On the value of time and human life

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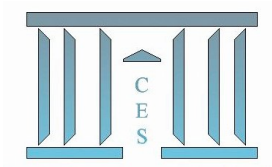

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J'éprouvais un sentiment de fatigue et d'effroi à sentir que tout ce temps si long non seulement avait, sans une interruption, été vécu, pensé, secrété par moi, qu'il était ma vie, qu'il était moi-même, mais encore que j'avais à toute minute à le maintenir attaché à moi, qu'il me supportait, moi, juché à son sommet vertigineux, que je ne pouvais me mouvoir sans le déplacer comme je le pouvais avec moi. Marcel Proust, Le Temps Retrouvé. [2]

Abstract

The opportunity cost of time is estimated using a model based on domestic productions depending on monetary and time expenditures and a direct utility depending on produced commodities. These factors of domestic productions are measured by the matching of a Family Budget survey with a Time Use survey. The new model is estimated on Canadian, French, Polish, U.S. and Burkina-Faso statistics. It allows estimating the economic value of human life based on the integration of the marginal value of each instant during the individual's life cycle. This value is shown to give a different pattern across countries compared to their per capita GDP. Finally, the opportunity cost of time is shown to vary between commodities according to the possibility to substitute money and time in the domestic production. It also increases relatively of the average wage rate at a macro level, between countries, according to the degree of liberalization of the labor market.

Keywords: opportunity cost of time, value of human life
JEL Classification: D13, D91, J317

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[2]"I had a feeling of intense fatigue when I realised that all this span of time had not only been lived, thought, secreted by me uninterruptedly, that it was my life, that it was myself, but more still because I had at every moment to keep it attached to myself, that it bore me up, that I was poised on its dizzy summit, that I could not move without taking it with me." Marcel Proust, Time Regained.

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Introduction

The goal of this article is to evaluate the value of time within the framework of domestic production, and to use this evaluation to calculate the value of a human life. In order to estimate the opportunity cost of time for each household, I propose a modified version of Becker's allocation of time model, in which the value of time is not set equal to the household's wage rate. This model is based on a direct utility depending on final goods home produced by the combination of monetary expenditures and time. These factors are measured by a matching of a Family Budget survey with a Time Use survey. The estimation of the opportunity cost of time allows proxies to be put forward for full prices, which can be used in the estimation of price elasticities. The calculation of these full prices, under alternative assumptions of complementarity or substitution between time and money, is also new in the literature.

Considering time allocation together with consumption expenditures is crucial since both result in a consumption activity which differs from that suggested solely by monetary expenditures. Aguiar and Hurst (2005) show for instance that food consumption by the elderly differs from their monetary expenditures because of a specific domestic production of meals compared to younger households. Alpman and Gardes (2015) explore the intratemporal substitution between market goods and time, the variations of individuals' full income, and their well-being during the Great Recession. This analysis provides empirical evidence on the importance of home production over the business cycles and shows that the reallocation of time absorbed approximately one third of the Great Recession negative welfare impact.

On the other hand, valuing time is a crucial issue in the domestic production framework since it allows the estimation of the monetary value of that production, which is "a central problem" according to Gronau (1977). The classical microeconomic model of the consumer introduced time only as a supplementary constraint, with the value of time being equal to the corresponding Lagrange multiplier. As a consequence, the opportunity cost of time is commonly set equal to the wage rate, net of taxes.[3] Estimations here prove that it is much lower, while there is also much heterogeneity in the population: the opportunity cost of time increases with the presence of children, as well as with the household's net wage and its relative income (compared to a reference population).

The difficulties encountered in exchanging time between two individuals imply that no market price exists for time. The valuation of time must therefore be based on the substitution between time and monetary resources for one individual or within a family. Curiously, it seems that Becker's home production theory has not been yet systematically applied to the practical estimation of the value of time and consequently of full income and full price elasticities, except in the literature on transportation costs. An exception is the estimation of the substitution between shopping time and expenditures by Aguiar and Hurst (2007). They find an elasticity between price and the frequency of shopping trips that is between 7 and 10 percent. This allows the opportunity cost to be

[3]This supposes that time is perfectly exchangeable between household's market and non-market activities, which is highly disputable. Another calibration used in the empirical literature is the official minimum wage rate, which supposes that this minimum wage is close to the market wage of market substitutes for domestic activities.

calculated at $1.67 per hour (see Alpman and Gardes 2015). While the opportunity cost derived from Aguiar and Hurst (2007) is significantly smaller than our estimates for the United States (around 12 dollars per hour for 2015, see Table 1 and Alpman and Gardes 2015)[4] and for France (see Table 1), its evolution with respect to age is similar to ours: the opportunity cost of time begins to decline when individuals reach 35-39 years old (Aguiar and Hurst 2007, Figure 4).

The estimation of the opportunity cost of time of an individual also allows estimating the economic value of its human life based on the integration of the marginal value of each instant during the individual's life cycle. The evaluation of the economic value of human life is necessary for various policy decision, for instance in case of deceases due to public investments or environmental catastrophes. It is also used to estimate the effect of risk attached to some job on the corresponding wages. Classic evaluation methods give rise to a large span of values: Dionne and Leveau (2010, p. 487) discuss evaluations going from 0.5 to 50 billions of 2000 US dollars, Miller (2000, Tables 1 and 2) from 0.6 to 8.3 billions of 1995 US dollars, with averages at 5.5 billions for the first, 3.45 billions de dollars for the second. Sunstein (2014, pp. 94, 104-105) proposes a distribution of values for various methods between 3.8 and 9 billions of US dollars. The corresponding values in 1990 for the three developed countries we examine (Canada, France, USA) are 2,9 to 4,4 billions of US dollars for Canada, 3.4 for France (Miller, Table 1, p. 176), 3 to 7 for the US (Viscusi, 1993, Table 2). These evaluation methods differ not only by their econometric methods, the periods or the countries but also by the concept of the economic value of human life which is adopted. For instance, the method of hedonic wages measures the value of differential risks between two jobs (and its consequences on deseases or accidents-hurts) in order to define a homogenous compensation for these risks. The method based on State preferences revealed by its decisions concerning for instance security on roads or investments on health, is dedicated to an harmonization of public policies as concerns their effects on the population rate of deaths and hurtings. The method based on the evaluation of the value of the agent's future revenues calculate the loss for the economy of its death. Methods based on individual direct answers on their disposition to pay in order to avoid some risk affords the personal evaluation of the marginal value of future life. Finally, some empirical analyses have been founded on the expenditures made by households to diminish the risks linked to their consumption, for instance for food or transportation.

Various critics have been adressed to these methods: the hedonic wage method depends on the assumptions made on the econometric specification and on the independence assumed between risks linked to the jobs. Market compensations for these riks exist only for some specific sectors. The method based on public investments revealing the State preferences give rise to very different evaluations according to the type of policy (it is for instance much larger for environmental risks). The evaluation of future revenues is generally made using cross-sections, and considering incomes for older individuals observed in the survey and with no information on changes due to economic cycles or possible unemployment. The willing to pay evaluation depends on the questionnaire and

[4]Note however that section 3.2 shows that the Opportunity Cost of Time should differ between household's activities

the individual characteristics (altruism for instance).

All methods are based on the choice of an intertemporal substitution rate (ITSR) necessary to calculate the present value of future incomes. This rate is often calibrated as the rate for public investments which is generally smaller than the households' psychological ITSR given by surveys. Sunstein (2014, pp. 62-3) remarks that the Federal State uses rates varying from 3 to 7% for its public investments concerning environment and security. The higher rate corresponds to interest rate of private investments, while the first is closer to the households' social rate of time preference, when it is governed by the interest on public debt. Pratically, the OIRA suggest to operate using these two alternatives. I will discuss later a possible endogeneization of the ITSR based on households' saving decisions.

In this article, I propose a new method to evaluate the economic value of a human life at the individual level based on the marginal value given by the individual to its disposable time.

The contribution of this paper is thus: i) to propose a new method to evaluate the opportunity cost of time used in the domestic production (enabling the monetary value of this production to be measured) and the opportunity costs corresponding to different activities; ii) to develop a new method in order to estimate the economic value of human life; iii) to define full prices of final goods under complementarity or substituability of money and time used in the domestic production of these goods, iv) to offer the possibility of calculating the level of indirect utility depending on monetary expenditures and time-uses and (v) to discuss the relation between the value of time and the degree of substituability on the labor market or in domestic production.

Section 1 defines a Beckerian model of the allocation of time with an endogenous value of time. Section 2 a new method for the estimation of the economic value of a human life and section 3 presents the resulting estimations for three developed and two under-developed countries.

