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**On the value of time and human life**

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# On the value of time and human life

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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*.<sup>2</sup>

## Abstract

The opportunity cost of time is estimated using a model based on domestic production (depending on monetary and time expenditures) and direct utility (depending on produced commodities). These factors of domestic production are measured by the matching of a Family Budget survey with a Time Use survey. The new model is estimated on Canadian, French, Polish, US and Burkina-Faso statistics. It allows the economic value of human life to be estimated, based on the integration of the marginal value of each instant during an 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 of substituting money and time in domestic production. It also increases between countries relatively to the average wage rate, according to the degree of liberalization of the labor markets.

**Keywords:** opportunity cost of time, value of human life, elasticity of substitution

**JEL Classification:** D13, D91, J317

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<sup>2</sup>"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*.

# 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 impact on welfare.

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.<sup>3</sup> 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 yet been 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 transport 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 calculated

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<sup>3</sup>This supposes that time is perfectly exchangeable between the market and non-market activities of the household, 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 corresponding to market substitutes for domestic activities.

at \$1.67 per hour (see Alpman and Gardes 2015). While the opportunity cost derived from Aguiar and Hurst (2007) is significantly smaller than estimates here for the United States (around \$12 per hour for 2015, see Table 1 and Alpman and Gardes 2015)<sup>4</sup> 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 decisions, 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 wage. Classic evaluation methods give rise to a large span of values: Dionne and Leveau (2010, p. 487) discuss evaluations going from 500000 to 50 million of 2000 US dollars, Miller (2000, Tables 1 and 2) from 600000 to 8.3 million of 1995 US dollars, with averages at 5.5 million for the first, 3.45 millions of dollars for the second. Sunstein (2014, pp. 94, 104-105) proposes a distribution of values for various methods between 3.8 and 9 million of US dollars. The corresponding values in 1990 for the three developed countries examined here (Canada, France, USA) are 2,9 to 4,4 million for Canada, 3.4 for France (Miller, Table 1, p. 176), 3 to 7 for the U.S. (Viscusi, 1993, Table 2): all figures here are US dollars. 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 diseases or accidents-injuries) in order to define a homogenous compensation for these risks. The method based on State preferences is dedicated to a harmonization of public policies, concerning their effects on the population deaths and injury rates. It is revealed by its decisions concerning for instance security on roads or investments in health. The method based on the evaluation of the value of an agent's future revenues calculates the loss for the economy of the agent's death. Methods based on individual direct answers about their willingness to pay in order to avoid some risk provide an indication of 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 transport.

Various criticisms have been leveled at 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 risks exist only for some specific sectors. The method based on public investments revealing the State preferences gives rise to very different evaluations, according to the type of policy (values are 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 willingness to pay depends on the questionnaire and

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<sup>4</sup>Note however that Section 3.2 shows that the opportunity cost of time should differ between household's activities, which may explain these differences.

the individual characteristics (altruism for instance).

All methods are based on an inter-temporal 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 relating to the environment and security. The higher rate corresponds to interest rate of private investments, while the former is closer to the households' social rate of time preference, when it is governed by the interest on public debt. In practical terms, the White House Office of Information and Regulatory Affairs (OIRA) suggests using these two alternatives. The interest rate serves in this article as an actualizing factor of future incomes, so that it corresponds to the ordinary rate of interest defined by von Mises. I will discuss later a possible endogenization of the interest rate based on households' permanent income.

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 her 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 substitutability 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 relationship between the value of time and the degree of substitutability on the labor market or in domestic production.

Section 1 describes a Beckerian model of the allocation of time with an endogenous value of time. Section 2 provides a new method for the estimation of the economic value of a human life, and Section 3 presents the resulting estimations for five developed and developing 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 ( $\omega$ ) 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  $\omega$  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, 2019).

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<sup>5</sup>. 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. Other papers (for instance 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 theater tickets in Germany using a reduced form demand equation. The specification is double logarithmic and two different equations relate the theater 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 valued 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

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<sup>5</sup>A unique utility function is assumed for households, thus neglecting collective decisions and the allocation of goods and time within the family.

component of the full income, which explain these not plausible estimates. This 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  $u(z_1, z_2, z_3, \dots, z_I)$ . In order to simplify the analysis, a separate activity  $i$  produces the final good  $i$  in quantity  $z_i$  using a unique market good<sup>6</sup> 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:

$$\text{Max } u(z_1, z_2, z_3, \dots, z_I)$$

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

$$\sum_i p_i x_i = y \text{ and } \sum t_i + t_w = T \quad (1)$$

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  $\gamma_i$ ,  $\alpha_i$  and  $\beta_i$ . The optimization program is<sup>7</sup>:

$$\text{Max}_{m_i, t_i} u(Z) = \Pi_i a_i z_i^{\gamma_i} \text{ with } z_i = b_i m_i^{\alpha_i} t_i^{\beta_i} \quad (2)$$

The household's Beckerian full income being defined as the maximum monetary income which could be earned when working during all disposable time  $T$ <sup>8</sup>, valued at the market wage rate net of taxes  $w$ , writes:

<sup>6</sup>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.

