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Measuring the Effects of the "Timing of Time" on Shadow Values of Leisure Time

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Abstract

The "timing of leisure time" is important to determining its opportunity cost. Shadow values of different leisure activities from a model of consumer choice subject to multiple binding time constraints are estimated from survey data on peoples' preferences for different activities, their time and money costs, and their consumption choices.

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Measuring the Effects of the "Timing of Time" on Shadow Values of Leisure Time

Developing better empirical measures of the shadow value of time is important in several areas of applied economics, including the evaluation of transportation projects (de Donnea; Quarmby), adjusting the national accounts for the value of home production (Gronau; Hersch), assessing the value of natural resources that support outdoor recreational activity (Knetsch; Smith *et al.*; Johnson), and understanding labor market choices both in developed and developing economies (Rosenzweig; Strauss; van Soest).

A number of approaches have been developed to estimate shadow values in the literatures on labor supply (e.g., Heckman; Wales and Woodland; Zabel; Macurdy *et al.*), farm household consumption and production choices (e.g., Jacobi; Lopez), and recreation demand (Feather and Shaw). Typically, these models are motivated by a consumer or producer making choices subject to a single constraint on time, in addition to money budget or technology constraints, and therefore yield a single estimate of the shadow, or scarcity, value of time. Yet, as Smith *et al.* have pointed out, this is a fairly simple treatment of time as a constraint. Often, the "timing of the time" is also important, as some activities are conducted during periods when time constraints bind much more tightly than in other periods, as anyone who has rushed to finish writing an exam before rushing off to get on an airplane can attest.

This paper aims to do two things. First, it develops a theoretical framework for interpreting consumer choices made subject to multiple binding time constraints. One of the implications of such a framework is that different activities have different scarcity values of time, depending on when during the course of the day, week, or month they take place. The second, and more novel, contribution is to show how one can measure the multiple scarcity values of time that an individual may experience. Using surveys that ask people how they like different activities at the margin, and collect information on how they allocate their time among activities with different money prices of consumption, the resulting data enable the estimation of the scarcity values of time that must underlie the individual's “observed” uses of her time.

There are two important features of the approach. First is that one can use the data supplied by an individual to estimate that person's shadow values, avoiding the need for interpersonal comparisons that would require full cardinality of utility. Instead, by using intra-person information on relative strength of preference for activities, the shadow values that result require only ordinal representations of the underlying utility function, as they are invariant to monotonic increasing transformations of utility.

A second important feature of the approach is that it is not necessary to ask the individual how many different constraints they face, which would be a difficult question to answer realistically. Instead, one can use the fact that activities that are chosen from the same time constraint have the same shadow value of time to determine empirically how many different shadow values explain the reported choices. Beginning with a “naive” model that allows (nearly) each activity to have its own shadow value, by sequentially testing equality restrictions on the shadow values, one can arrive at a specification of the minimum number of unique (stastically different) shadow values that the data support. Even though the number of degrees of freedom are small, the precision of shadow value estimates is sufficiently high to enable rejection of the equality restrictions when the number of shadow values is relatively small.

The first section develops the model of consumer choice subject to multiple binding time constraints. Then the empirical estimation approach is illustrated for two individuals using data from a pre-test of the survey. The paper closes with some remarks about the approach and the results obtained, along with extensions that could be implemented.

Consumer Choice With Multiple Time Constraints

To develop the conceptual model, consider a consumer with utility function u(**x**), where **x** is an n-vector of activities or (used interchangeably) consumption goods. Activities have money prices and time requirements for consumption, so that the consumer is constrained by both time and money in making her choices. Because different activities might have different shadow values, the individual's overall time T is assumed to be representable by a series of mutually exclusive and exhaustive time constraints T^k, so that

$$T = \Sigma_k T^k, \quad (1)$$

where k=1,…,N indexes the different periods that T is comprised of. The consumer does not have the ability to adjust the individual time constraints, so the marginal utilities of the T^k's are, in general, not equal. This gives rise to different shadow values of activities, depending on which time budget they are taken out of. Also, because overall time is partitioned into the fixed periods $T^1,...,T^N$, the marginal utilities of some types of time, that are perhaps necessary but not enjoyable, can be negative. Examples might include doing housework, visiting the in-laws, or activities undertaken out of a sense of duty rather than for their own pleasure.

Each activity x_i^k (with i=1,…,n_k) is assumed to have a money price $p_i^k \geq 0$, and a time "price" $t_i^k \geq 0$. The time price formulation recognizes that most types of consumption require time in addition to money in consumption. A common example is outdoor recreation, where some time must be spent in transit to the place of consumption, in addition to the time spent in the outdoor recreation activity itself. In fact, most activities (e.g., eating, shopping, reading, watching movies) require at least some time in consumption, though whether this is a major part of the cost to the consumer depends on the type of good, the technology of consumption, and the consumer herself. The time price, for an individual, is taken to be fixed and exogenous, like the money price.