1 A Beckerian Model of the allocation of time with an endogenous value of time

1.1 Opportunity cost compared to the wage rate

The opportunity cost of time is usually defined as the Lagrange multiplier of a time constraint: in such a model, households are supposed to maximize a direct utility depending on the time devoted to leisure T_d and on the quantities consumed x of a Hicksian composite good containing all market goods whose relative prices are supposed to be constant across the population. Under perfect substitution between market and domestic labor, the ratio of the marginal utilities of time and market expenditure equals both the opportunity cost divided by the price of the market good and the wage rate divided by the same price. The opportunity cost of time is thus supposed to be equal to the net wage rate. However, all direct surveys asking individuals to reveal their opportunity cost of time (OCT) give values which are much lower than their wage rate net of taxes, by at least 50%. For instance, the estimate derived by Aguiar and Hurst (2007b) looking at consumers' market behavior (time spent compared to expenditures) are around \$1.5 per hour, a probable under-estimate of the OCT for

other activities. Various reasons may explain a difference between the opportunity cost of time and the wage rate, including the case when the two adults of a couple are not employed in the labor market or if expenses due to working in the labor market (clothes, transportation costs, investment in human capital, etc.) must be deduced from the wage rate. Also, constraints in the labor market (for instance if working time cannot exceed a legal maximum) impart a virtual cost corresponding to the Lagrange multiplier of each particular constraint. Finally, the opportunity cost of time may differ from the market wage, not only because of the disutility attached to market labor compared to home production, but also because of the possibility of joint production which characterizes the latter (see a discussion in Gardes, 2018).

The model put forward in the following section is based on the estimation for each household of its opportunity cost of time by means of the first order conditions in a domestic production framework[5]. It thus differs from the methods used for instance in transport economics, which are based on the calculation of the Lagrange multiplier corresponding to a time constraint, which necessitates specific identification constraints (see for instance Jara-Diaz et al, 2017a, b, c and DeSerpa, 1971).

1.2 Previous methods

In empirical applications, when the opportunity cost of time is not calibrated at the net wage rate (which is the usual assumption), it is defined under very special and disputable hypotheses. For instance, in a paper on transportation costs, de Vany (1973) supposed that income and price elasticities of air travel depend linearly on the trip distance. Recent papers by Jara-Diaz et al. (2017) are also characterized by such restrictive assumptions. The direct specification of a reduced form demand function over the monetary prices of market goods, the value of time and some income variable (either monetary income or full income) is highly disputable, since it mixes the effects of changes in the monetary and time components of the full price with the effect of the opportunity cost of time through the full income. Take for instance the recent article by Zieba (2009) which estimates the price elasticity of theatre tickets in Germany using a reduced form demand equation. The specification is double logarithmic and two different equations relate the theatre attendance per capita to the ticket price, the price of leisure and, either the household's monetary disposable income, or its full income. The time used for transportation and attendance is valuated at the regional average market wage of the German population multiplied by the proportion of households working on the labor market (an empirical proxy of the household's expected wage). The full-income sums the household's monetary disposable income and leisure time income. The elasticity over the price ticket is estimated at -0.28, while the full price elasticity culminates at -4.16 and the monetary and full income elasticities are respectively 1.16 and 5.65. The full-income and full price elasticities thus appear as extremely high. In this specification with full income and full prices, the effect of a change in the opportunity cost for time is double: through the full price elasticity and the time component of the full income, which explain these not plausible estimates. This

[5]A unique utility function is assumed for households, thus neglecting collective decisions and the allocation of goods and time within the family.

can be shown by multiplying the full income elasticity by the ratio between the time component and the full income (0.64 in average as measured on our French statistics - note that a correct specification may use instead the marginal effect of the time component of the full income): the sum of the income and price effects of a change in the opportunity cost for time amounts to -0.53, which is close to the ticket price elasticity.

1.3 The Cobb-Douglas specification

In the Becker's original home production theory, the same opportunity cost of time applies for the time factor of the home production and on the labor market. I now turn to a model where the value of time in domestic production can differ from the wage rate and where the agent maximizes a direct utility function depending on the quantities of a set of activities given by the domestic production functions. I follow here, for the Cobb-Douglas specification, the presentation in Gardes (2018). I consider, as in Becker (1965), a set of final goods (activities such as eating, transportation, housing, clothing or leisure) the quantities of which enter the direct utility of the consumer $u(z_1, z_2, z_3..., z_I)$. In order to simplify the analysis, a separate activity i produces the final good i in quantity z_i using a unique market good[6] in quantity x_i and time t_i together with all other (socio-economic) resources or characteristics of the household in a vector G: $z_i = f(x_i,t_i;G)$. The consumer's program writes:

$$Max\, u(z_1,\, z_2,\, z_3..., \, z_I)$$

such that $z_i = f(x_i,t_i;G)$ under the constraints on resources

$$\Sigma_i p_i x_i = y \; and \, \Sigma t_i + t_w = T \tag{1}$$

with $y = wt_w + y_0$ the monetary income which sums the labor income with other incomes y_0, t_w the labor time on the market and T the total disposable time for one period.

I first assume Cobb-Douglas structures both for the utility and the domestic production functions of the final goods. Note that all the parameters can be estimated locally (i.e. for each household in the dataset), so that this specification just assumes additive separability of the utility and, for each household, the constancy, in a neighborhood of its equilibrium point, of the elasticities γ_i , α_i and β_i. The optimization program is:[7]

$$Max_{m_i,t_i} u(Z) = \Pi_i a_i z_i^{\gamma_i} \; with \; z_i = b_i m_i^{\alpha_i} t_i^{\beta_i} \tag{2}$$

under the full income constraint with y_0 designing other monetary incomes:

$$\Sigma_i(m_i + \omega t_i) = wt_w + \omega(T - t_w) + y_0 \tag{3}$$

The full income y^f is the maximum monetary income which could be earned when working during all disposable time T[8] , valued at the market wage rate

[6] In case multiple market goods are used in activity i, a generalization to a bundle of market goods used to produce the activity can be performed by defining an aggregate commodity of the market goods corresponding to this activity. The monetary price will be defined in this case as a price index for this aggregate, coherent with the monetary budget constraint.

[7] All variables correspond to a household h which index is omitted in the equations.

[8] Excluding sleeping time, although, as remarked by Aguiar and Hurst (2007a) sleeping time is in fact a choice variable over which individuals optimize. Sleeping time is generally excluded from domestic and leisure time in the time use literature.

net of taxes w:

$$y^f = wT + y_0 = y + \omega(T - t_w) = y + \omega\Sigma_i t_i.$$

It is assumed here that the agent's opportunity cost ω (supposed to be the same for all domestic activities.) differs from her net wage, so that the full budget constraint writes:

$$\Sigma_i(p_i + \omega t_i) = y^f + (\omega - w)(T - t_w) = y^f + (\omega - w)\Sigma_i t_i.$$

In this formula, the full income is thus corrected by the difference between the market (w) and the personal valuation (ω) of the total domestic time $\Sigma_i t_i$: the agent subtracts the transaction cost between her leisure and market labor opportunity cost of time from her full income (this correction applies when the market labor supply t_w is predetermined, which defines the monetary income). This full budget constraint differs from the usual one whereby leisure or consumption time is valued by the agent's net market wage rate. This particularity allows a new method to be proposed to estimate the agent's opportunity cost of time.

Note that $T - t_w = \Sigma_i t_i = T_d$ and that both the market wage and the shadow wage (i.e. the opportunity cost of time ω) appear in the budget equation: the shadow wage corresponds to the valuation of time in domestic production, and it is supposed to differ from the market wage w. Note that prices p_i enter the utility function via $m_i = p_i x_i$ (instead of a specification of utility over quantities x_i) but the monetary prices are supposed to be the same for all households (since no direct information on prices per household is available in the dataset) so that this specification corresponds to a utility depending on quantities.

This specification supposes that market work is exogenous (it is in fact the residual after domestic times have been subtracted from disposable time, supposed to be given as total time less necessary time for sleeping). It corresponds to the assumption that households follow a two-stage budgeting approach where market working time does not affect monetary expenditures and domestic times. This assumption is natural if the market time is fixed at an official amount as is the case in France (35 hours a week), but it can be discussed for all individual able to work supplementary hours or less than the official limit. It can indeed be assumed that while hours may be more regulated in fulltime jobs, part time employment exists also which may be quite relevant in the decision between child care expenses and market work, for example. This is a limitation of the paper. Integrating the choice of market work would be possible but necessitates incorporating some variables which are not present in our dataset (but disposable in surveys on labor supply, which could be matched with our dataset).