<sup>7</sup>All variables correspond to a household  $h$  which index is omitted in the equations.

<sup>8</sup>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.



$$y^f = wT + y_0 = wt_w + y_0 + w\Sigma_i t_i$$

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

$$\Sigma_i (m_i + \omega t_i) = y^f + (\omega - w) \Sigma_i t_i. \quad (3)$$

In this formula, the Beckerian full income is thus corrected by the difference between the market ( $w$ ) and the personal valuation ( $\omega$ ) 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<sup>9</sup>.

Note that  $T - t_w = \Sigma_i t_i = T_d$  is the total disposable income after market labor time and that both the market wage and the shadow wage (i.e. the opportunity cost of time  $\omega$ ) 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 monetary 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 can be considered in fact as the residual after domestic times have been subtracted from total disposable time). This 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 (depending on the difference between the market wage and the opportunity cost of time) 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).

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<sup>9</sup>It allows also defining full prices and estimating full income and full price effects on a cross-section (see Gardes, 2019).

## Resolution of the model

In order to estimate the opportunity cost for time, the utility function is re-written:

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

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 time  $T_d$  gives the opportunity cost of time:

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

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<sup>10</sup>. 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  $(\alpha, \beta, \gamma)$  and on its monetary and time expenditures  $m_i$  and  $t_i$ <sup>11</sup>.

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)<sup>12</sup>. 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

<sup>10</sup>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.

<sup>11</sup>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).

<sup>12</sup>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.

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:

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

under the constraint of a constant economy of scale for each production function:  $\alpha_i + \beta_i = 1$ .<sup>13</sup> It is also assumed that all marginal productivities are positive:  $\alpha_i, \beta_i, \gamma_i > 0$  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:

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

so that:

$$\gamma_i = \gamma_1 \frac{m_i}{m_1} \cdot \frac{\alpha_1}{\alpha_i} \quad (8)$$

for all  $i > 1$ .

All other substitutions between monetary and time resources devoted to different activities can be derived from (8) and (9).

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 (7) thus give an estimate of  $\alpha_i$  and  $\beta_i$  for each household, which gives  $\gamma_i$  by equation (8). In the second step, an estimate of the opportunity cost of time  $\omega$  is given by equation (6) which allows the computation of the individual values of the parameters  $\alpha, \beta, \gamma$  for each household using equations (7) and (9). These values enter equation (6) to give for each household the second step estimate of  $\omega$ . The estimations on the French data as well as simulations<sup>14</sup> 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 (7) and (9) which imply for all activities  $i, j$ :

$$m_i \gamma_j = m_j \gamma_i + \omega \gamma_i t_j + \omega \gamma_j t_i \quad (9)$$

This could be estimated as a system of  $\frac{n(n-1)}{2}$  independent equations, calibrating  $\gamma_j$  at the average full budget share for one good<sup>15</sup> 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

<sup>13</sup>This restriction is necessary for the identification of the model, which could also be obtained fixing the sum of each couple  $(\alpha_i, \beta_i)$  to some pre-determined value.

<sup>14</sup>Performed by J. Boelaert and P. Merrigan.

<sup>15</sup>Note that taking together equations 7, 8 and 9 to calculate the value of  $\omega$  gives rise, as noticed by Philip Merrigan, to a highly non-linear equation in  $\gamma_i$  and  $\omega$  which cannot be solved algebraically.

as all  $\gamma_j, j > 1$ .<sup>16</sup> We can also sum equations (9) over  $j$  with  $\sum \gamma_j = 1$  to obtain (n-1) independent equations:

$$m_i = \gamma_i(m + \omega T) - \omega t_i, i = 1, \dots, n \quad (10)$$

This system of equations can be estimated for the whole population, which gives a unique estimate of  $\omega$  for all households.<sup>17</sup> The estimation without constraints (no additivity constraint on coefficients  $\gamma_i$ ) shows that the absence of economies of scale in the utility ( $\sum \gamma_i = 1$ ) 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  $\omega$  and the parameters  $\gamma_j$  of the utility function are then used through equations (9) and (10) to calculate  $\alpha, \beta$  and  $\gamma$  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 (6). 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 (10). The test of these differentiated  $\omega$  is left for a future research.