As special cases, a good could have either a zero time price in consumption or a zero money price in consumption, but not both. This recognizes that consumption will always be costly, but accommodates a wide range of activities that have only one type of price as well as those that have both. For time spent earning money (i.e., in labor), the price is a net price representing the difference between outlay (e.g., for meals and snacks) and the wage earned per hour, which will typically be negative. For activities that do not generate income, the price will be non-negative (though typically positive).

An aside on the definition of time "prices" may be helpful. How they are defined is necessarily a consequence of how the activity being valued is defined. Using the outdoor recreation example, some travel from one's home to a distant recreation site is required to consume the activity. Suppose it takes an hour each way to travel to a state park, and the recreationist spends 4 hours at the park. By defining the activity being valued (i.e., the activity that generates utility or disutility) as consumption on-site, the time price is 6/4=1.5, reflecting the fact that 1.5 hours of total time are required to consume each hour of the activity.

Alternatively, one could define the activity being valued as time away from home. In this case, all time spent is part of consumption, as opposed to being simply part of the price paid to gain access to consumption. The time price under this definition is 6/6=1, as all six hours away from home contribute to the activity being consumed.

Other activities conducted away from home similarly have fixed and variable time requirements in consumption, and whether the time price is 1 or greater than 1 depends on whether both expenditures of time are considered part of the activity, or whether the access time is viewed as simply part of the cost. In many cases, it is reasonable to expect that time prices are 1 by virtue of the activities being valued, but the framework accommodates other cases where it is not appropriate to assume time prices are 1.

The formulation of the time constraint in (1) also assumes that each activity occurs only within a single time constraint.[1] This simplification does not restrict the generality of the overall approach, which could easily be reformulated to accommodate activities appearing in multiple constraints.[2]

The consumer's choice problem is then

$$\mathrm{Max}_{\mathbf{x}}\ \ u(\mathbf{x}) + \lambda[M - \mathbf{p}\mathbf{x}] + \textstyle\sum_k \mu_k [\, T^k - \mathbf{t}^k\mathbf{x}^k] \qquad (2)$$

where $\mathbf{x}^k$, k=1,...,N, are the groups of activities appearing in time constraint T^k, and $\mathbf{x} = [\mathbf{x}^{1},...,\mathbf{x}^{k}, ...,x^N] = [x^{1}_{1}, \ldots, x^{1}_{n_1}, ..., x^{N}_{1}, \ldots, x^{N}_{n_N}]$ is the full consumption vector whose corresponding price vector is $\mathbf{p} = [\mathbf{p}^{1},...,\mathbf{p}^{k}, ...,p^N] = [p^{1}_{1}, \ldots, p^{1}_{n_1}, ..., p^{N}_{1}, \ldots, p^{N}_{n_N}]$. The money constraint is assumed to be binding, so that the conditions for optimal choice of the activities an individual participates in (i.e., for $x^k_i \geq 0$) are

$$u^k_i \;-\; \lambda\, p^k_i \;-\; \mu_k\, t^k_i = 0, \qquad\qquad \lambda > 0, \qquad \mu_k \gtrless 0, \qquad (3)$$

for $i = 1,...,n_i$, $k = 1,...,N$.

Dividing (3) by the marginal utility of money, λ, and rearranging terms, one obtains the familiar equality of marginal value and marginal cost of goods that are consumed,

$$u_i^k/\lambda = p_i^k + (\mu_k/\lambda) \cdot t_i^k, \tag{4}$$

or

$$MV_i^k = p_i^k + \nu_k \cdot t_i^k, \tag{5}$$

where $MV_i^k \equiv u_i^k/\lambda$ is the marginal value of good x_i^k and $\nu_k \equiv \mu_k/\lambda$ is the scarcity value of time in constraint k. In particular, ν_k is the shadow value of time for good x_i^k and all other goods in the k^{th} time constraint.

An important point to note is that the shadow values MV_i^k and ν_k in equation (5) are invariant to monotonic increasing transformations of the utility function. Thus they are based on ordinal, not cardinal, utility. This can be seen by replacing the utility function $u(\mathbf{x})$ with the increasing transformation $T[u(\mathbf{x})]$. The problem is now

$$\text{Max}_{\mathbf{x}} \;\; T[u(\mathbf{x})] + \lambda'[M - \mathbf{px}] + \textstyle\sum_k \mu'_k [\, T^k - \mathbf{t}^k\mathbf{x}^k] \tag{2$'$}$$

where the shadow values λ' and μ'_k are in general different from the original λ and μ_k. The new first order conditions are

$$T' \cdot u_i^k - \lambda' p_i^k - \mu'_k \cdot t_i^k = 0. \tag{3$'$}$$

where $T' \equiv \partial T/\partial u$. The same optimal **x** solve (2) and (2′), since monotonic increasing transformations of the utility function don't affect observed consumption choices. This means u_i^k is the same in (3) and (3′), and dividing through (3′) by T′ and comparing with (3), it is apparent that the relationships between the shadow values λ', μ'_k, λ, and μ_k are

$$\lambda = \lambda'/\,T' \quad \text{and} \qquad \mu_k = \mu'_k/T'.$$

Replacing λ' with $\lambda T'$ and μ'_k with $\mu_k T'$ in (3) and dividing by T′, it can be seen that (3′) is identical to (3), so the same shadow values MV_i^k and ν_k result under the transformed utility function.