Resolution of the model

In order to estimate the opportunity cost for time, the utility function is rewritten:

$$u(Z) = \Pi_i a_i z_i^{\gamma_i} = \Pi_i a_i b_i^{\gamma_i} \left[\Pi_i m^{\frac{\alpha_i\gamma_i}{\Sigma\alpha_i\gamma_i}}\right]^{\Sigma\alpha_i\gamma_i} \left[\Pi_i t^{\frac{\beta_i\gamma_i}{\Sigma\beta_i\gamma_i}}\right]^{\Sigma\beta_i\gamma_i} = a m'^{\Sigma\alpha_i\gamma_i} t'^{\Sigma\beta_i\gamma_i} \tag{4}$$

with $m^{'}$ and $t^{'}$ the geometric weighted means of the monetary and time inputs with weights $\frac{\alpha_i \gamma i}{\Sigma \alpha_i \gamma_i}$ and $\frac{\beta_i \gamma i}{\Sigma \beta_i \gamma_i}$. Deriving the utility over monetary income y and total leisure and domestic production timeT_d gives the opportunity cost of time:

$$\omega = \frac{\frac{\partial u}{\partial T_d}}{\frac{\partial u}{\partial y}} = \frac{\frac{\partial u}{\partial t'} . \frac{\partial t'}{\partial T_d}}{\frac{\partial u}{\partial m'} . \frac{\partial m'}{\partial y}} = \frac{m' \Sigma_i \beta_i \gamma_i}{t' \Sigma_i \alpha_i \gamma_i} . \frac{\frac{\partial t'}{\partial T_d}}{\frac{\partial m'}{\partial y}} = \frac{\Sigma_i \beta_i \gamma_i}{\Sigma_i \alpha_i \gamma_i} . \frac{y El_{t'/T_d}}{T_d El_{m'/y}}. \quad (5)$$

The ratio of the time and income elasticities: $\frac{El_{t'/T_d}}{El_{m'/y}}$ is estimated on our data as smaller but close to one. The value of time is thus proportional to the ratio of an index of monetary expenditures over time use.[9] Note that all parameters of the utility function are estimated locally by the first order conditions, so that the household's welfare depends both on the set of parameters (α, β, γ) and on its monetary and time expenditures m_i and t_i [10]

The Cobb-Douglas specification of the utility and the domestic production functions are necessary in order to be able to write the utility in terms of geometric means of expenditures and time uses. As these functions are estimated locally, they can correspond to any global specification for a static comparison between households (the Cobb-Douglas specification concerns only small deviations from the household's equilibrium).[11] But our commodities are defined broadly and each contains a large part of all consumptions, so that the expenditure and time inputs are always positive on our dataset (even on data containing both expenditures and time use, the inputs are positive for all households for such broad commodities: see for example an application of the model for such surveys from Burkina Faso in Gardes and Thiombiano, 2017 and Alpman, Gardes and Thiombiano, 2017).

Estimation of the opportunity cost of time

In order to calculate the parameters of the utility and domestic production functions, I consider the substitutions which are possible, first between time and monetary resources for the production of some activity, second between monetary expenditures (or equivalently time expenditures) concerning two different activities. First, the substitution between time and money in the domestic production function of activity i generates the first order conditions:

$$\frac{\frac{\partial u}{\partial t_i}}{\frac{\partial u}{\partial m_i}} = \omega = \frac{\alpha_i}{\beta_i} = \frac{m_i}{\omega t_i}$$

which implies:

$$\alpha_i = \frac{m_i}{m_i + \omega t_i}, \; \beta_i = \frac{\omega t_i}{m_i + \omega t_i} \quad (6)$$

[9] Note a similar proportionality in the first order condition for minimizing the cost of shopping intensity in Aguiar and Hurst study: using their equation 2 (2007b, page 1536), the opportunity cost of time can be written as the negative of the product of the elasticity of price with respect to shopping time cross the ratio of monetary over time expenditures.

[10] This utility function can be used to estimate welfare calculations, which generalize usual indirect utility calculations based solely on wages and monetary expenditures (see the discussion by Aguiar and Hurst, 2007a and an application in Canelas et al., 2014).

[11] Note however that the Cobb-Douglas structure rules out complete specialisation (in case where some activity is fully made using only one factor), in the sense that the both inputs must be positive in order to insure a positive production.

under the constraint of a constant economy of scale for each production function: $\alpha_i + \beta_i = 1$.[12] It is also assumed that all marginal productivities are positive: α_i, β_i, $\gamma_i > 0$ and the utility is normalized with the constraint $\Sigma\gamma_i = 1$ (no economy of scale in the utility. Note that the estimation of these coefficients without that restriction gives a sum close to 1 up to 0.01).

Consider now the substitution between times t_i and t_j in the domestic production of two different final goods i and j: this substitution implies another condition between the parameters of the domestic production functions and the utility function:

$$\frac{\gamma_i}{\gamma_j} = \frac{\beta_j t_i}{\beta_i t_j} = \frac{\alpha_j m_i}{\alpha_i m_j} \tag{7}$$

so that:

$$\gamma_i = \gamma_1 \frac{m_i}{m_1} . \frac{\alpha_1}{\alpha_i} \tag{8}$$

for all i>1.

All other substitutions between monetary and time resources devoted to different activities can be derived from (7) and (8).

In order to estimate these parameters, a possible method consists in the calibration of the opportunity cost of time in a first stage, for instance at the minimum wage rate which is constant over the population. Equations (6) thus give an estimate of α_i and β_i for each household, which gives γ_i by equation (7). In the second step, an estimate of the opportunity cost of time ω is given by equation (5) which allows the computation of the individual values of the parameters α, β, γ for each household using equations (6) and (8). These values enter equation (5) to give for each household the second step estimate of ω. The estimations on the French data as well as simulations[13] tend to show that this procedure may not converge rapidly to the true value of the opportunity cost of time.

Another method can be based on equations (6) and (8) which imply for all activities i, j:

$$m_i \gamma_j = m_j \gamma_i + \omega \gamma_i t_j + \omega \gamma_j t_i \tag{9}$$

This could be estimated as a system of $\frac{n(n-1)}{2}$ independent equations, calibrating γ_j at the average full budget share for one good[14] or as a system of $\frac{(n-1)(n-2)}{2}$ equations under the homogeneity constraint of the utility function: $\Sigma\gamma_i = 1$. In this system, the opportunity cost of time is over-identified, as well as all $\gamma_j, j > 1$.[15] We can also sum equations (9) over j with $\Sigma\gamma_j = 1$ to obtain (n-1) independent equations:

$$m_i = \gamma_i(m + \omega T) - \omega t_i,\ i = 1, ..., n \tag{10}$$

[12]This restriction is necessary for the identification of the model, which could also be obtained fixing the sum of each couple (α_i, β_i) to some pre-determined value.

[13]Performed by J. Boelaert and P. Merrigan.

[14]Note that taking together equations 7, 8 and 9 to calculate the value of ω gives rise, as noticed by Philip Merrigan, to a highly non-linear equation in γ_i and ω which cannot be solved algebraically.

[15]Note that an estimation of this system of equation without constraint on the set of coefficients Îş_i gives estimates the sum of which is close (up to 5%) to 1. On the contrary, estimating without the non-linear structure of the system of equations over the OCT and the Îş, gives different estimates of the OCT, which shows that these constraints must be imposed in the estimation.

This system of equations can be estimated for the whole population, which gives a unique estimate of ω for all households.[16] The estimation without constraints (no additivity constraint on coefficients γ_i) shows that the absence of economies of scale in the utility ($\Sigma\gamma_i = 1$) is verified.

The estimation can also be performed on sub-populations or by a non-parametric local regression, which affords a set of individual estimates over the population. The resulting estimates of the opportunity cost of time ω and the parameters γ_j of the utility function are then used through equations (8) and (9) to calculate α, β and γ for each household. Finally, the estimates of these three parameters are used to estimate the opportunity cost of time $\omega(h)$ for each household h in the population by equation (5). A generalization of the model with several different opportunity costs of domestic activities is possible defining T and Y as time and monetary resources for a subset of activities and separating this subset from their complementary use for other activities in the utility. This gives rise to a system of equations which differ from the definition of the opportunity cost of time in equation (9). The test of these differentiated OCT is left for a future research.

Note that the Cobb-Douglas specification does not allow to calculate opportunity costs ω_i specific to each commodity since:

$$\frac{\frac{\partial u}{\partial t_i}}{\frac{\partial u}{\partial m_i}} = \omega$$

equals the common opportunity cost ω by equation (6). This calculation of different values of time follows from the CES specification of domestic production functions.