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

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

equals the common opportunity cost  $\omega$  by equation (7). 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  $i$  is:  $z_i = [a_i m_i^{\rho_i} + (1 - a_i) t_i^{\rho_i}]^{\frac{1}{\rho_i}} = a_i^{\frac{1}{\rho_i}} \left[ m_i^{\rho_i} + \frac{1-a_i}{a_i} t_i^{\rho_i} \right]^{\frac{1}{\rho_i}}$  which is embedded in a CES direct utility function:  $U = [\sum_i A_i z_i^{\zeta_i}]^{\frac{1}{\sum \zeta_j}}$ . The partial derivative of  $U$  over  $m_i$  is:

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

<sup>16</sup>Note that an estimation of this system of equation without constraint on the set of coefficients  $\gamma_i$  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  $\omega$  and the  $\gamma$ 's, gives different estimates of the  $\omega$ , which shows that these constraints must be imposed in the estimation.

<sup>17</sup>The opportunity cost of time  $\omega$  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).

which gives with a similar derivative over time:

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

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

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

gives the same expression of the opportunity cost. The coefficients  $\rho_i$  of the production functions are linked to the elasticity of substitution  $\sigma_i$  by the relationship:  $\rho_i = 1 - \frac{1}{\sigma_i}$ . These elasticities of substitution have been estimated in Canelas et al. (2018).

In order to calibrate  $a_i$ , I compute the ratio of time over monetary expenditures using the marginal productivities of time and money in the CES function as proxies for the cost of time and monetary price (valuing time by the household's wage rate  $w_i$ ):

$$\frac{w_i t_i}{m_i} = \frac{w_i t_i}{p_i x_i} = \frac{\partial z_i}{\partial t_i} \frac{t_i}{x_i} = \frac{1 - a_i}{a_i} \left( \frac{t_i}{m_i} \right)^{\rho_i} \quad (12)$$

The ratio of  $a$ 's thus writes:

$$\frac{1 - a_i}{a_i} = \frac{w_i t_i}{m_i} \left( \frac{m_i}{t_i} \right)^{\rho_i} \quad (13)$$

which corresponds to equation (11) if the wage rate is equalized with the opportunity cost of time.  $a_i$  can be calibrated by equation (13) for the average domestic time, monetary expenditures and market wage (or a fraction of it) in the population.  $a_i$  can also be calibrated at several values between 0 and 1, for instance 0.5, one third and two third, and the results compared.

Finally, the relationship between the set of opportunity costs of time for each commodity  $\omega_i$  and a general cost  $\omega$  can be recovered considering the full budget constraint:

$$y^f = \Sigma (m_i + \omega_i t_i) = w t_w + y_0 + \omega (T_d - t_w)$$

, which implies:  $\omega = \frac{1}{\Sigma t_i} \Sigma t_i \omega_i$ . The overall 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  $\omega_i$  using the CES specification with  $a_i = 0.5$  and the resulting average overall  $\bar{\omega}$  which can be compared to the  $\omega$  estimated by equations (9). The  $\omega_i$  are then corrected by the ratio of these average  $\omega$  (corresponding to the coefficient  $\frac{a_i}{1 - a_i}$  in the formula giving  $\omega_i$ ), 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 :

$$z_i = [a_i m_i^{\rho_i} + (1 - a_i) (\omega_i t_i)^{\rho_i}]^{\frac{1}{\rho_i}} \quad (14)$$

gives :

$$\omega_i = \frac{m_i}{t_i} \quad (15)$$

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

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

Suppose an economic agent evaluates her marginal value for disposable time at  $\omega_t$  in period  $t$ . This marginal value can be integrated over the agent's whole life (or remaining life) to obtain a monetary value of her total living time. This marginal value is applied to all types of activities, an assumption which is also made in all other methods, for instance those based on the willingness to pay for an extra hour or hedonic wages.

The economic value of a length of time  $\tau_0$  lived by some individual is the product of  $\omega$  with this duration, actualized at the interest rate  $\rho_0$  over the life cycle from  $t=1$  to  $\tau_0$ :

$$V = \int_0^{\tau_0} \omega_t T_0 e^{-\rho t} dt \quad (16)$$

with  $T_0$  the number of disposable hours during one year. The assumption of that  $\omega$  is constant along the life cycle gives the following value:

$$V_1 = \left( \frac{1}{r} - \frac{e^{-rT}}{r} \right) \omega T_0 \quad (17)$$

Disposable hours are defined as those which could be substituted for another activity, either domestically or on the labor market. It may correspond to 24 hours a day (including sleep in this substitution) or disposable time after necessary activities (16 hours for instance)<sup>18</sup>.