Estimating Individual-Specific Scarcity Values of Time

The individual's relative preference for good x_i^k over good x_j^h, S_{ikjh}, can be expressed as the ratio of the marginal utilities of the two goods, $S_{ikjh} = u_i^k/u_j^h$, or as the ratio of their marginal values,

$$S_{ikjh} = \ (u_i^k/\lambda)/(u_j^h/\lambda).$$

In light of (4) and (5), this can also be written as

$$S_{ikjh} = \ (p_i^k + \nu_k \cdot t_i^k)/(p_j^h + \nu_j \cdot t_j^h). \tag{6}$$

Equation (6) is the key equation used in the empirical application to assess the opportunity costs of time associated with different activities. It is a direct extension to the multiple-time constraint setting of the usual equality of marginal rates of substitution between two goods to their relative price ratios, where the relevant prices here are full prices that are dependent on endogenous shadow values of time.

The left hand side of (6), S_{ikjh}, is the relative strength of preference for the activities x_i^k and x_j^h, i.e., the ratio of their marginal utilities. Whereas in the single- (money) constraint case the price ratio reveals S_{ikjh} directly, in (6) there are two unknowns on the right side, namely the scarcity values of time for the two activities.[1] Thus, in the multiple- time constraint case, (6) does not reveal S_{ikjh} unless ν_k and ν_j are known. Alternatively, though, if the marginal rate of substitution between activity i and j is known, equation (6) can be used to estimate ν_k and ν_j.

The relative marginal utilities of activities can, in principle, be obtained through ratings surveys that are an increasingly-familiar cognitive exercise for today's consumers. Ratings are a common and widely understood mechanism for conveying relative marginal utility (and sometimes marginal value), as evidenced by the popularity of consumer guide books such as *Consumer Reports*. By asking a consumer to rate different activities according to the marginal utility they provide, the ratios of those ratings convey the relative preferences required to construct S_{ikjh}. Provided that the ratings scale is sufficiently flexible to accommodate a wide range of relative ratings, the induced variable S_{ikjh} can be treated as continuous for estimation purposes.

By appending an additive error to (6), the relative preferences can be written as

$$S_{ikjh} = (p_i^k + \nu_k \cdot t_i^k)/(p_j^h + \nu_j \cdot t_j^h) + u_{ij}, \qquad i=1,\ldots,n_k, j=1,\ldots,n_h, \; i \neq j \tag{7}$$

If data are also collected on the money and time prices the individual faces for each activity, equations (7) represent a system of equations for the individual from which that person's shadow values ν_i can be estimated, via nonlinear least squares or maximum likelihood. An individual's rankings of n activities provides n(n-1) observations on relative ratings S of pairs of activities, though only n-1 are unique. Thus up to n_m-1 individual shadow values can be identified from information on n_m activities provided by a given individual m.

A key question is how many shadow values should be estimated. This question arises immediately upon noticing that at most, only n_m-1 shadow values can be estimated from information on n_m activities. This implies that at least one equality restriction is necessary to obtain parameter estimates.

More fundamentally, though, the issue turns on how many constraints the individual faces in the activities of interest to the researcher, and which constraints pertain to which activities. Both of these are unknown. One could attempt to ask the individual directly for this information, but it is unlikely that it could be obtained reliably or accurately.

This paper uses a sequential hypothesis testing procedure to determine the number of unique scarcity values applicable to the activities of interest in the analysis. The estimation strategy relies on the fact that activities that are chosen from the same time constraint have the same scarcity value.

Initially, each activity but one is allowed to have a unique scarcity value of time. Hypothesis tests of equality of estimated scarcity values are performed to determine whether the set of shadow values can be reduced. The scarcity values chosen for hypothesis testing in each step are those which have the smallest likelihood ratio or pairwise Student's-t statistic on the null hypothesis of coefficient equality. The testing sequence stops when hypothesis tests on equality of all remaining shadow values reject the hypothesis of equality. At this point, the remaining scarcity values, applicable for groups of activities, are significantly different from zero, and from each other.

Data

The data required for the estimation of time shadow values are ratings of satisfaction or marginal utility of different activities that are consumed, and their time and money prices. Results based on responses by two individuals to a survey on how they spent their time, and how they enjoyed the activities they spent time on, are developed and presented. This serves to illustrate both the hypothesis testing procedure, and that the estimation strategy produces individual-specific shadow values of time.

Both respondents were asked about a set of 18 different activities in which they may have participated during the previous week, under the broad categories of household work, school work, employment, and leisure time activities.