1.4 The CES specification

The CES specification of the domestic production function for commodity i writes: $z_i = [a_i m_i^{\rho_i} + (1-a_i)t_i^{\rho_i}]^{\frac{1}{\rho_i}} = a_i^{\frac{1}{\rho_i}}\left[m_i^{\rho_i} + \frac{1-a_i}{a_i}t_i^{\rho_i}\right]^{\frac{1}{\rho_i}}$ which is embedded in a CES direct utility function: $U = \left[\sum_i A_i z_i^{\zeta_i}\right]^{\frac{1}{\Sigma\zeta_j}}$. The partial derivative of U over m_i writes:

$\frac{\partial U}{\partial m_i} = A_i \frac{\zeta_i}{\Sigma\zeta_j} z_i^{\zeta_i - \rho_i - 1} a_i \frac{U}{\Sigma A_j z_j^{\zeta_j}} m_i^{\rho_i - 1}$

which gives with a similar derivative over time:

$$\omega_i = \frac{U'_{t_i}}{U'_{m_i}} = \frac{1-a_i}{a_i}\left(\frac{t_i}{m_i}\right)^{\rho_i - 1} \tag{11}$$

Note that a Cobb-Douglas specification of the utility function:

$$V = \Pi a_i^{\frac{1}{\rho_i}} \left[a_i m_i^{\rho_i} + (1-a_i)t_i^{\rho_i}\right]^{\frac{\gamma_i}{\rho_i}}$$

gives the same expression of the opportunity cost. The coefficients ρ_i of the production functions are linked to the elasticity of substitution σ_i by the relationship: $\rho_i = 1 - \frac{1}{\sigma i}$. These elasticities of substitution have been estimated in

[16] The opportunity cost of time ω is over-identified in this system, which can be tested: a test for proportionality between equations shows that the structure of the system is not automatically verified in an unconstrained estimation (note that the large number of observations leaves no room for another result).

Canelas et al. (2018). In order to calibrate a_i, consider now an isoquant:

$$\begin{aligned} dz_i &= 0 \\ &= a_i^{\frac{1}{\rho_i}} \frac{1}{\rho_i} \Big[\rho_i m_i^{\rho_i - 1} (a_i m_i^{\rho_i} + (1-a_i) t_i^{\rho_i})^{\frac{1}{\rho_i} - 1} dm_i \\ &\qquad + \rho_i \frac{1-a_i}{a_i} (a_i m_i^{\rho_i} + (1-a_i) t_i^{\rho_i})^{\frac{1}{\rho_i} - 1} dt_i \Big]. \end{aligned} \tag{12}$$

This implies that: $\frac{1-a_i}{a_i} = -(\frac{m_i}{t_i})^{\rho_i} \frac{dm_i}{dt_i} = -\left(\frac{m_i}{t_i}\right)^{\rho_i} El_{m_i/t_i}$.

The elasticity of monetary expenditure $m_i$over the corresponding time must be recovered along an isoquant. This estimation could be empirically applied to a sub-population with similar levels of domestic production. A simpler method consists to use a Cobb-Douglas specification for the domestic production function, which gives rise to a calibration of $El_{m_i/t_i} = -\frac{\alpha_i}{1-\alpha_i}$ for coefficients $\alpha_i = \frac{m_i}{m_i + \omega t_i}$ defined in section 2.1 (using the wage rate or a first estimation of ω as the opportunity cost of time). However, this solution does not correspond to the assumption made on the CES domestic production functions. Also, an estimation on the whole sample affords rather small elasticities, around -0.15,compared to those of the Cobb-Douglas solution (around -1) or its value in terms of elasticities over ω.[17]Thus, one may just calibrate a_i at several values between 0 and 1, for instance 0.5, one third and two third, and compare the results.

Finally, the relationship between the set of opportunity costs of time for each commodity ω_i and a general cost ω can be recovered considering the full budget constraint: $\mathrm{y}^f = \Sigma (m_i + \omega_i t_i) = w t_w + V + \omega (T - t_w)$ with $\mathrm{y}^f$the full income, w the household's wage rate, t_w its market labor supply, T the total available time (less sleeping time and other necessities),$T - t_w = \Sigma t_i$the time devoted to domestic activities and V other monetary incomes, which implies: $\omega = \frac{1}{\Sigma t_i} \Sigma t_i \omega_i$. The global opportunity cost of time is thus a weighted average of partial costs, weighted by the time budget shares. This relation gives another solution for the computation of a_i: compute the individual opportunity costs of time ω_i using the CES specfication with $a_i = 0.5$ and the resulting average global $\overline{\omega}$ which can be compared to the OCT estimated by equations (9). The ω_i are then corrected by the ratio of these average OCT (corresponding to the coefficient $\frac{a_i}{1-a_i}$ in the formula giving ω_i) in order to sum to the estimation given by the system of equations (9).

Note that a CES specification with domestic production functions depending on the monetary value of time use :

$$z_i = [a_i m_i^{\rho_i} + (1-a_i)(\omega_i t_i)^{\rho_i}]^{\frac{1}{\rho_i}} \tag{13}$$

gives :

$$\omega_i = \frac{m_i}{t_i} \tag{14}$$

which corresponds to the Cobb-Douglas case with $\alpha_i = \beta_i = 0.5$ and to the CES specification with $El_{m_i/t_i} = -1$.

[17]The elasticity of monetary expenditure $m_i$over the corresponding time can also be written in terms of the elasticity of substitution and the elasticities of monetary or time expenditures over the opportunity cost of time (which depend on the commodity full price elasticities, see Gardes, 2018): $El_{m_i/t_i} = \frac{El_{m_i/\omega}}{El_{m_i/\omega} + \sigma_i} = 1 - \frac{\sigma_i}{El_{t_i/\omega}}$. This formula gives estimates between -1.7 and -2.

2 Tout ce temps si long...: A new evaluation of the economic value of human life

Suppose an economic agent evaluates its marginal value for disposable time at ω. This marginal value can be integrated over its whole life (or remaining life) to obtain the monetary value of its total living time, as defined by Proust in the liminar sentence. This marginal value is applied to all types of activities, an assumption on the constancy of parameters which is also made in all other methods, for instance those based on the willingness too pay for one hour more or hedonic wages.

The economic value of a length of time lived by some individual is the product of ω with this duration, actualized over the life cycle for t=1 to T:

$$V = \int_0^T \omega_t T_0 e^{-rt} dt. \tag{15}$$

The assumption of that ω is constant along the life cycle gives the following value:

$$V_1 = \left(\frac{1}{r} - \frac{e^{-rT}}{r}\right) \omega T_0 \tag{16}$$

with T_0 the period (number of disposable hours during one year). Disposable hours are defined as those which can be substituted to another activity, either domestic or on the labor market. It can correspond to 24 hours a day (including sleeping in this substitution) or disposable time after necessary activities (16 hours for instance).[18] Empirical analysis on our datasets indicate that the OCT depends on the individual age with a quadratic specification corresponding to a maximum at 40 to 45 years of age (see Table 3): $\omega_t = \alpha + \beta_1 t + \beta_2 t^2$. The integration of equation (14) with this dpendency on age gives a second formula for the value of a human life :

$$V_2 = \left(\frac{1}{r} - \frac{e^{-rt}}{r}\right) \alpha + \beta_1 \frac{T^2}{2(1-r)} e^{-rt} + \beta_2 \frac{T^2}{1-r} e^{-rt} \tag{17}$$

The average life duration T is very similar in developed countries: 81.24 years in France, 81.66 in Canada, 77.8 in the US. The value of a human life thus depends on the ITSR, the function indicating the OCT in terms of age, and the life duration. Another evaluation could be based on the sum of market wages, other monetary incomes and the value of domestic time measured by the OCT. I propose in equations (15) and (17) to consider a common evaluation of time uses, either on the market or at home, under the assumtion of a perfect substitution between market work and domestic work.

[18]The estimation of these necessities is left for a future research. The integration of sleeping time is debated in the literature on time use budgets. It could be set at the value corrsponding to the first decile of ime use for each activity, or estimated by a Linear Expenditures system. However, Aguiar et al. (2013) observe that more than one fifth of supplementary domestic time created by partial unemployment during the Great Recession (2008 – 2010) has been consacrated to sleeping.