The empirical analysis of the datasets used here indicates that the opportunity cost of time  $\omega$  depends on the individual's age, with a quadratic specification corresponding to a maximum at 40 to 45 years of age  $A_t$  (see Table 3):  $\omega_t = \alpha + \beta_1 A_t + \beta_2 A_t^2$ . The integration of equation (14) with this dependency on age gives a second formula for the value of a human life :

$$V_2 = \left\{ \alpha \left[ \frac{1}{\rho} - \frac{e^{-\rho t}}{\rho} \right] + \beta_1 \left[ -\frac{e^{-\rho t}}{\rho} \left( \tau_0 + \frac{1}{\rho} \right) + \frac{1}{\rho^2} \right] + \beta_2 \left[ -\frac{1}{\rho} e^{-\rho t} \left( \tau_0^2 + 2\frac{\tau_0}{\rho} + \frac{2}{\rho^2} \right) + \frac{2}{\rho^3} \right] \right\} \tau_0 \quad (18)$$

The average life duration  $\tau_0$  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 interest rate  $\rho$ , the function indicating the opportunity cost of time in terms of age, and life duration. Another evaluation could be based on the sum of market wages, other monetary incomes and the value of domestic time measured by  $\omega$ . In equations (18) and (19), I suppose a common evaluation of time uses spent during the life cycle, either in the market or at home, which corresponds to the assumption of a perfect substitution between market work and domestic work (the difference between the wage rate and  $\omega$

<sup>18</sup>The estimation of these necessities is left to future research. The integration of sleeping time is debated in the literature on time use budgets. It could be set at the value corresponding to the first decile of time used for each activity, or estimated, for instance, 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 dedicated to sleeping.

being caused by the desutility of market labor.

When evaluated at the age of an individual during her life cycle, the value of future remaining years to live till  $\tau_0$  is much smaller than the value evaluated for the whole life from time birth to death. In that case, the value of human life would diminish along the life cycle towards zero at time  $\tau_0$ . But an individual aged  $0 < \tau < \tau_0$  could consider that the value of her life at that age depends, not only on her future life, but also on the years lived before since her birth. Indeed, these past years are integrated into her consciousness, as put exquisitely by Proust, and increase the value of future years. Past years (from time 0 to  $\tau$ ) could then be backward actualized at the same rate as future years or at a different (perhaps larger  $\rho_1 > \rho$ ) rate to be compared to the value of life over the whole life cycle calculated at time 0 <sup>19</sup>.

### Endogeneization of the ISTR: Relating time preference $\rho$ to the value of time $\omega$

The increase of the opportunity cost of time  $\omega$  at the beginning of the life cycle and its stabilization or small decrease thereafter could be used to justify the positivity of the ISTR, at least for early ages. Another method relies on the assumption that the household's time preference determines its saving rate, while the value of time is correlated with its expenditures, so that it could be possible to establish a relationship between them equalizing the values of its household's savings depending on these two variables. The calculus, presented in Gardes (2020, Appendix A) implies a positive relationship between the intertemporal rate and the value of time. This model relies on the assumption that the decision to save part of income is taken in relation with an interest rate independently from a decision to consume income based on income changes, which is a heroic hypothesis whence it applies to the same agent (while it is perhaps more naturally applied to aggregates in the simple keynesian model).

I propose considering instead that the ISTR and the opportunity cost of time both influence the present value of the household's permanent full income (equal to the discounted sum of all future full incomes corresponding to the full budget constraint in equation 4). Following the assumption made in the permanent income theory, this present value remains constant over the household's life cycle, so that it is possible to calculate the change of the opportunity cost of time which gives rise to a reverse change due to a change in the intertemporal rate of substitution. The present value of the permanent income stream can be written for an income flow  $y_t$  and an ISTR  $\rho$ :

$$v(y^f) = \int [y_t^f \exp(-\rho t)] dt \quad (19)$$

The derivative over  $\omega$  of this integral equals, under usual conditions, the integral of the derivative, which is, with  $\rho$  depending on  $\omega$ :

<sup>19</sup>Note that this measure of the value of life in  $\tau$  corresponds to the actualized (by  $\exp -\rho\tau$ ) sum of the evaluation over the period  $[0, \tau]$  with an interest rate  $-\rho_1$  and of the second evaluation over the second period  $\tau, \tau_0$  with an interest rate  $\rho$ . It differs from the value in  $t=0$  whenever the permanent income is not constant over the whole life cycle.

$$\frac{\partial y^f}{\partial \omega} = w \frac{\partial t_W}{\partial \omega} + (T - t_W) - \omega \frac{\partial t_W}{\partial \omega} \exp(-\rho t) + y^f \frac{\partial \exp(-\rho t)}{\partial \rho} \frac{\partial \rho}{\partial \omega} \quad (20)$$

The integration over time of this derivative is, with  $\Phi$  and  $\Gamma$  the two components of the right side of equation (20):

$$\int \left\{ \frac{\partial y^f}{\partial \omega} \right\} dt = \frac{\Phi}{\rho} + \frac{\Gamma}{\rho^2} \frac{\partial \rho}{\partial \omega} \quad (21)$$

for an integration from 0 to infinity<sup>20</sup>. Under the assumption that households' permanent income does not change for corresponding changes of the intertemporal rate and the opportunity cost ( $d\rho, d\omega$ ), the derivative of these parameters is, for the stream of a constant income  $y_t = y$ :

$$\frac{\partial \rho}{\partial \omega} = \rho \frac{\left(\frac{W}{\omega} - 1\right) \frac{\partial t_W}{\partial \omega} + (T_d - t_W)}{W t_W + y_0 + \omega (T_d - t_W)} \quad (22)$$

which implies for elasticities:

$$El_{\frac{\rho}{\omega}} = \frac{(W - \omega) t_W El_{\frac{t_W}{\omega}} + \omega \sum t_i}{W t_W + y_0 + \omega \sum t_i} \quad (23)$$