Under household work, the activities mentioned were washing the dishes, washing clothes, cleaning the house, and cleaning the yard. In the school work category, the activities asked about were attending lectures, attending discussion section or lab, studying, and travelling to and from school. Employment-related activities were time spent at the workplace and spent traveling to and from work. The leisure-time activities included reading for pleasure, watching TV, playing on the computer, eating meals at home, eating meals out, going to a movie, playing sports, and exercising or working out.

Each respondent was asked to indicate how many hours per week s/he had spent in each activity, and what the total money cost for the week was. They were instructed to include the variable costs that they incur less frequently than on a weekly basis, such as monthly health club fees or purchase of laundry soap, prorated to a weekly cost. They were asked not to include durables such as the cost of washing machines to do the laundry. Not all activities have money prices (e.g., some forms of working out or cleaning the yard), so zero can be an appropriate money price, depending on the activity. The price applicable to work time is typically negative because the wage enters with a negative sign, as noted earlier. All of the time spent in each activity was assumed to be utility-generating, so that the time prices are 1, following the earlier discussion of defining time prices.

The respondents were also asked to rate, on a Likert scale from 1 to 10, how they liked each activity that they participated in. The instructions asked that they consider how much they liked the marginal unit of consumption, by asking them to consider how much they'd like a little more or less time spent in each activity per week, to help obtain marginal utility ratings. The Likert ratings can be viewed as scaled marginal utilities, and provided the rating-marginal utility correspondence is affine, the ratios of Likert ratings are marginal rates of substitution or ratios of marginal utilities.

The number of activities that a person had actually participated in determines n_m , the number of possible shadow values. Respondent 1 was a graduate student, while respondent 2 was a non-student, so respondent 1 participated in the 4 schoolwork activities while 2 did not. Overall, respondent 1 participated in 14 of the 18 possible activities while 2 participated in 12 (Table 1).

Results

For each individual, ratios of the Likert ratings S for each activity were formed, and these along with the money prices of each activity were used in estimating the system of equations

$$S_{i^k j^h} = (p_i^k + \nu_k)/(p_j^h + \nu_j \cdot t_j^h) + u_{ij}, \qquad i=1,\ldots,n,\ j=1,\ldots,n,\ i \neq j \qquad (8)$$

Equations (8) were estimated by nonlinear least squares, using Gauss version 3.2.25.

Table 2 shows the sequence of model estimation and hypothesis testing for person 1. Initially, each activity, 1-14, has its own scarcity value, ν_1-ν_{14}, with the activity that corresponds to work time (activity 8 in the case of person 1, activity 4 for person 2) labeled as ν_w. In each model, beginning with the first, successive equality restrictions between parameters are imposed, based on which pair had the lowest χ^2 statistic for the equality restriction. The restriction imposed can be identified by the scarcity value in **bold** type, which indicates what the activity scarcity value was set to. The χ^2 statistic for the test is reported at the bottom of each column. Coefficient estimates and χ^2 statistics in **bold** type are statistically different from zero at the 5% significance level.

Not surprisingly, equality restrictions among estimated scarcity value parameters are not rejected for the first several hypothesis tests, because degrees of freedom are low and standard errors of the parameter estimates are high. For person 1, it is not until Model 6, when eight scarcity values are estimated and 6 equality restrictions are imposed, that the χ^2 statistic rejects an equality restriction (at the 5% level, though not at the 1% level). At this juncture, the model has more than the optimal set of scarcity values to adequately describe person 1's relative preferences, money prices, and activity levels: only two of the six scarcity values are statistically different from zero, the coefficient on work time, with a scarcity value of \$21.40/hour, and the scarcity value on washing clothes, with a scarcity value of -\$4.92/hr.

A smaller set of scarcity values that more completely describe the activity set may be preferable, so further equality restrictions are tested, resulting in Model 9. In Model 9, five scarcity values are estimated, and all are significantly different from zero and from each other, at the 5% level. Model 9 is the preferred model, as no equality restrictions were rejected in moving from Model 5 to Model 9, and when one imposes additional restrictions beyond Model 9, they are strongly rejected by the data (e.g., a χ^2 statistic in imposing an additional restriction on Model 9 of 26.3, significant at the 0.5% level). It is also a more parsimonious model in that fewer parameters (five) are estimated, with greater precision.

Table 3 presents more detail on both models, providing the estimated scarcity values and their Student's-t statistics for a test of difference from zero. In the preferred Model 9 for Person 1, five activities had negative scarcity values, including 4 (eating meals at home, eating out, washing the dishes, and cleaning house) with a scarcity value of -$1.04/hour, and 1 (washing clothes) with a scarcity value of -$5.04/hr. The remaining 9 had positive scarcity values, including 6 (all four school-related activities, reading for pleasure, and playing on the computer) with a scarcity value of $8.31/hr., work time with a scarcity value of $20.78/hr., and the leisure activities of working out and going to a movie, with scarcity values of $5.43/hr.