Endogeneization of the ISTR

The increase of the OCT in the beginning of the life cycle and its stabilization or small decrease after could be used to justify the positivity of the ITSR, at least for early ages. I propose to consider instead the dependency of the household's savings with both the ITSR and the OCT. Savings is indeed the residual income after consumption (thus related with the OCT by means of the elasticity of expenditures as concern the OCT) and also a differed consumption (depending on the psychological interest rate). A priori, an increase in the OCT tends to substitute monetary expenditures to time use in the domestic productions, so that savings may decrease ceteris paribus. The elasticity of expenditures as concerns the OCT have been derived in Gardes (2014, p. 11; 2018) in terms of the full prices elasticities E_{x_i/π_j}:

$$E_{x_i/\omega} = \Sigma_j E_{x_i/\pi_j} \frac{\omega t_j}{p_j x_j + \omega t_j} \tag{18}$$

The weighted average of these elasticities defines the change of total monetary expenditures and thus of household's savings. The positive relation between savings and the psychological interest rate (ISTR) is governed by elasticities varying from 0.1 to 2, according to the country and the estimation method. The elasticity of the ISTR over the OCT thus writes:

$$S(\omega, p) = \bar{S} \Rightarrow S'_\omega d\omega + S'_r dr = 0 \Rightarrow E_{r/\omega} = -\frac{E_{S/\omega}}{E_{S/r}} \tag{19}$$

so that, with $S = Y - \sum p_i x_i$:

$$E_{S/\omega} = \frac{1}{S}\left[E_{Y/\omega} - \sum w_i E_{x_i/\omega}\right] \tag{20}$$

The elasticity of househod's income over the OCT depends on the elasticity of the household's market labor time t_w over the wage rate and on the ratio between the OCT and the household's average wage rate. The elasticity of market labor has been evaluated at 0.86 in France, 0.42 in Canada and 0.32 in the US (see Gardes and Margolis, 2015). For France, the elasticity of the household's income over its OCT : $E_{Y/\omega} = \frac{wt_w}{Y}\left[E_{w/\omega} + E_{t_w/\omega}\right]$ is estimated between 0.75 and 1.92 according to the assumption that the wage rate is constant ($E_{w/\omega} = 0$) or not. The second term in equation (18) is evaluated in France as 0.172 (Gardes, 2014, Tableaux 2 et 3). It allows calibrating the elasticity of savings over the OCT at 2,8 for the first evaluation of $E_{Y/\omega}$ and a savings rate equal to 0.20. Finally, the elasticity of the Inter-temporal Substitution rate over the OCT is -2,8 for a unitary elasticity of savings over the ISTR. For instance, if households characterized by a small value of time (1,83 euros in France in 2000) have a psychological interest rate of 7%, households with the highest value of time (11.33 euros) would have a psychological interest rate at 1,4%. Therefore, these two parameters (the ISTR and the OCT) add their positive effect on the estimation of the economic value of a human life.

I suppose that the average household has an Intertemporal Substitution rate at 3% and an opportunity cost of time at 7.32 US dollars (the average for the french survey). The ISTR of a household characterized by an opportunity cost of ω writes: $r(\alpha) = -\frac{0.03\,\omega}{7.32^{-2.08}}$. The values of human life V_1 and V_2 for that household can be computed using this individual ISTR and averaged over the population.

3 Empirical analysis

The estimation operates for five countries: Burkina-Faso, Canada, France, Poland and USA. For each country, a Time-Use survey is matched with a Family Expenditures survey corresponding to the same period. The matching is operated either (for the French and Polish datasets) by a regression of the time-uses observed in the matched survey using common covariates observed in the two surveys (such as education level and the age of the head, the family demographic structure or location) or (for Burkina-Faso, Canada and US datasets) by the Rubin matching model decribed in Appendix. Datasets are presented in Appendix B.

3.1 Estimates of the opportunity cost of time

A unique OCT $\widehat{\omega}$ for all commodities is first estimated by the system of equations (9) and (5) under the Cobb-Douglas specification. The estimates of a unique OCT are approximately equal to one half of the average wage rate, as indicated by surveys on willingness to pay for one hour more. They are therefore much greater than the value indicated by Aguiar and Hurst experiment on the value of time for purchase in a great surface.[19] The Cobb-Douglas model seems to affords a correct estimate of this value. This estimate is positively correlated to the household's wage rate (elasticity equal to 0.65 for instance in France) and also (in France) to the relative position of the household in the income distribution elasticity equal to 0.43). It increases with the family size (+0.37 per child in France), which may indicate economies of scale in domestic production. It increases till 45 years, then decreases for the three developed countries (as shown in Table 3), which is exactly the change observed by Aguiar and Hurst.[20]

In order to estimate the opportunity costs by activity, formulas (11) and (14) are used with a correction by $\frac{a_i}{1-a_i}$ computed as the ratio of the average individual estimates and $\widehat{\omega}$ (the correction factor is 1.18 for formula (11) and 0.67 for formula (14)). These estimations (reported in Table 2 for France) are performed over the whole sample and for sub-populations defined by age classes, family composition and education level. The estimates by (11) and (14) are not so different from $\widehat{\omega}$: the first estimates of the individual OCT are similar in average to the estimate of $\widehat{\omega}$, while the second averages two third. Formulas (11) and (14) give close estimates for each activity, except for transport and clothing. The individual opportunity costs of time vary from 2 to 12 between the different commodities, with small OCT for Food and Leisure and large ones for Housing and Transport. This means that the marginal utility of time changes much from one commodity to another.

That variation of the opportunity cost of time between different activities has been considered as possible by Becker in his original 1965 article: "Presumably, the cost of time varies considerably among commodities and at different periods. for example, the cost of time is often less on week-ends and in the

[19] The estimation of the opportunity cost for various activities in Table 2 suggests that this low value may be specific to this purchasing activity.

[20] It could be expected that the value of domestic time is positively correlated to the probability to be present on the labor market, which is the case for both men and women in their middle age (presumably for women when children are not too young). This proximity to the labor market increases the possibilities to substitute market work to domestic labor.

Country	Formula	ω	$\frac{\omega}{wage}$	$\frac{\omega}{min\ wage}$	Cent.1 ω	Cent.99 ω
Burkina Faso	Eq (5) 1st step Eq (9)	0.09	0.30	0.28	0.02	0.40
s.e.		0.01	-	-	-	-
Canada	Eq (5) 1st step Eq (9)	10.93	0.69	1.58	1.45	59.82
s.e.		14.63	-	-	-	-
France	Eq (5) 1st step Eq (9)	7.01	0.52	0.73	2.51	13.95
s.e.		8.67	-	-	-	-
Poland	Eq (5) 1st step Eq (9)	4.26	0.43		0.34	38.42
s.e.		9.21	-	-	-	-
USA	Eq (5) 1st step Eq (9)	12.75	0.74	2.88	2.80	31.17
s.e.		0.42	-	-	-	-

Table 1: Estimates of the Opportunity Cost by country, US dollars 2015

evening because many firms are closed then, which explains why a famous liner intentionally includes a week-end in each voyage between the United States and Europe. The cost of time would also tend to be less for commodities that contribute to productive effort, traditionally called "productive consumption". A considerable amount of sleep, food and even "play" fall into this heading. The opportunity cost of time is less because these commodities indirectly contribute to earnings." He discussed it later (Becker, 1981), considering that the degree of effort which is dispensated by the individual in a given activity may increase the value of the time used for that activity. Under this hypothesis and supposing that "married women spend less energy on each hour of market work than married man", he explains the difference between the man and spouse wage rates and the specializations of women in domestic productions. We propose later another explanation based on the relative possibility to substituate between money and time in the domestic production of each activity.

Table 2 contains the estimates of the opportunity costs of time for the whole sample in France and different sub-populations. The value of time increase between the first income quartile and the last one by 60%, with an income elasticity equal to 0.25. This increase is particuliarly large for Leisure and Other activities). They also increase with the eduction level, specially for Food, Housing, Clothing and Leisure (and remain constant for Transportation and Other activities). Finally, the presence of children seems to have an opposite effect on the OCT compared to the number of adults: indeed, it increases the OCT for all activities, while the OCT is the same for singles and couples without children. All activities characterized by a larger OCT due to children (i.e. transportation, Clothing and Leisure) have smaller OCT for couples compared to singles, while the reverse correlation exists for those activities the OCT deceases with children (Housing and Other activities). That means that the increase of family size by

