the database were combined into the following six composite expense categories [Jara-Díaz et al. (*6*) give details about the definition of these categories]: commuting, household chores, personal care, education, activities with children, and entertainment. These six categories are in the activity type categorization (i.e., in the context of time allocation) as well. Among the other activities, it is reasonable to assume that work activity has no expenditures (because it generates income). It is also reasonable that the remaining five activities—assisting friends and family, administrative chores, sleeping and relaxing, and other activities—do not have expenditures. Further, similar to the time allocation case, it was assumed that individuals do not incur commuting expenses more than the minimum necessary. As a result, the expenditures (goods consumption) in only the following five categories are true decision variables: household chores, personal care, activities with children, education, and entertainment (i.e., $K = 5$). Further, the monetary budget available for expenditures is computed by subtracting commute expenses from the individuals' available income. Finally, although all individuals participated in personal care activities, not all of them spent money on associated consumption. Therefore, although time allocation to personal care was viewed as an essential alternative, expenditure on personal care was not treated as essential (i.e., corner solutions were allowed).

The descriptive statistics of activity time allocations and goods expenditures are presented in Table 1. As discussed earlier, all individuals in the sample allocate time to work, sleeping, and relaxing: on average, individuals work (6.6 h/day), sleep or relax (8.4 h/day), and perform personal care (1.3 h/day). Most workers allocate some time to commuting, entertainment, and personal care, whereas edu-

TABLE 1 Descriptive Statistics

		Duration (h/week)[a]				Expenditure (euros/week)[a]			
Activity	Participation (%)	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Work	100.0	33.4	13.7	1.0	100.0	—	—	—	—
Household chores	97.8	12.4	9.8	0.3	90.0	5.90	9.80	5.30	107.50
Personal care	100.0	9.1	5.8	0.5	49.0	96.90	66.50	7.20	1,005.00
Education	24.7	7.4	9.3	0.2	87.7	1.40	7.40	8.00	125.00
Activities with children	31.2	14.3	11.7	0.5	65.0	17.60	29.10	9.50	166.30
Entertainment	99.8	31.9	16.1	1.0	102.0	38.70	63.10	7.80	725.00
Assisting friends and family	57.6	7.5	7.8	0.2	81.3	—	—	—	—
Administrative chores and family finances	86.6	3.1	3.5	0.2	50.0	—	—	—	—
Sleeping and relaxing	100.0	58.8	11.4	28.0	119.2	—	—	—	—
Other activities	42.5	11.7	12.5	0.3	71.0	—	—	—	—

NOTE: — = not applicable; number of observations = 1,193.
[a]Durations and expenditures are computed only for workers participating in the corresponding activity.

cation and activities with children present the lowest participation rates; this finding suggests the importance of accommodating corner solutions (i.e., zero time allocation) for these activities. In the context of expenditures, personal care presents the highest average value and is also the most expenditure-intensive activity (average of €10/h) (1€ = $1.28 in 2012). Although people spend a relatively large amount of money on entertainment activities, these represent an expenditure rate of only €2.2/h, which is considerably lower than the average wage of €18/h. The values of E_q and ω_q were obtained as explained earlier. The minimum time allocations (t^0_{qn}) and minimum consumption of goods (x^0_{qk}) were set equal to the minimum nonzero values observed in the sample for the corresponding categories (see the fifth and ninth columns in Table 1), except for the essential alternatives. The minimum work duration t^0_{qw} and the minimum time of the essential alternatives were set to be the corresponding observed minimum duration in the sample minus 1. Finally, by minimum time allocation to an activity (consumption of a good) is meant the minimum required time allocation (consumption of the good) if the individual participates in that activity (consumed that good). The concept of minimum required time allocation (consumption) does not arise if the individual does not allocate time to that activity (consume that good).

Estimation Results

A number of different empirical specifications were explored with different sets of explanatory variables, different functional forms of variables, and different groupings. All the demographic variables available in the data were considered in characterizing the latent segments as well as the baseline preference specification. These variables include respondents' gender, age, presence of children in the household, income level, marital status, level of education, race, household size, household location (urban or rural area), and dwelling type (renter or owner). The final specification was based on the presence of adequate observations in each category of explanatory variables, a systematic process of rejecting statistically insignificant effects, combining effects when they made sense and did not degrade the fit substantially, and judgment and insights from earlier studies. To identify the appropriate number of latent segments (G), the model for increasing values of G was estimated until a point was reached at which an additional segment did not significantly improve the model fit. Details of the evaluation of model fit can be found in the online supplement mentioned earlier. In this analysis, the three-segment model provided the best fit. The log likelihood value at convergence for this model was −8,486.12. The rho-squared value of the final model specification with respect to the naive mode (no latent segmentation and only constants) was .462.