Because time constraints are generally strictly binding—time must be "spent" in one way or another—there is nothing intrinsically surprising about negative scarcity values of time. They indicate blocks of time that the individual would prefer were shorter in duration, but cannot be made so because of the inability to fully rearrange time between uses. This may be because the activities chosen within the block of time themselves are not enjoyable, but are necessary for the longer-term well-being. One might imagine going to the dentist as such an activity, whose marginal value is negative. Because, according to equation (5), the (negative) marginal value equals the (positive) money price plus the scarcity value of time for the activity, this would assure that the scarcity value associated with going to the dentist was negative.

Alternatively, negative scarcity values may arise when an activity is enjoyable, but simply takes too long. In such cases, the marginal value of an activity within the constraint is positive, but because the money price is greater, the scarcity value must be negative when the activity is observed to be undertaken. Examples no doubt would vary greatly based on individual preference, but examples might include going clothes shopping, or travel to distant locations to visit relatives or enjoy recreational activity.

Table 4 presents person 1's marginal values for each activity, along with their scarcity values, for Models 5 and 9. (The differences between the two are the monetary prices per hour.) All marginal values are positive, ranging from just under \$1/hr to \$9.30/hr, indicating that Person 1 enjoys all activities. However, for the cleaning (1-3) and eating (11-12) activities, the marginal value per hour is not as high as the monetary cost per hour, implying a negative scarcity value of time for those activities.

Person 1, the student, has a wage of \$16/hour, which shows up as a price of -\$16/hr for work time (activity 8). The scarcity value of work time is \$20.78, so that the s/he has a marginal value of work time of \$4.78. Because this person enjoys work time, the wage does not fully cover the opportunity cost of work time.

Tables 5-7 go through a similar analysis of scarcity values and marginal values for Person 2, the non-student. In the case of person 2, the magnitudes of the scarcity values were quite similar for washing dishes and clothes (activities 1-2) and all leisure time activities except eating meals out (activity 9), throughout the analysis (Table 5). Starting from Model 3, where the degrees of freedom in estimation reduced the critical values of the Student's-t test to 4 and below, all but one of the scarcity values were significantly different from zero, though not from each other. The similarity of the scarcity values suggests that these activities were chosen from within a common time constraint, and hypothesis testing essentially confirmed this. Equality restrictions placed on estimated scarcity values were not rejected until Model 10, which had only two scarcity values explaining all the data and performed much worse than Model 9. Model 9 is the model which best explains the data, in terms of a scarcity value for work time (-$2.68/hr), a scarcity value for all leisure and housework except cleaning house ($14.94/hr), and a scarcity value for cleaning house ($6.45/hr). All scarcity values are significantly different from each other and from zero (Table 6). The negative scarcity value of work time suggests that if this person worked less s/he would be better off (that is, if the time constraint within which work time is chosen had less hours).

Table 7 presents the estimated scarcity values and the implied marginal values of activities for person 2. All marginal values are positive except for work time, and most are similar in magnitude, ranging from $15-$18 per hour, except for cleaning house and travel time to work (about $7/hour) and work time (-$20/hour). The negative marginal value of work is an example of how disliking an activity can give rise to a negative scarcity value. In this case, person 2's wage is $17.75/hr, but this does not fully compensate for the marginal disutility of work of -$20.43/hr.

Conclusions, Limitations, and Extensions

This paper has developed a simple empirical model to estimate the scarcity values of different activities a person participates in, based on the theory of consumer choice subject to multiple binding time constraints. The approach uses information on a person's relative preferences for different activities, along with the money and time prices and consumption levels of each, to estimate individual-specific shadow values of the activities. These shadow values appear as part of the full prices in the expressions of equality of marginal rates of substitution between activities to their full price ratios.

The modeling approach recognizes that "the timing of time" is important; that is, that multiple time constraints may bind in different ways at different times and for different activities for an individidual, thereby generating different shadow values representing the opportunity costs of those activities. These opportunity or scarcity costs are important in a variety of applications, both in research and in private enterprise. Being able to estimate them them in a rigorous hypothesis testing framework, using readily obtainable data and easily applied methods, is important.

Some of the advantages of the modeling approach include the fact that it avoids interpersonal comparisons of utility, instead relying on information provided by an individual to estimate that person's shadow values of different activities. The shadow value estimates are invariant to the form of the underlying utility function, so they are based on ordinal utility functions. The ratings of activities that are used in estimation are a familiar exercise cognitively and can be obtained via simple survey research techniques. Perhaps most importantly, it is not necessary to specify in advance how many time constraints the consumer faces, nor which activities are chosen within which constraints. The process of testing for significant differences in shadow values determines how many shadow values are needed to adequately represent the data.

This empirical model was applied to data collected from two different individuals, one of whom provided information on 14 activities that s/he had participated in during the previous week; the other had participated in 12 activities. For individual 1, the preferred model that emerged from sequential hypothesis testing had 5 unique shadow values, all of which were significantly different from each other and from zero. For individual 2, the preferred model had 3 unique shadow values, also significantly different from each other and from zero. The fact that the preferred models for each individual had multiple statistically different scarcity values strongly suggests that models which estimate only a single scarcity value of time do not adequately reflect the differences in the costliness of time, depending on which activity is considered.