Therefore, the ISTR increases with the opportunity cost of time with an elasticity smaller than 1 whence  $y_0 \geq 0$ ,  $El_{\frac{t_W}{\omega}} \leq 1$  and  $W \geq \omega$ . It is for instance equal to 0.81 for the estimates of these parameters on the french dataset. This elasticity may vary between households, which implies different intertemporal rates across the population (that change is discussed in Gardes, 2020a). If for instance 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 equal to  $\omega$  is given by:  $\log(\rho) = -4.77 + 0.81 * \log(\omega)$ . The values of human life  $V_1$  and  $V_2$  for that household can be computed using this individual ISTR depending on  $\omega$ , then averaged over the population.

### 3 Empirical analysis

The estimation operates for five countries: Burkina-Faso, Canada, France, Poland and the 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 time survey using common covariates observed in the two surveys (such as education level and the age of the household head, the family demographic structure or location); or (for the Burkina-Faso, Canada and US datasets) by the Rubin matching model described in Appendix. Datasets are presented in Appendix B.

<sup>20</sup>Households being supposed to leave their permanent wealth to their inheritants. Considering the life cycle from birth to the maximum age  $\tau_0$  multiplies the derivative of  $\rho$  over  $\omega$  by the fraction  $\frac{e^{-\rho\tau_0}-1}{\rho e^{-\rho\tau_0}} \left(\tau_0 + \frac{1}{\rho}\right) - 1$  which is for instance 0.925 for  $\tau_0 = 80$  years (corresponding to the life cycle in developed countries) and  $\rho = 5\%$  and 0.418 for  $\tau_0 = 20$  (corresponding to an evaluation at the end of the household's life cycle  $\tau_0 - 20$ ).



### 3.1 Estimates of the opportunity cost of time

A unique  $\omega\hat{\omega}$  for all commodities is first estimated by the system of equations (10) and (6), under the Cobb-Douglas specification (Table 1). These estimates are approximately equal to one half of the average wage rate, as is also indicated by surveys on willingness to pay for an extra hour. They are therefore much greater than the value indicated by the Aguiar and Hurst experiment on the value of time for shopping in large supermarkets.<sup>21</sup> The Cobb-Douglas model thus seems to provide 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, which is exactly the change observed by Aguiar and Hurst<sup>22</sup>.

In order to estimate the opportunity costs  $\omega_i$  by activity, formula (12) is used with a factor  $a$  supposed to be the same for all commodities and derived from the CES specification of domestic production functions:

$$\frac{1-a}{a} = \frac{\omega \cdot t}{m} \left(\frac{m}{t}\right)^\rho \quad (24)$$

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 are conformed to the previous estimate of  $\hat{\omega}$  using the Cobb-Douglas model: the first estimates by equation (12) of the individual  $\omega'$  are indeed similar on average to the estimate of  $\hat{\omega}$ , while the second by (15) averages two thirds. the two formulas give close estimates for each activity, except for Transport and Clothing. The individual opportunity costs of time vary a lot from 2 to 12 between the different commodities, with a small Opportunity cost 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 discussed 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 weekends and in the evening because many firms are closed then, which explains why a famous airline company/ocean liner intentionally includes a weekend 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." Becker discussed this later (Becker, 1981), considering that the degree of effort which is used up by an individual in a given activity may increase the value of the time used for that activity. Under this hypothesis and supposing

<sup>21</sup>The estimation of the opportunity cost for various activities in Table 2 suggests that this low value may be specific to this purchasing activity.

<sup>22</sup>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	$\omega$	$\frac{\omega}{\text{wage}}$	$\frac{\omega}{\text{min wage}}$	Centile 1 $\omega$	Centile 99 $\omega$
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, Cobb-Douglas specification

that "married women spend less energy on each hour of market work than married man", he explains the difference between the men's and women's wage rates and the specializations of women in domestic productions. I propose later another explanation of the variability of the value of time between activities based on the relative possibility of substituting 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 grouped by income, family size and education. The average value of time increases between the first income quintile and the last one by 192%, with an income elasticity equal to 0.56. This increase is particularly large for Housing, Clothing, Leisure and Other activities. They also increase with the education level, specially for Housing, Clothing and Leisure (and remain constant for transport and other activities). Finally, the presence of children seems to have an opposite effect on the opportunity cost, compared to the number of adults: indeed, it increases the opportunity cost for all activities, which can be related to the constraints on the time budget linked to the presence of children. On the contrary, couples without children have a smaller cost of time which corresponds to economies of scale in time, especially for activities such as Food or Housing. All activities characterized by a larger  $\omega$  due to children (i.e. Food, Housing, transportation, clothing and leisure) have smaller opportunity cost of time for couples compared to singles, while the reverse correlation exists for Other activities characterized by a decreasing  $\omega$  with the number of children. This means that the increase of family size by means of the number of adults has an inverse impact on the value of time compared to the increased size by children. The presence of children thus seems to change a lot the domestic production technology.