Latent Segmentation Variables

The first (upper) section of Table 2 corresponds to the probabilistic assignment of individuals to each of the three latent segments (the first segment is the base). The constants in this latent segmentation part of the model contribute to the size of each segment and do not have a substantive interpretation. The other parameter estimates in

TABLE 2 Model Estimation Results for Three Segments

	First Segment (YS)		Second Segment (LIPSM)		Third Segment (OCWOC)	
Variable	Estimate	*t*-Stat.	Estimate	*t*-Stat.	Estimate	*t*-Stat.
Segment Probabilities						
Alternative specific constant	—	—	0.956	2.50	0.591	3.16
Gender: male	—	—	−0.175	−2.10	—	—
Age: 50 years or older	—	—	0.166	2.00	0.537	2.72
Single-person household	—	—	−0.702	−3.00	−0.813	−3.20
Presence of children in household	—	—	0.680	3.12	—	—
Income less than €3,000/month	—	—	1.204	2.25	0.322	4.51
Baseline Utilities						
Household size specific to						
Assisting friends and family time	—	—	0.328	2.56	—	—
Administrative chores and family finances time	—	—	0.290	2.49	—	—
Activities with children expenditure	—	—	0.210	4.78	—	—
Urban household specific to						
Entertainment expenditure	0.478	3.24	0.497	3.45	0.422	3.20
Entertainment time	0.326	2.07	0.590	3.00	0.371	3.49
Graduate school studies specific to						
Education expenditure	0.046	2.74	0.105	2.30	0.096	2.22
Education time	0.190	4.67	0.341	6.22	0.271	5.10
Personal care expenditure	−3.090	−3.40	−4.223	−5.12	−4.107	−2.60
Personal care time	−0.110	−4.75	−0.486	−9.11	0.214	3.61

NOTE: Log likelihood at convergence = −8,486.12; YS = younger and singles; LIPSM = low-income parents or single mothers; OCWOC = older couples without children; — = not significant.

the top section of Table 2 indicate that the second segment relative to the other two segments is likely to have proportions of individuals who are single (i.e., living alone) and individuals age 50 years or older between the first and third segments and is more likely to include individuals with children and have a low income. The third segment comprises individuals who tend to belong to the older age category (older than 50), who are unlikely to be living alone and unlikely to have children. The first segment, however, is more likely than the other two segments to consist of younger individuals and those who live alone. Similar to the third segment, this segment also has a low proportion of individuals with children.

A better way to characterize the different segments is to estimate the means of the demographic variables in each segment (*12*). The results are presented in Table 3, which shows the means of the demographic variables in each segment as well as the overall sample (and supports the observations from the model estimation results on the characteristics of the three market segments). From these results, the first segment is referred to as the "younger and singles" (YS) segment, the second as the "low-income parents or single mothers" (LIPSM) segment, and the third as the "older couples without children" (OCWOC) segment. The segment sizes are estimated and results show that LIPSM is the most prominent segment in the population (44.8%), followed by OCWOC (29.6%) and YS (25.6%).

Variables in Utility Functions

The second part of Table 2 presents the parameter estimates corresponding to the baseline marginal utility function specifications of the MDCEV model corresponding to each segment. (To conserve space, the alternative-specific constants in the baseline marginal utility functions and the satiation parameters are not presented in Table 2, but they are available from the authors.) Within each segment, the baseline marginal utility parameters corresponding to time or goods consumption utility components are presented for each demographic variable (depending on the utility functions the variable enters). The first demographic variable in the table, household size, enters the utility functions of the time allocation utility functions for two activities—assisting friends and family and administrative chores and family finances—and the expenditure (goods consumption) utility function corresponding to activities with children. As expected, those in the LIPSM segment are more likely to spend time assisting family and friends and doing administrative chores or family finances as their household size increases [Bhat et al. had similar findings (*16*)]. A larger family implies a greater need to spend time on these activities, especially families with children or single mothers. Similarly, those from larger households are more likely to expend more money on activities with children.