Final good	Food	Housing	Transport	Clothing	Leisure	Other	All
Elasticity of substitution	-0.415	-0.849	-0.399	-1.038	-0.655	-0.651	-0.665
OCT A	3.96	15.95	5.98	10.78	2.18	6.57	5.04
OCT B	4.11	15.52	12.02	3.84	0.67	3.70	5.04
OCT A Quartile 1	3.36	10.44	5.87	7.08	1.39	4.43	4.06
OCT B Quartile 1	1.62	4.76	26.43	2.47	0.33	1.28	4.06
OCT A Quartiles 2 and 3	3.75	12.30	6.82	8.75	1.93	6.55	4.89
OCT B Quartiles 2 and 3	1.40	20.79	14.06	1.94	0.26	2.21	4.89
OCT A Quartile 4	4.35	17.00	7.71	13.70	3.05	9.35	6.49
OCT B Quartile 4	3.13	21.32	21.52	2.85	0.45	3.63	6.49
OCT A Singles	3.79	18.93	4.92	8.57	1.84	6.09	4.84
OCT B Singles	5.95	14.95	6.43	16.14	1.47	4.21	4.84
OCT A Two adults	3.85	12.35	7.66	7.82	1.80	8.75	4.83
OCT B Two adults	3.02	17.00	12.33	3.30	0.77	5.19	4.83
OCT A With children	3.72	12.20	6.56	10.80	2.49	5.28	5.48
OCT B With children	5.35	11.93	8.52	6.14	1.80	3.82	5.48
OCT A Education 1	3.74	11.20	6.84	7.36	1.57	6.92	4.67
OCT B Education 1	2.89	13.04	13.96	3.40	0.70	3.73	4.67
OCT A Education 2	3.83	12.56	6.94	9.26	2.47	6.17	5.23
OCT B Education 2	2.58	24.24	8.28	3.39	0.68	2.15	5.23
OCT A Education 3	4.01	17.15	6.76	13.39	2.75	6.40	5.70
OCT B Education 3	5.71	23.59	9.65	5.27	1.00	2.99	5.70

Table 2: Estimates of the Opportunity Costs by activity for France

the number of adults has an inverse impact on the value of time compare to the increased size by children. The presence of children thus seems to change a lot the domestic production technology, which is not the case of the increase of the number of adults.

3.2 Substitution and the value of time

The comparison between the order of the elasticities of substitution (in absolute value) and the Opportunity Costs ω_i for the different activities gives an interesting result, since it shows clearly an positive relationship between them: a small substitution between money and time corresponds to a small opportunity cost of time. Indeed, when no substitution is possible (or when it is difficult) between the two factors (as in the cases of Food, Clothing and some types of leisure activities), that is when monetary expenditures and time use are complementary, the time factor becomes necessary as soon as a quantity of the commodity has been chosen. That means that its marginal utility is small conditional to complementarity with the corresponding monetary expenditure and large in case of substitution. Therefore, the classification of commodities according to the value of the elasticity of substitution between the two factors gives an important information concerning the probable opportunity cost of time of this commodity, a result I name the law of *correspondance between substitution and time value*. Looking for instance to Food (respectively Housing), this activity is characterized by small elasticities of substitution (respectively a large one), a small OCT (respectively large) and negative (respectively positive) elasticities of both that OCT and the elasticity of substitution as concerns income and education.

Note however that in case of Leisure, the elasticity of substitution is large

(-0.65) in the estimates for France, while the value of time devoted to these activities is around 2 euros. We suppose that there exist a composition effect in the computation of the elasticity of substitution due to differences in the substituability between money and time in the different types of leisure activities. The estimation for other countries (Canada, Ecuador and Guatemala) give elasticities which are smaller - between 0.4 and 0.7. The opportunity cost given by equation (11) depends on the ratio of monetary expenditures over time use, which is small for this commodity as many monetary expenditures and time use corresponding to leisure are classified as transportation cost, rent for dwelling, food (away from home) or clothing. Therefore, this ratio is underestimated for leisure activities since monetary expenditures are relatively important for these commodities. The verification of the correspondence between the specific opportunity cost of time and substituability for leisure thus needs a more precise classification of expenditures. Many leisure activities cannot be performed without a neccessary amount of time which cannot be substituted for monetary expenditure or made by another person (for instance time to attend an artistic performance or time for sport). Time is in that case complementary to the level of consumption (looking at two movies double the necessary time).

Becker explained the possible variation of the cost of time between commodities by the fact that some commodities, such as food, sleep or "play", are productive consumption, i.e. indirectly contribute to earnings. These three commodities are characterized by small substituability between money and time, since no market substitute exists for instance for sleep or playing activities (and a minimum amount of time is necessary for food). Therefore, an alternative explanation to the one proposed by Becker is the dfficulty to substitute factors of these domestic productions.

Another indice of this relation between factors substituability and the value of time is the inverse quadratic shape of this value relatively to the head's age (see Table 2). Indeed, the allocation of time betwen domestic work and market labor is the highest in the middle of the life cycle, when adults have finished their formation and acquired some professional experience which help to find a job on the labor market, and on the other hand are in a stable family position which increases the productivity of the domestic production process.[21]

Interestingly, this empirical result obtained on micro data applies also to the comparison between countries whence the average value of time is measured relatively to the average wage rate in the economy. This ratio indicates whether time spent in domestic activities can be subtituted to market labor time, since a low ratio corresponds to the situation where individuals may not be able to use their free time to work more. The US have, for the period 2004-2011, a ratio of its average OCT and the average hourly wage rate equal to 0.74, Canada a ratio of 0.69 (in 2002), France 0.45 (in 2000), Poland 0.43 (1997-2000) and Burkina Faso 0.31 (in 2008).[22] Conversely, the substitution between factors of production can be supposed to be the higher for more concurrential economies (US and Canada) and smaller for France, Poland and Burkina Faso. The ratio of the value of time in domestic activities and on the labor market thus seems

[21] Also, both the value of time and elasticities of substitution generally increase with income. The increase of substituability can be explained by the development of discretionary income (income less expenditures on necessities) which helps to substitute it with domestic production.

[22] Note that in Table 4, the ratio of the value of human life over the GDP actualized over the life cycle is also positively correlated to the average OCT for these countries.

to be positively correlated to the general degree of concurrence in the economy.

This ratio could then be used as a indicator of the degree of concurrence in the country. Its change in the US during the Great Recession indicates a decreasing trend of the ratio before 2008 and after 2010, and an increase during the recession (the OCT decreasing less rapidly than the wage rate) which could be interpreted by a rise of concurrential forces in the economy in recession.

3.3 Estimating an enlarged GDP

The domestic production made by households can be valued by the opportunity cost of each activity (see Gardes, 2018b), since whatever its substituability with monetary expenditures (which is incorporated in the estimate of the value of time), some time is always necessary to accomplish any domestic activity. A measure of an enlarged GDP can therefore add the value of domestic production to the GDP or, using surveys on households' expenditures, to the total monetary expenditure made by households. That enlarged GDP is therefore positively impacted by the value of time. As a consequence, a greater substituability between market and domestic labor or inside the domestic production, increases the domestic component of the total national production and thus increases its the economic development. For instance, suppose that chore activities in the domestic production (defined as the component of that activity which can be replaced by market goods or services) correspond to 60 per cent of the market production.[23] If France was characterized by the US ratio of the value of time and market wage (0.74 instead of 0.45), the value of domestic production should increase by one third and its global (enlarged) production would be increased by 12.5% compared to its present value (corresponding to 20% of the GDP). Liberalizing the economy facilitates the substitution between market and domestic labor, and renders the domestic processes of production more efficient, which both increase the value of this component of the households' economic well-being.

3.4 Estimates of the value of a human life

The statistical economic values of human life in table 3 are comparable althought somewhat smaller than those in the literature, and quite homegenous across developed countries. The values of human life for Poland and Burkina Faso are much smaller, as expected. The estimate obtained under the constancy of the value of time across the life cycle are substentially greater for France and Canada and similar for the US[24] than in the case of a value of time depending

[23] Chores are defined as those domestic productions which can be replaced by a market good or service. That means that the elasticity of substitution between monetary expenditure and time is large, say -2 if one supposes that the elasticity of substitution between one euro of monetary expenditure with one euro spent on time (i.e. time valued by the its value) equals one. Suppose the domestic activity is divided between chores with elasticity of substitution -2 and other component with elasticity zero, the elasticity of the aggregate is a weighted average of the elasticity of chores (-2) and the elasticity of other components (0), so that the elasticity of the aggregate is two times the proportion of chores. For instance, chores would represent in France 30% for food while they correspond to 15% for housing. These proportions could be multiplied by the corresponding opportunity costs to calculate the value of domestic productions.

[24] The quadratic effect of age is not significant for Burkina-Faso and Poland.

on age (as indicated in Table 3). It depends heavily on the choice of the inter-temporal substitution rate. Note also that taking into account the endogeneity of the ISTR increases the value (V_1, r(ω)) a lot, by 25% in average, compared to the value for 3% taken as the average ISTR of the population, which shows that this dependency of the ISTR on the average value of time benefits to those households which have a large value of time.