Final good	Food	Housing	Transport	Clothing	Leisure	Other	All
Elasticity of substitution	-0.430	-0.488	-0.360	-759	-1.050	-0.491	-0.645
$\omega A$	2.48	9.90	4.05	6.47	0.75	2.41	5.08
$\omega B$	3.20	10.00	5.32	7.41	1.62	3.69	5.77
$\omega A$ Education 1	2.10	6.90	3.43	3.81	0.43	2.15	3.78
$\omega A$ Education 2	2.81	10.61	4.58	6.90	1.06	2.40	5.39
$\omega A$ Education 3	3.13	17.65	4.76	12.48	1.32	2.79	8.24
$\omega A$ Income quintile 1	1.61	5.21	2.43	2.42	0.24	1.03	2.79
$\omega A$ Income quintile 2	2.24	7.42	3.27	4.38	0.47	1.88	3.91
$\omega A$ Income quintile 3	2.73	10.71	4.27	7.11	0.81	2.64	5.45
$\omega A$ Income quintile 4	3.65	19.24	6.34	14.55	1.75	5.07	9.60
$\omega A$ Income quintile 5	3.43	16.34	6.05	12.04	1.43	4.15	8.16
$\omega A$ Singles	2.12	14.27	2.11	4.64	0.52	1.83	7.04
$\omega A$ Couple without children	1.88	6.67	3.39	3.50	0.43	2.63	3.65
$\omega A$ Couple with children	3.20	11.73	5.42	9.91	1.26	2.52	6.11

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

Note:  $\omega A$ =estimation by formula (12) for the CES specification. The elasticities have been calibrated so that their average is equal to the global opportunity cost estimated for all commodities by the system of equations (9).  $\omega B$ =ratio of monetary and time estimation (formula 15) corresponding to the Cobb-Douglas specification with  $\alpha = \beta = 0.5$  and to the CES specification with an elasticity of monetary expenditures on time equal to 1.

### 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 of Time  $\omega_i$  for the different activities gives an interesting result, since it shows up clearly a 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 of domestic productions (as in the cases of the activities of eating, 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. This means that its marginal utility is small in the case of 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 provides important information concerning the probable opportunity cost of time of this commodity, as result, which can be named the law of *correspondance between substitution and time value*. Looking for instance to Food (respectively all other activities), this activity is characterized by a small elasticity of substitution: -0.43 (respectively a large one: -0.71), a small  $\omega = 2.48$  (respectively large: 5.53) and negative (respectively positive) elasticities of both that  $\omega$  and the elasticity of substitution as concerns income and education.

Note however that in case of Leisure, the elasticity of substitution is large (-1.00) in the estimates for France, while the value of time devoted to these activities is around 2 euros. We suppose that a composition effect exists in the computation of the elasticity of substitution due to differences in the substitutability of money and time, in the different types of leisure activities. The estimation for other countries (Canada, Ecuador and Guatemala) gives elastic-

ities which are much smaller: between 0.4 and 0.7. By the fact, many leisure activities cannot be performed without a necessary amount of time which cannot be substituted for monetary expenditure or be carried out by another person (for instance, time to attend an artistic performance or time for sport). Time is in this case complementary to the level of consumption (looking at two movies doubles the necessary time). The opportunity cost given by equation (11) depends on the ratio of monetary expenditures over time use, which is small for this commodity, as much monetary expenditure and time use corresponding to leisure are classified as transport 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 substitutability for leisure thus needs a more precise classification of expenditures.

Becker explained the possible variation of the cost of time between commodities, either by the effort devoted to the activity (Becker, 198), or by the fact that some commodities, such as food, sleep or "play", are productive consumption, i.e. indirectly contribute to earnings, so that the value of time producing these commodities must be increased by their indirect contribution. These three commodities are most probably characterized by a reduced substitutability 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). This is in favor of our alternative explanation which is the difficulty of substituting factors in such domestic productions.