Another variable that affects the baseline utilities is the household's type of residential neighborhood. Workers living in urban

TABLE 3 Quantitative Characterization of Three Segments

Segmentation Variable	First Segment (YS)	Second Segment (LIPSM)	Third Segment (OCWOC)	Overall Market
Gender (%)				
Male	51.1	43.1	50.4	51.6
Female	48.9	56.9	49.6	48.4
Age (%)				
Younger than 50	66.8	58.6	50.8	59.9
50 years or older	32.2	41.4	49.2	40.1
Household structure (%)				
Single person	38.2	26.1	28.0	27.6
Couple	29.9	28.6	37.2	32.6
Single parent	3.8	6.3	3.3	4.8
Nuclear family, multifamily, or nonfamily	28.1	39.0	31.5	35.0
Income (%)				
Less than €3,000/month	55.8	67.5	57.4	56.4
More than €3,000/month	44.2	32.5	42.6	43.6
Value of time from proposed model (€/h)				
Value of leisure	37.9	17.3	41.2	36.2
Value of work	14.8	1.6	18.9	18.9
Value of time (€/h) using "all essential alternatives" formulation				
Value of leisure	42.0	17.3	43.7	39.5
Value of work	23.9	4.1	23.1	21.4
Value of time (€/h) using Castro et al. (*9*) formulation				
Value of leisure	51.9	24.7	65.1	50.3
Value of work	31.3	8.2	43.7	36.2
Value of time (€/h) using Jara-Díaz et al. (*4*) formulation				
Value of leisure	44.5	18.1	47.0	41.2
Value of work	25.5	4.9	25.5	23.9
Segment size (%)	25.6	44.8	29.6	na

NOTE: na = not applicable.

neighborhoods are likely to spend more time and money on entertainment, perhaps because of their greater proximity (than those living in rural neighborhoods) to activity centers such as restaurants, theaters, cinema, museums, or parks. Consistent with these findings, Born et al. find that individuals living in urban areas participate more in out-of-home entertainment (*17*). Individuals who have completed graduate school are more likely to spend time and money on education than those with lower levels of education, probably because they are more likely to continue their education or spend for the education of other, nonworkers in the household. Interestingly, well-educated individuals spend less time and less money on personal care, as can be observed from the negative coefficients for the graduate school variable in all three segments. Reasons behind this particular effect should be explored in detail in future research.

Values of Time

Average values of leisure time and work for each market segment identified from the latent class model are reported in the last eight rows but one of Table 3. Notably, the values of time for different market segments are quite different; this finding highlights the importance of the latent segmentation model. The OCWOC segment has the greatest value of work, followed by the YS segment, and the lowest value of work corresponds to the LIPSM segment. This finding is perhaps due to the following three reasons. First, workers who have children generally present a negative value of work time (*6, 18*); this value indicates that they do not derive pleasure from work at the margin (i.e., they would work less if they could). This finding is perhaps because individuals who do not have to economically support children might choose a more satisfying job than workers who need to provide for their family. An alternative explanation is that parents prefer to spend time out of work with their children (*19*). Second, younger workers (age 50 years or younger) have a smaller value of work, whereas older workers (age older than 50 years) have a greater value. It is possible that younger workers compared with older workers have more debt or commitments (college debt, mortgage) that to some extent force them to choose less satisfying jobs. Furthermore, younger workers in Europe may experience different working conditions than older workers because the recent deregulation of labor markets in Europe and the Netherlands led to weaker work protection levels for younger workers. [Heyes and Lewis present insights on how labor deregulation has affected employment among younger individuals in Europe (*20*).] Also, earlier studies have shown that older workers generally have more positive job attitudes (such as overall job satisfaction, satisfaction with work itself, satisfaction with pay, job involvement, or satisfaction with coworkers) than younger workers [Mather and Johnson (*21*) and Ng and Feldman (*22*) present findings on this subject]. Third, income is a relevant determinant of the value of time. The results of this study show that lower-income workers (monthly income less than or equal to €3,000) have a lower valuation of time than higher-income workers.

Comparison with Alternative Model Formulations

The models in this study were compared with results from three alternative model formulations. One alternative is a simpler version of the current model that does not allow corner solutions, called an "all essential alternatives model":

$$\max U(\boldsymbol{x}, \boldsymbol{t}, t_w) = \sum_{k=1}^{K} \psi_k \ln\left(x_k - \vec{x}_k^0\right) + \sum_{n=1}^{N} \tilde{\psi}_n \ln\left(t_n - \vec{t}_n^{\,0}\right) + \tilde{\psi}_w \ln\left(t_w - t_w^0\right)$$

$$\sum_{k=1}^{K} p_k x_k = E + \omega t_w$$

$$\sum_{n=1}^{N} t_n + t_w = T \tag{20}$$

where $\vec{x}_k^0$, $\vec{t}_n^{\,0}$, t_w^0 correspond to exogenous minimum consumption for good k, exogenous minimum time allocation for activity n, and exogenous minimum duration for work, respectively. These values are computed as the observed minimum in the sample minus 1. The minus 1 ensures that the utility function is defined at zero consumption values as well.