Final good	Food	Housing	Transport	Clothing	Leisure	Other
Total log expenditure	-2.495	-0.271	-2.923	0.640	0.342	-1.560
Log expenditure squared	0.122	0.016	0.154	-0.038	-0.020	0.069
Log age	-0.423	-0.528	-2.127	-1.173	-0.685	-1.491
Log age squared	0.044	0.070	0.287	0.197	0.099	0.182
Log size	-0.052	-0.028	-0.147	0.162	0.091	0.061
Proportion of children	-0.066	-0.026	0.273	-0.225	-0.222	-0.051
R^2	0.057	0.155	0.274	0.209	0.243	0.234

Table 3: Change of the Opportunity Costs of time according to age (France)

Country	V_1, r=0.03	V_1, r=0.05	V_1, r(ω)	V_2, r=0.03	GDP per capita	V_1/GDP
Burkina Faso	14 213	9 848	15 798	-	619	0.85
s.e.	16 538	11 753	-	-	-	-
Canada	2 333 843	1 506 750	3 105 174	2 687 282	50 304	1.52
s.e.	3 125 873	2 018 092	8 553 544	-	-	-
France	2 090 225	1 350 595	2 423 370	2 191 876	42 503	1.36
s.e.	2 584 788	1 670 595	6 642 630	-	-	-
Poland	332 939	220 940	490 540	-	11 705	0.97
s.e.	872 021	578 679	-	-	-	-
USA	3 597 295	2 341 061	4 294 601	3 485 992	53 042	2.25
s.e.	1 607 551	1 046 194	4 176 040	-	-	-

Table 4: Estimates of the Value of a Human Life in US dollars 2015

Note that the ratio of the value of a human life V1 (calculated for a ITSR equal to 3%) to GDP per capita (indicated in the last row of Table 4) is equal to 2.25 and 1.52 in the US and Canada, while it is only 1.36 in France, 0.97 in Poland and 0.85 in Burkina-Faso. Therefore, this ratio differs from 1: this means that the actualization of the flow of all incomes through the individual life cycle (which is frequently used in the literature) cannot be considered as a correct measure of the economic value of human life except for Poland where this ratio is close to 1. Moreover, the relative magnitude of the Value of human life compared to the GDP is positively correlated to the average value of time and thus correspond to the degree of economic liberalization in these countries,

as discussed before.[25]

Inequality in the value of a human life

The model can be used to estimate the value of a human life for different types of family or individual, which may illuminate the discussion on the ethics of a differential valuation of the human life (see on this subject Sunstein, 2014, Chapitre V). The computation of the value V_1 conditional to an Intertempral Sustitution rate depending on the value of time (as indicated in section 2) gives values which increase by 70% between the first and the third level of education of the head, while the increase using a common ISTR (not linked to ω) increase the value human life by only 22%. The corresponding increases between the first income class (till the 10^{th} centile) and the last (up to the 90^{th} centile) are 349% and only 78%. This shows that endogeneizing the ISTR changes a lot the evaluation of the human life V_1.[26]

Sub-Population	Educ 1	Educ 2	Educ 3	Till 10^{th} centile	20^{th} to 80^{th} centile	up to 90^{th} centile
ITSR (%)	2.54	1.85	1.45	4.08	2.15	0.81
V_1	1 404 617	1 928 658	2 384 543	814 799	1 665 995	3 661 315

Table 5: Estimates of the Value of a Human Life V_1 in US dollars 2015 (France)

Conclusion

The results obtained applying the domestic production framework to the computation of the value of time shows the interest to dispose of statistics containing both households' monetary expenditures and time uses. I suggest that questions on time use should be included in Family Expenditures surveys. Models estimated on this type of data allows indeed to derive many applications such as: the proof of the existence of Barten substitution effects in the calculation of equivalence scales, the estimation of equivalence scales for full expenditures (Gardes and Starzec, 2017), the study of a micro foundation of households' labor supply and the Okun law (Gardes, 2018c; Gardes and Margolis, 2014) or tests of axioms on revealed preference by means of full prices (Gardes, 2017).

A final result of this paper is that liberalizing the economy increases the value of time used in domestic production and thus increases the households' well-being. This gives an incentive to liberalize the labor market in order to increase the enlarged GDP containing the value of labor made on informal markets and the value of domestic production.

[25]It would be interesting (but difficult) to compare indices of the households' financial satisfaction such as those which are informed in some households' surveys, with these values of human life.

[26]The length of life T also depends on the sub-population, but considering that dependency would probably change the values by a limited amount.

Appendix A: Two definitions of full prices

Full prices under substituability assumption

Cobb-Douglas case

Following Gronau (1977)[27] , the full expenditure can be written as the sum of its monetary and time components:

$$p_i^{f1} z_i = p_i x_i + \omega t_i \tag{21}$$

with p_i^{f1} and p_i the full and the monetary prices corresponding to the quantities z_i and x_i of activity i and of the corresponding market good (note that prices and the opportunity cost of time depend on household and time, which indices are removed).

The full price is the derivative of the full expenditure over z, which writes for the Cobb-Douglas specification of the domestic production functions:

$$p_i^{f1} = p_i \frac{\partial x_i}{\partial z_i} + \omega \frac{\partial t_i}{\partial z_i} \tag{22}$$

The utility function (4) gives rise to the first order condition: $\frac{t_i}{x_i} = \frac{p_i}{\omega}.\frac{\beta_i}{\alpha_i}$ corresponding to equations (7) in section 1 (note that both α_i and β_i depend on the household). Writing the quantity of the activity z_i defined in equation (2) in terms, either of t or x, gives, with $\alpha_i + \beta_i = 1$:

$$t_i = \frac{1}{b_i} z_i \left(\frac{p_i \beta_i}{\alpha_i} \right)^{\alpha_i} and\, x_i = \frac{1}{b_i} z_i \left(\frac{\omega \alpha_i}{p_i \beta_i} \right)^{\beta_i}. \tag{23}$$

So that the full price becomes:

$$p_i^{f1} = \frac{1}{b_i} p_i^{\alpha_i} \omega^{\beta_i} \left\{ \left(\frac{\beta_i}{\alpha_i} \right)^{\alpha_i} + \left(\frac{\alpha_i}{\beta_i} \right)^{\beta_i} \right\}. \tag{24}$$

This derivation of ω, α and β at the individual level allows identifying the full price for each household (a_i being supposed constant since monetary prices are the same for all households).

CES case

Equation (14) gives the following expression for the CES production functions:

$$p_i^{f2} = \left[\frac{1}{a_i} m_i^{1-\rho_i} + \frac{\omega}{1-a_i} t_i^{1-\rho_i} \right]^{1-\rho_i}. \tag{25}$$

Full prices under complementarity assumption

Becker's full price for one unit of activity i can be written: $p_i^{f3} = p_i + \omega \tau_i$ with τ_i the time use necessary to produce one unit of the activity i. Suppose (as

[27] Suggested by Anil Alpman (see Alpman and Gardes, 2016).

in Becker's model) that a Leontief technology allows the quantities of the two factors to be proportional to the activity:

$$x_i = \xi_i z_i, t_i = \theta_i z_i \tag{26}$$

so that: $t_i = \tau_i x_{ii}$ $\tau_i = \frac{\theta_i}{\xi_i}$.

This case corresponds to an assumption of complementarity between the two factors in the domestic technology, which allows calculating a proxy π for the full price of activity i by the ratio of full expenditure over its monetary component:

$$\pi_i = \frac{(p_i + \omega\tau_i)\, x_i}{p_i x_i} = \frac{p_i + \omega\tau_i}{p_i} = 1 + \frac{\omega\tau_i}{p_i} = \frac{1}{p_i} p_i^{f3}. \tag{27}$$

Note that under the assumption of a common monetary price p_i for all households in a survey made in period t, this ratio contains all the information on the differences of full prices between households deriving from their opportunity cost for time ω and the home production technology represented by the coefficient of production τ_i. If the monetary price p_i changes between households or periods, the full price can be computed as the product of this proxy π_i with p_i: ${p_i}^{f3} = p_i \pi_i$. With these definitions, it is possible to measure the full prices, observing only monetary and full expenditures.