Another indicator of this relation between factors substitutability and the value of time is the inverse quadratic shape of this value relative to the head's age (see Table 2). Indeed, the allocation of time between domestic work and market labor is the easiest in the middle of the life cycle, when adults have finished their education and training and have acquired some professional experience which helps them 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.<sup>23</sup>

Interestingly, this empirical result on substitutability 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 substituted to market labor time, since a low ratio corresponds to a situation in which individuals may not be able to use their free time to work more on the labor market. For the period 2004-2011, this ratio declines from 0.74 and 0.69 in the US and Canada (in 2002), to 0.43 in Poland (1997-2000) and 0.31 in Burkina-Faso (2008), with an intermediate value in France (0.45 in 2000).<sup>24</sup> Conversely, the substitution between factors of production may be assumed to be the higher for more competitive economies (the US and Canada) and smaller for France, Poland and Burkina Faso. The ratio of the value of time in domestic activities and in the labor market thus seems to be positively correlated to the general degree of

<sup>23</sup>Also, both the value of time and elasticities of substitution generally increase with income. The increase of substitutability can be explained by the development of discretionary income (income less expenditures on necessities) which helps to substitute it with domestic production.

<sup>24</sup>Note that in Table 4, the ratio of the value of time over the GDP discounted over the life cycle is also positively correlated to the average  $\omega$  for these countries.

competition in these economies. It could therefore be used as an indicator of the degree of competition in the country. Its change in the US during the Great Recession (Alpman and Gardes, 2015) corresponds indeed to a decreasing trend of the ratio before 2008 and after 2010, and an increase during the recession (the opportunity cost of time  $\omega$  decreasing less rapidly than the wage rate) which could be caused by rising competitive forces in the economy during the recession.

### 3.3 Estimating an enlarged GDP

The households' monetary expenditures of market goods and services, either used for direct consumption or as factors of domestic production, are already counted in the GDP. Including the value of home production valued by the opportunity cost of time use in each domestic activity gives rise to a measure of an enlarged GDP (which could be increased by the value of goods and services produced in the informal sector). That enlarged GDP is therefore positively impacted by the value of time. As a consequence, the greater substitutability between market and domestic labor or in-home domestic production, increases the domestic component of the total national production and thus raises economic development. In France for instance, domestic work doing chores corresponds (considering only the time component <sup>25</sup>) to 60 per cent of the market production<sup>26</sup>. Supposing that France is characterized by the US ratio of the value of time and market wage (0.74 instead of 0.45), the value of domestic production would increase by one third and its global (enlarged) production would rise 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, which renders the domestic processes of production more efficient and increases the value of this component of the households' economic well-being.

### 3.4 Estimates of the value of a human life

In order to compare it between countries, the value of human life is calculated over the entire life cycle of the individual, from birth to her final year ( $\tau_0$ ). If one considers the statistical value for an individual aged 50 for instance, that total value would incorporate past life, the value of which is still considered as incorporated in the individual. The value of an individual for her remaining years to live is just the difference between the entire value and the value corre-

<sup>25</sup>In case of complementarity between the two factors of domestic productions, the amount of time devoted to some domestic activity also indicates the corresponding monetary expenditures, which allows to estimate the total value of domestic production.

<sup>26</sup>Including only *substituable chores* defined as those domestic productions which could be replaced by a market good or service. That means that the elasticity of substitution between monetary expenditure and time in the domestic production of some commodity is large, say -1. Supposing that the domestic activity is divided between substituable chores with a unitary elasticity of substitution -1 and other activities with a zero elasticity, the elasticity of the aggregate is a weighted average of the elasticity of chores (-1) and the elasticity of other components (0), so that the absolute value of the elasticity of substitution of the aggregate is equal to the proportion of chores (see Gardes, 2020). For instance, substituable chores would represent in France 30% for food while they correspond to 15% for housing. The value of domestic production is therefore the sum of time uses multiplied by the corresponding opportunity cost of time and weighted by the absolute value of the corresponding elasticity of substitution.

sponding to a  $\tau_0$  equal to her present age.

The statistical economic values of human life in Table 4 are comparable (in Canada, France and the US), although somewhat smaller, than those in the literature, and quite homogenous across developed countries. The values of human life for Poland and Burkina Faso are much smaller, as expected. The estimate ( $V_1$ ) obtained under the constancy of the value of time across the life cycle are similar to those obtained with a rate depending on age ( $V_2, \rho = 0.03$ )<sup>27</sup> On the contrary, the value of human life depends heavily on the choice of the inter-temporal substitution rate, being smaller by one third for a rate at 5% compared to 3%. Taking into account the endogeneity of the ISTR (compared to the value  $V_1$  for 3% taken as the average ISTR of the population) does not change much the estimates, which shows that this dependency of the ISTR on the average value of time does not benefit to some particular type of household, but it diminish drastically its standard error: inferring the intertemporal rate from the opportunity cost of time allows to unify substantially the estimates of the value of life across the population.

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)

Note that the ratio (indicated in the last row of Table 4) of the value of a human life  $V_1$  (calculated for a ISTR  $\rho$  equal to 3%) to GDP per capita (cumulated over the life cycle) is equal to 1.80, 1.53 and 1.56 in the US, Canada and France, while it is only 0.97 in Poland and 0.85 in Burkina-Faso. Therefore, this ratio generally 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 as indicating the level of being) 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<sup>28</sup>.