Negative scarcity values can occur in this empirical model, and are a reflection of the fact that time constraints are strictly binding, and often there is limited ability to reschedule activities between time constraints. They may also reflect the fact that some activities that are not enjoyed must nevertheless be undertaken. They indicate that the individual could benefit were it possible to make some activities and uses of time shorter.

For individual 1, two of the five estimated scarcity values, those pertaining to cleaning and eating, were negative, though all estimated marginal values were positive. This implies that individual 1 enjoyed all activities, but some were not enjoyed as much as their costs of consumption. For individual 2, only work time had a negative scarcity value, and it also had a negative marginal value.

It is important also to note some potential limitations of the results presented here. The marginal and scarcity values may be somewhat sensitive to the fineness of gradation of the ratings scale used to collect relative preference data. While a 10-point Likert scale was used in this application, it may be that finer resolutions of the preference scale will produce more precise shadow value estimates. While ratings are a cognitively familiar exercise, it is important that ratings obtained be for marginal utilities rather than total or average utilities. Collecting money price information about different activities can be complicated by the fact that people do not always think of what they are spending in activities for which purchases are infrequent or irregular. Focusing on variable costs of consumption is appropriate for generating short-term scarcity value estimates, but for life cycle applications it may be necessary to consider the role of durables purchases for at least some activities.

Footnotes

1. For simplicity, consumption is also assumed to be non-joint; that is, within each time constraint, activities are mutually exclusive and exhaustive.

2. If consumption of an activity were positive in two different time constraints, either the shadow values of the constraints must be equal (in which case they could be combined into a single constraint) or the activity must have different marginal utility or money price in each constraint. In the latter case, the activity could be considered as two separate activities whose (presumably different) scarcity values could be estimated separately.

3. While these scarcity values could be equal, in general this needn't be the case.

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Table 1. Activity Lists

Activity	Person 1's Activity Number	Person 2's Activity Number
Household Work		
Washing the dishes	1	1
Washing clothes	2	2
Cleaning the house	3	3
Cleaning the yard		
School Work		
Attending lectures	4	
Attending discussion section/lab	5	
Studying	6	
Traveling to and from school	7	
Employment		
Time spent at the workplace	8	4
Traveling to and from Work		5
Leisure Time Activities		
Reading for pleasure	9	6
Watching TV		7
Playing on computer	10	
Eating meals at home	11	8
Eating meals out	12	9
Going to a movie	13	10
Playing sports		11
Working out/exercising	14	12

Table 2. Sequential Testing for the Shadow Values of Person 1

Model	1		2		3		4		5	
Activity	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate
1	ν_1	-1.0122	ν_1	-1.0517	ν_1	-0.99	ν_1	-1.1524	ν_1	**-1.3175**
2	ν_2	-5.0122	ν_2	-5.0517	ν_2	**-4.99**	ν_2	**-5.1524**	ν_2	**-5.3175**
3	**ν_1**	.	ν_1	.	ν_1	.	ν_1	.	ν_1	.
4	ν_4	8.8901	ν_4	8.8778	ν_4	9.095	ν_4	7.5524	**ν_6**	.
5	ν_5	9.8779	ν_5	10	ν_5	10.1	ν_5	8.4762	ν_5	6.8248
6	ν_6	7.8023	ν_6	7.9	ν_6	8.03	ν_6	6.7921	ν_6	5.643
7	ν_7	7.9023	ν_7	8.	**ν_6**	.	ν_6	.	ν_6	.
8	ν_W	20.9389	ν_W	21.	ν_W	**21.05**	ν_W	**20.2381**	ν_W	**19.4124**
9	ν_9	8.8779	**ν_4**	.	ν_4	.	ν_4	.	**ν_6**	.
10	ν_{10}	8.1758	ν_{10}	8.2857	ν_{10}	8.3757	**V6**	.	ν_6	.
11	ν_{11}	0.2124	ν_{11}	0.2857	ν_{11}	0.3457	ν_{11}	-0.6286	ν_{11}	-1.6194
12	ν_{12}	-1.1099	ν_{12}	-1.	ν_{12}	-0.91	ν_{12}	-2.3714	ν_{12}	-3.8576
13	ν_{13}	5.3901	ν_{13}	5.5	ν_{13}	5.59	ν_{13}	4.1286	ν_{13}	2.6424
14	ν_{14}	5.9267	ν_{14}	6.	ν_{14}	6.06	ν_{14}	5.0857	ν_{14}	4.0949
χ^2		-1.1E-12		5.62E-13		.0099		.0987		1.79