The second formulation is the multiple constraint–MDCEV model proposed by Castro et al. (*9*), whose utility specification is only a function of time allocation (but not goods consumption) and does not allow for minimum time allocation:

$$\max U(\boldsymbol{x}) = \sum_{k=1}^{K} \frac{\gamma_k}{\alpha_k} \psi_k \left(\left(\frac{x_k}{\gamma_k} + 1 \right)^{\alpha_k} - 1 \right) \tag{21}$$

subject to

$$\sum_{k=1}^{K} p_k x_k = E$$

$$\sum_{k=1}^{K} g_k x_k = T$$

The third formulation is the model of Jara-Díaz et al. (*4*), which specifies utility as a Cobb–Douglas form that is a function of both time allocation and goods consumption and also allows for minimum time allocation but without allowing for corner solutions (zeros) in time allocation or consumption:

$$\max U(\boldsymbol{x}, \boldsymbol{t}, t_w) = \Omega t_w^{\theta_w} \prod_n t_n^{\theta_n} \prod_k x_k^{\varphi_k}$$

$$\sum_{k=1}^{K} p_k x_k = E + \omega t_w$$

$$\sum_{n=1}^{N} t_n + t_w = T$$

$$x_k \geq x_k^0$$

$$t_n \geq t_n^0 \tag{22}$$

For each individual in the sample, the probability was computed that he or she belongs to each of the three segments (see Equation 17) and the individual was deterministically assigned to one of the segments following those probabilities. Then the values of time within each of the segments were computed. The values of time implied from these alternative models are presented in the last six rows but one of Table 3 and those implied from the proposed model are presented in the last row. It can be observed that all three alternative models overestimate the values of time allocated to both work and leisure. The first alternative model and the formulation of Jara-Díaz et al. (*4*) do not allow corner solutions and do not allow minimum consumption and minimum time allocation. In the formulation of Castro et al., a linear relationship is assumed between time assigned to activities and the expense associated with those activities by using money prices of time allocation to different activities (*9*). This method not only creates a transformation between money and time that is not necessarily always true but also precludes the inclusion of goods consumed (or expenditures for consuming goods) in the utility functions. Also, the formulation of Castro et al. does not consider minimum consumption. Therefore, one can conclude that either ignoring corner solutions and minimum consumption or ignoring goods consumption in time use models can lead to overestimation of the values of leisure and work times.

CONCLUSIONS

A microeconomic theory–based MDC choice model was developed that considers utility functions with both time allocation to activities and goods consumption as decision variables, time and money budget constraints, corner solutions, and technical constraints in the form of minimum consumption and minimum time allocation. The proposed model was applied in the form of a latent class market segmentation model (to consider heterogeneity) on a Dutch data set. The empirical model was used to understand the sociodemographic determinants of time allocation and goods consumption behavior as well as to derive different values of time: value of work time and value of leisure (nonwork) time. The latent class model helped identify three market segments—YS, LIPSM, and OCWOC—based on differences in the time allocation and goods consumption preferences. The values of time implied by the model are notably different between these market segments. Comparison of the values of time implied by the proposed model with those from simpler models proposed earlier in the literature suggests that either ignoring corner solutions and minimum consumption or ignoring goods consumption in time use models can potentially lead to overestimation of the values of leisure and work times.

Apart from a better understanding of the determinants of the valuation of time, the empirical model is applicable in many ways. For example, it could be used to assess the influence of transportation improvements that reduce weekly travel time on overall time allocation and goods consumption patterns (i.e., what happens if the total time budget increases because of reductions in travel time?). Similarly, the model can be used to forecast the impact of changes in demographic characteristics (those in the model) on weekly time use and expenditure patterns.

A limitation of the model presented here is that the technical constraints—minimum time allocation values and minimum consumption amounts—were treated as exogenous and not related to each other. Recognition of the relationships between goods consumption and time allocation in the form of technical constraints, for example, a minimum required time allocation dependent on the amount of goods consumed, while considering corner solutions is an important avenue for future research [Jara-Díaz et al. recognize such relationships albeit without considering corner solutions (*6*)].

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