<sup>27</sup>The quadratic effect of age is not significant for Burkina-Faso and Poland.

<sup>28</sup>It would be interesting (but difficult) to compare indices of the households' financial

Country	$V_1, \rho=0.03$	$V_1, \rho=0.05$	$V_1, \rho(\omega)$	$V_2, \rho=0.03$	GDP per capita	$V_1/GDP$
Burkina Faso	21 382	14 809	19 373	-	619	1.27
s.e.	24 756	17 146	5 174	-	-	-
Canada	2 350 792	1 517 692	2 089 144	1 955 219	50 304	1.53
s.e.	3 148 574	2 032 747	563 567	306 657	-	-
France	2 179 985	1 408 892	2 122 241	2 211 724	42 503	1.66
s.e.	708 124	457 650	295 022	290 173	-	-
Poland	342 719	223 212	377 460	6	11 705	0.97
s.e.	94 047	61 252	38 614	-	-	-
USA	2 866 871	1 865 760	3 091 324	3 711 738	53 042	1.80
s.e.	1 291 622	840 587	636 534	225 296	-	-

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

Note:  $V_1$  : *equation(17)usingtheinterestrate*;  $V_1, \rho(\omega)$ : *equation (17) with the interest rate depending on the opportunity cost of time (equation (22))*;  $V_2$  : *equation(18)*.

## 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 Intertemporal Substitution 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 using a unique ISTR  $\rho$  (not linked to  $\omega$ ) increases the value of human life by only 22%. The corresponding increases between the first income class (till the 10<sup>th</sup> centile) and the last (up to the 90<sup>th</sup> centile) are 349% and only 78%. This shows again that endogeneizing the ISTR diminishes the heterogeneity of the value of human life across the population.<sup>29</sup>

Sub-Population	Educ 1	Educ 2	Educ 3	Income Till 10 <sup>th</sup> centile	Income 20 <sup>th</sup> to 80 <sup>th</sup> centile	Income up to 90 <sup>th</sup> centile
ITSR (%)	2.78	2.24	2.45	2.42	2.94	3.69
s.e. (%)	0.71	0.78	0.79	0.56	0.73	0.70
$V_1$	1 999 651	2 237 842	2 448 854	1 684 127	2,142 899	2 837 761
s.e.	637 064	708 047	725 236	482 229	656 902	652 040

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 up the importance of having statistics cov-satisfaction such as those which are informed in some households' surveys, with these values of human life.

<sup>29</sup>The length of life  $T$  also depends on the sub-population, but considering that dependency would probably change the values by a limited amount.

ering both households' monetary expenditures and time uses. I suggest that questions about time use should be included in family expenditures surveys<sup>30</sup>. Models estimated on this type of data do indeed allow many applications to be carried out, 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 estimation of full income and full price-elasticities using cross-section individual data (Gardes, 2019); the study of a micro foundation of households' labor supply and the Okun's law (Gardes, 2018b; Gardes and Margolis, 2014); or tests of axioms on the revealed preference by means of full prices (Gardes, 2020b).

Inferring the intertemporal rate of substitution from the opportunity cost of time results in comparable but much less dispersed evaluations of the value of human life across the population. This is an interesting feature of that indicator for public choices.

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 used in informal markets and the value of domestic production.

## Appendix: Datasets

The definition of comparable good and time groups of expenditure is a difficult exercise which needs some arbitrary assumptions about the substitution between time use and monetary expenditures (see Gronau and Hamermesh 2006 for a discussion). Indeed, the commodity consumption structure does not correspond exactly to what is very often used as a standard classification of activities. 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 the 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 (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 using the Rubin's Multiple Imputation method (1986) for Burkina-Faso, Canada and the US, 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).<sup>31</sup>

<sup>30</sup>Is it necessary to highlight the interest of such surveys during the 2020 virus episode?

<sup>31</sup>Rubin's procedure does not assume 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



A matching of the Consumer Expenditure and the American 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 <sup>32</sup>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, culture of trees, 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. I have no information on this repartition so that I 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

and the Stata program in Alpman, 2017).

<sup>32</sup>Dataset prepared by Noel Thiombiano, University of Ouaga II, CEDRES

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 indicates that these times 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 <sup>33</sup>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<sup>34</sup>: 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 expenditures on education, 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 <sup>35</sup>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).

<sup>33</sup>Dataset prepared by Philip Merrigan, UQAM, Montréal

<sup>34</sup>Matching performed by Christophe Starzec

<sup>35</sup>Matching performed by Christophe Starzec

## 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 <sup>36</sup>to the American Time Use survey (ATUS) which gives detailed information on time budgets for one year (see a presentation of these data in Aguiar et al., 2013). Both surveys are delivered each year since 2003. A continuous matching using Rubin's method has been made for the period between 2003 and 2011 in order to analyze the change of domestic production during the great recession (see Alpman and Gardes, 2015, 2020).

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