Model	6		7		8		9		10	
Activity	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate
1	ν_1	-0.9204	**ν_1**	**-0.8461**	**ν_1**	**-0.7057**	**ν_{11}**	.	**ν_{11}**	.
2	ν_2	**-4.9204**	ν_2	**-4.8461**	ν_2	**-4.7057**	ν_2	**-5.0432**	ν_2	**-4.9699**
3	ν_1	.	ν_1	.	ν_1	.	**ν_{11}**	.	ν_{11}	.
4	ν_6	.	ν_6	.	ν_6	.	ν_6	.	ν_6	.
5	**ν_6**	.	ν_6	.	ν_6	.	ν_6	.	ν_6	.
6	ν_6	9.4136	ν_6	**10.0829**	ν_6	**11.3462**	ν_6	**8.3092**	ν_6	**8.2202**
7	ν_6	.	ν_6	.	ν_6	.	ν_6	.	ν_6	.
8	ν_W	**21.3978**	ν_W	**21.7696**	ν_W	**22.4714**	ν_W	**20.7842**	ν_W	**21.1505**
9	ν_6	.	ν_6	.	ν_6	.	ν_6	.	ν_6	.
10	ν_6	.	ν_6	.	ν_6	.	ν_6	.	ν_6	.
11	ν_{11}	0.763	ν_{11}	1.2092	ν_{11}	1.85	ν_{11}	**-1.0432**	ν_{11}	**-0.9699**
12	ν_{12}	-0.284	ν_{12}	0.3853	**ν_{11}**	.	ν_{11}	.	ν_{11}	.
13	ν_{13}	6.216	ν_{13}	**6.9044**	ν_{13}	**7.9571**	ν_{13}	**5.4263**	**ν_6**	.
14	ν_{14}	6.4773	**ν_{13}**	.	ν_{13}	.	ν_{13}	.	**ν_6**	.
χ^2		**4.43**		.0080		.222		2.99		**26.3**

[a] Coefficients in **bold** are significant at the 5% significance level

Table 3. Two Alternative Models of Person 1's Shadow Values

	Model Number 5			Model Number 9		
Activity	Scarcity Value	Parameter Estimate[a]	Student's-t Statistic	Scarcity Value	Parameter Estimate	Student's-t Statistic
1	ν_1	**-1.3175**	-3.72	ν_{11}	**-1.0432**	-14.85
2	ν_2	**-5.3175**	-8.89	ν_2	**-5.0432**	-7.41
3	ν_1	**-1.3175**	-3.72	ν_{11}	**-1.0432**	-14.85
4	ν_6	5.643	1.81	ν_6	**8.3092**	12.04
5	ν_5	6.8248	1.91	ν_6	**8.3092**	12.04
6	ν_6	5.643	1.81	ν_6	**8.3092**	12.04
7	ν_6	5.643	1.81	ν_6	**8.3092**	12.04
8	ν_W	**19.4124**	10.59	ν_W	**20.7842**	27.26
9	ν_6	5.643	1.81	ν_6	**8.3092**	12.04
10	ν_6	5.643	1.81	ν_6	**8.3092**	12.04
11	ν_{11}	-1.6194	-0.74	ν_{11}	**-1.0432**	-14.85
12	ν_{12}	-3.8576	-1.20	ν_{11}	**-1.0432**	-14.85
13	ν_{13}	2.6424	0.82	ν_{13}	**5.4263**	7.62
14	ν_{14}	4.0949	1.88	ν_{13}	**5.4263**	7.62
Critical $t_{.05}$ (2-tailed)		2.57			2.31	
Mean log-L		-0.06783			-0.34121	

[a] Coefficients in **bold** are significant at the 5% significance level

Table 4. Person 1's Scarcity Values and Marginal Values of Activities

	Model Number 5		Model Number 9	
Activity	Scarcity Value ($/hr)	Marginal Value ($/hr)	Scarcity Value ($/hr)	Marginal Value ($/hr)
1	-1.32	0.68	-1.04	0.96
2	-5.32	0.68	-5.04	0.96
3	-1.32	0.68	-1.04	0.96
4	5.64	5.64	8.31	8.31
5	6.82	6.82	8.31	8.31
6	5.64	5.74	8.31	8.41
7	5.64	5.64	8.31	8.31
8	19.41	3.41	20.78	4.78
9	5.64	6.64	8.31	9.31
10	5.64	6.36	8.31	9.02
11	-1.62	4.09	-1.04	4.67
12	-3.86	6.14	-1.04	8.96
13	2.64	6.14	5.43	8.93
14	4.09	4.09	5.43	5.43