The first definition of full prices corresponds to the assumption of a possible substitution between the two factors of the domestic production functions, with a unitary (in the Cobb-Douglas specification) or non-unitary elasticity of substitution (in the CES case). Its relies on the estimation of parameters: α, β, γ and ρ_i. On the other hand, the second definition supposes no substitution between the two domestic production factors but it may give a more robust measure of the full prices since it depends only on the estimation of the households' opportunity cost for time ω. However, there exists a simple relation between these two definitions of the full prices in the Cobb-Douglas case. Using equation (24) we obtain:

$$p_i^{f1} = \frac{1}{b_i} \left(\frac{m_i}{\omega t_i} \right)^{\beta_i} \left\{ 1 + \frac{\omega t_i}{p_i} \right\}. \tag{28}$$

So that the logarith of p_i^{f1} and p_i^{f3} differ only by $\beta_i log\left(\frac{m_i}{t_i}\right)$ on a cross-section:

$$log\left(p_i^{f1}\right) = constant + \beta_i log\left(\frac{m_i}{t_i}\right) + log\left(p_i^{f3}\right) \tag{29}$$

Two hypotheses were necessary to derive full prices from monetary and time expenditures: first, the domestic production functions are supposed to be Leontief functions with constant production coefficients (for prices under complementarity), Cobb-Douglas functions or CES functions (for prices under substitution); second no joint production exists, which may be more easily verified for broad categories of activities such as housing and food.[28]

[28] A joint production of two different activities (made by the same individual in the same time, for instance smoking and drinking or preparing meals while speaking with the children) would create a correlation between these activities. Grouping the two activities into a broader one (food, alcohol and tobacco) suppresses the problem.

Changes of full prices for France

The full prices calculated for the CES substitution case differ between households with coefficients of variation from 0.08, 0.10 and 0.18 for Housing and Leisure to 0.28, 0.28 and 0.30 for Food, Transport and Clothing.[29] These full prices are not much correlated between them, except for Housing and Transport, Clothing and Leisure, Leisure and Other commodities and Housing and Clothing (all other correlations R^2 are smaller than 0.09). Total expenditure, family composition and age explain in average 20% of their variation, with small income elasticities. The full price for food is characterized by a U shape as concerns income (minimum for the 43^{th} centile), while full prices increase over the whole income distribution for Housing and Transportation and decrease for Clothing, Leisure and Other Activities. The presence of children decreases the full prices in all cases.[30] The age of the head first increases all prices (till mid-age for Housing, Transport and Leisure, till 60 for Other commodities), then decreases them.

Appendix B: Datasets

The definition of comparable good and time groups of expenditure is a difficult and sometimes arbitrary operation. This rather difficult exercise needs some arbitrary assumptions about the substitution between time use and monetary expenditures (see Gronau and Hammermesh 2006 for a discussion). The commodity consumption structure does not correspond exactly to what is very often used as a standard classification even if differences can be limited. The reason is that not all time use activities can have a clear work equivalent. This is particularly the case of the leisure time. However, comparing our classification with other similar approaches (Gronau and Hamermesh, 2006) we obtain similar patterns of what these authors call "relative goods/time intensity" defined as a ratio of good to time inputs relative to total amount of goods and time allocated to commodity production. For France, like for Israel and United States in Gronau-Hamermesh paper, the goods/time intensity is relatively high for Dwelling, Health, Clothing and to the less extent for Transport. However, the Eating item differs considerably between France and these countries, being weakly good intensive in France (0.57) and highly good intensive in the US and Israel (1.62, 1.82 respectively).

The matching procedure of a Family Expenditures survey with a Time-Use survey is either made by a regression of the time-uses observed in the matched survey using common covariates observed in the two surveys (such as education level and the age of the head, the family demographic structure or location), or using the Rubin's Multiple Imputation method (1986) which takes into account the correlations (conditional to covariates) for each variable which is matched between the two surveys (see Alpman, 2017, and Alpman and Gardes, 2015).[31] A matching of the Consumer Expenditure and the American

[29] This order does not seem to be related to the order between the opportunity costs of time.

[30] The effect of the family size is inverse to the income elasticity, which shows that full prices depend on income per Unit of Consumption.

[31] Rubin's procedure does not assume implicitly that the variables to be matched are conditionally independent, which is implicitly supposed by other statistical matching methods. This assumption leads to highly biased results when it is not verified by the dataset (see Rubin, 1986 and the Stata program in Alpman, 2017).

Time use surveys using both methods shows that simple matching by regression gives often similar estimates. On the other hand, Alpman (2017) compares regression based imputation with Rubin's multiple imputation for simulated data and shows that the later furnishes imputed data which are closer to the original dataset. In Alpman and Gardes (2017), we use a survey containing both monetary expenditures and time uses for three final goods (Food, Domestic Activities and Other) and check that Rubin's procedure gives imputed values of time uses close to the true values.

Burkina Faso

Burkina Faso is located in West Africa. The country accounts for 16.9 millions of citizens having an average life expectancy of 56 years. The population is very young (46% of young less than 15 years). The country is ranked 181th over 187 countries based on its human development (United Nations Development Program, 2014). The per capita GDP is 720 US dollars, mainly concentrated in the service sector (52%), industry and agriculture representing only 26% and 22%. Its average annual economic growth has been 5% since 2000, the unemployment rate is 3%, but 83% of the population is below the poverty line according to the UNDP multidimensional index and 40.1% according to the National Institute for Statistics and Demography (INSD, 2015), with 92% of the poor in rural areas. The data used for this study are taken from the 2008 round of the farm household survey conducted by the Ministry of Agriculture of Burkina Faso. The survey covers 71 villages in the 45 provinces, with a total of 6941 households surveyed. It contains information on family characteristics (incomes from agriculture or other activities, age of the head and the spouses, number and age of children, education level, accessibility to social services, income, financial situation, equipment...), households' expenditures (over 40 goods and services) and time use over 14 activities: unproductive activity, rain fed agriculture, vegetable farming, arboriculture, livestock farming, fishing, gathering, wood harvesting for selling on a market, wood harvesting for household needs, search for water, market work, other domestic activities, personal activities, other activities. Times are recorded for all adults in the family, while expenditures concern the whole family, including children (the numbers of adults and children are on average 5.36 and 5.72 respectively). The hypothesis is thus made that only adults contribute to the domestic productions. Time uses for activities such as gardening or cattle breeding are both for domestic use and for selling products or services on the market. We have no information on this repartition so that we made the assumption that 70% of time uses corresponds to consumption by the household and 30% to a production which is sold on the market. In this paper, the monetary expenditures and the time use have been grouped into three common domestic activities: (i) food (ii) domestic activities and (iii) leisure and other activities. Expenditures are recorded for one week for food and one quarter for other expenditures, while time uses correspond to one week. All have been transformed into yearly values. As family size can be very large, time uses corresponding to all adults in the household may be performed in fact by a small part of these households (say two or three). The descriptive analysis in Gardes and Thiombinao (2017, Table 1) indicates indeed that couples with two adults have a significantly greater ratio of monetary expenditures to time uses than singles, which indicate that their time are not the fact of all adults

in the family. In order to correct for this probable bias, time uses have been multiplied by the ratio of the OECD equivalence scale (one for the first adult, 0.7 for other adults) over the number of adults (which perhaps still overstates the true number of adults corresponding to recorded time uses).

Canada

The Survey of Household Spending for 1998 is matched with the survey of time use budgets contained in the General Social survey for the same year. The family size and the number of children are not informed sufficiently so that the matched sampling contains only couples with zero or one child less of 14. The categorization of time use in the SHS is very similar to the categorization of spending in the SHS simplifying our task considerably. The matching is made using the Rubin's method.

France

The French dataset from INSEE combines at the individual level the monetary and time expenditures into a common, unique goods and services consumption structure by a statistical match of the information contained in two surveys: the Family Expenditure Survey (FES, INSEE BDF 2001) and the Family Time Budget (FTB, INSEE BDT 1999). I define 8 types of activities or time use types compatible with the available data both from FES and BDT: Eating and cooking time (FTB) and food consumption (FES), cleaning and home maintenance and dwelling expenditures (including imputed rent), clothing maintenance and clothing expenditures, education time and education expenditures, health care time and health expenditures, leisure time and leisure expenditures, transport time and transport expenditures, miscellaneous time use and miscellaneous goods and services. Time uses for all selected activities are regressed on the households' characteristics for all observation units in FTB survey and these estimations serve to predict the time spent on these activities for the corresponding units in the FES survey.

Poland

The Polish panel of family expenditures contains 3052 households over four years (1987-90). This panel is matched with one Time use survey conducted in 2003-2004 over approximately 10000 households (20000 individuals). The matching procedure is made by regression over a common set of socio-economic characteristics of households which are present in both surveys. The estimated coefficients are used to predict these times for each household in the Family Expenditure survey. We define 6 types of activities or time use types compatible with the available data both from FES and BDT: food, housing, clothing, transport, leisure and various expenditures (including health services).

USA

The Consumer Expenditure (CE) survey is performed each quarter over 5000 to 7000 households. Usual expenditures are recorded on a weekly basis, some less frequent for one month. It is matched to the American Time Use survey (ATUS) which gives detailed information on time budgets for one year (see a presentation

og these data in Aguiar et al., 2013). Both surveys are delivered each year since 2003. A continuous matching has been made for the period between 2003 and 2011 (see Alpman and Gardes, 2015) using the Rubin's method.

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