Table 5. Sequential Testing for the Shadow Values of Person 2

Model	1		2		3		4		5	
Activity	Scarcity Value	Estimate[a]	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate
1	ν_1	15.8718	ν_1	15.8751	**ν_7**	.	ν_7	.	ν_7	.
2	ν_2	12.6234	ν_2	12.6263	ν_2	**12.6221**	ν_2	12.6119	ν_2	**12.2089**
3	ν_3	6.4784	ν_3	**6.4798**	ν_3	**6.4827**	ν_3	**6.4774**	ν_3	**6.487**
4	ν_w	-2.8107	ν_w	-2.8091	ν_w	**-2.802**	ν_w	-2.8088	ν_w	**-2.7858**
5	**ν_w**	.	ν_w	.	ν_w	.	ν_w	.	ν_w	.
6	ν_6	13.7119	ν_6	**13.7158**	ν_6	**13.7216**	ν_6	**14.1437**	ν_6	**14.1634**
7	ν_7	15.7758	ν_7	**15.629**	ν_7	**15.678**	ν_7	**15.6727**	ν_7	**15.686**
8	ν_8	11.8785	ν_8	**11.8857**	ν_8	**11.8906**	ν_8	**11.8725**	**ν_2**	.
9	ν_9	4.3785	ν_9	4.3857	ν_9	4.3906	ν_9	4.3725	ν_9	4.3908
10	ν_{10}	14.6398	ν_{10}	**14.6411**	ν_{10}	**14.645**	**ν_6**	.	ν_6	.
11	ν_{11}	15.4731	**ν_7**	.	ν_7	.	ν_7	.	ν_7	.
12	ν_{12}	16.8065	ν_{12}	**16.8076**	ν_{12}	**16.8114**	ν_{12}	**16.8117**	ν_{12}	**16.8352**
χ^2		-1.1E-12		0.0072		0.0034		0.0730		0.0410

Model	6		7		8		9		10	
Activity	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate	Scarcity Value	Estimate
1	ν_7	.	ν_7	.	ν_7	.	ν_7	.	ν_7	.
2	ν_2	**12.2068**	ν_2	**13.2577**	ν_2	**13.5014**	**ν_7**	.	ν_7	.
3	ν_3	**6.4846**	ν_3	**6.4714**	ν_3	**6.4206**	ν_3	**6.4471**	**ν_7**	
4	ν_w	**-2.7951**	ν_w	**-2.8418**	ν_w	**-2.6952**	ν_w	**-2.6775**	ν_w	**-3.2325**
5	ν_w	.	ν_w	.	ν_w	.	ν_w	.	ν_w	.
6	**ν_6**	**14.1622**	**ν_2**	.	ν_2	.	ν_7	.	ν_7	.
7	ν_7	**16.0214**	ν_7	**15.9984**	ν_7	**16.2617**	ν_7	**14.9357**	ν_7	**11.9758**
8	ν_2	.	ν_2	.	ν_2	.	ν_7	.	ν_7	.
9	ν_9	4.3773	ν_9	4.3282	**ν_3**	.	ν_3	.	**ν_7**	.
10	**ν_6**	.	ν_2	.	ν_2	.	ν_7	.	ν_7	.
11	ν_7	.	ν_7	.	ν_7	.	ν_7	.	ν_7	.
12	**ν_7**	.	ν_7	.	ν_7	.	ν_7	.	ν_7	.
χ^2		0.1450		0.5986		0.6473		2.1151		**32.099**

[a] Coefficients in **bold** are significant at the 5% significance level

Table 6. Two Alternative Models of Person 2's Shadow Values

	Model Number 3			Model Number 9		
Activity	Scarcity Value	Parameter Estimate[a]	Student's-t Statistic	Scarcity Value	Parameter Estimate	Student's-t Statistic
1	ν_1	**15.678**	8.00	ν_7	**14.9357**	10.475
2	ν_2	**12.6221**	4.29	ν_7	**14.9357**	10.475
3	ν_3	**6.4827**	8.02	ν_3	**6.4471**	8.283
4	ν_W	**-2.802**	-3.31	ν_W	**-2.6775**	-3.307
5	ν_W	**-2.802**	-3.31	ν_W	**-2.6775**	-3.307
6	ν_6	**13.7216**	5.40	ν_7	**14.9357**	10.475
7	ν_7	**15.678**	8.00	ν_7	**14.9357**	10.475
8	ν_8	**11.8906**	4.63	ν_7	**14.9357**	10.475
9	ν_9	4.3906	1.71	ν_3	**6.4471**	8.283
10	ν_9	**14.645**	5.23	ν_7	**14.9357**	10.475
11	ν_{11}	**15.678**	8.00	ν_7	**14.9357**	10.475
12	ν_{12}	**15.678**	8.00	ν_7	**14.9357**	10.475
Critical $t_{.05}$ (2-tailed)			3.18			2.31
Mean log-L			-8.17729			-8.32856

[a] Coefficient estimates in **bold** are significant at the 5% significance level

Table 7. Person 2's Scarcity Values and Marginal Values of Activities

	Model Number 5		Model Number 9	
Activity	Scarcity Value ($/hr)	Marginal Value ($/hr)	Scarcity Value ($/hr)	Marginal Value ($/hr)
1	15.68	16.48	14.94	15.74
2	12.62	14.29	14.94	16.60
3	6.48	7.15	6.45	7.11
4	-2.80	-20.55	-2.68	-20.43
5	-2.80	7.20	-2.68	7.32
6	13.72	14.39	14.94	15.60
7	15.68	16.08	14.94	15.34
8	11.89	14.39	14.94	17.44
9	4.39	14.39	6.45	16.45
10	14.64	17.98	14.94	18.27
11	15.68	18.18	14.94	17.44
12	16.81	17.98	14.94	16.10