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ARTICLE

The Health-Augmented Lifecycle Model

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Abstract
There is a need to value health technologies in a way that accommodates their broader economic impacts and competing approaches for doing so have emerged. The Pareto principle (PP) requires policymakers to resolve intrapersonal trade-offs by deferring to the preferences of the individuals facing those trade-offs. Many broad value frameworks such as cost-utility analysis and its extensions, health-centric multicriteria decision analysis, and poverty-free life expectancy are not sufficiently deferential to these preferences, violating PP. I propose using the health-augmented lifecycle model (HALM) to value health technologies in a way that flexibly incorporates the interactions among health and economic factors – specifically mortality and morbidity risks, paid and unpaid work, consumption, leisure, and public and private transfer inflows and outflows--over the life course. It relies on individual preferences, satisfying PP. It is compatible with cost-benefit analysis, social welfare functions, and equivalent income approaches. I calibrate the HALM for the US setting and apply it to a pediatric vaccine.

1. Introduction

1.1. Forks in the road in health technology valuation

A fundamental policy question in the economic evaluation of health technologies and policies is whether to evaluate them narrowly or broadly (or equivalently, whether to evaluate them from a health payer's or societal perspective) (Neumann *et al.*, 2016). Narrow evaluation focuses on health-centric impacts (i.e. on mortality, morbidity, and health resource utilization), while broad evaluation in principle incorporates all impacts on the economy (e.g. worker productivity, household financial security, macroeconomic impacts) and society (e.g. sociopolitical stability). Assuming broad valuation, there are further forks in the road regarding which type of analysis to perform: cost-effectiveness- or cost–utility analysis (CEA or CUA) or one of their variants such as extended or distributional CUA (see, e.g. Neumann *et al.*, 2016; Verguet *et al.*, 2016; Cookson, 2023), cost-benefit analysis (CBA, see, e.g. Robinson *et al.*, 2019), multicriteria decision-analysis (MCDA, see, e.g. Ilyas *et al.*, 2022), or analyses centered on social welfare functions (SWFs, see, e.g. Adler, 2019), equivalent incomes (EI, see, e.g. Fleurbaey *et al.*, 2013), wellbeing-adjusted life years (WELLBYs, see, e.g. Frijters, 2021), poverty-free life expectancy (PFLE, see, e.g. Riumallo-Herl *et al.*, 2018), and others.

The fundamental normative premise underlying this article is the principle of the sovereignty of an individual's idealized preferences in resolving trade-offs among various goods such as health and consumption within that individual's own life ("intrapersonal trade-offs"). Call this principle "preferencism." Idealized preferences are simply those an individual would have under ideal circumstances for making value judgments, such as having sufficient empirical information and time to deliberate, and being sufficiently free from cognitive and motivational impairments, such as biases in belief formation and addictions. Preferencism is subjectivist as opposed to objectivist with respect to value in that it holds that values ultimately flow from the subject (i.e. from the individual whose life is affected by policy) rather than from the object (e.g. from the intrinsic nature of the goods such as health or consumption conferred by policy). It agrees with Hamlet that there is nothing good or bad but thinking makes it so. And it rejects the hard paternalist notion that policymakers understand individuals' well-being better than those individuals themselves would under ideal circumstances.

Preferencist value frameworks satisfy the preference-based version of the Pareto principle (PP), which combines Pareto Indifference (if all individuals are indifferent between two policies, then a value framework should value these policies equally) and Strong Pareto (if all but one individual weakly prefers a first policy to a second, and the remaining individual strongly prefers the first to the second, then a value framework should value the first policy strictly more than the second) (Adler, 2019).

Preferencism traces a path through the abovementioned forks in the road. It supports broad valuation since individuals under ideal circumstances value not just the health-related impacts of health technologies and policies but their socio-economic impacts as well. It rejects types of analyses like CEA, CUA, and MCDA that shift at least partial and often significant weight away from individual preferences toward policymaker preferences (see, e.g. Brouwer *et al.*, 2008). It also rejects types of analyses like CUA that try to accommodate individual preferences but impose drastic simplifying assumptions on them (Bleichrodt & Quiggin, 1999; Hammitt, 2013), thus limiting their sensitivity to more general preferences not satisfying those assumptions.

Preferencism supports valuing policy impacts on an individual using that individual's willingness-to-pay (WTP) for those impacts since such WTP reflects that individual's preferences. Of the value frameworks enumerated earlier, CBA, SWFs, and EI all rely on using WTP to resolve intrapersonal trade-offs, thus satisfying preferencism. These frameworks differ with respect to how to resolve distributional issues, that is, how to trade off the well-being or preference satisfaction of different individuals ("interpersonal trade-offs"). These differences can be understood in terms of whether or how to weigh different individuals' WTP (see discussion in Fleurbaey *et al.*, 2013). CBA resolves interpersonal trade-offs by adding up unweighted WTP across individuals, which risks being disproportionately sensitive to the interests of the wealthy who have higher ability-to-pay (ATP) for policy benefits. SWFs and EI address interpersonal trade-offs by differentially weighing different individuals' WTP: utilitarian SWFs weigh individuals' WTP by their respective marginal utilities of income, prioritarian SWFs weigh them by the product of these individuals' marginal utilities of income and the marginal social value of these individuals' utilities, and EI weighs them by the product of the partial derivative of an individual's equivalent income with respect to their actual income and the marginal social value of these individuals' equivalent incomes (see Fleurbaey *et al.*, 2013 for details).

In the next section, I discuss a promising microeconomic and utility-theoretic approach to the broad valuation and quantification of WTP, the *health-augmented lifecycle model* (HALM). The *lifecycle model* is a model of lifetime utility maximization subject to constraint and is the workhorse model used by economists to explain or predict economic choices or behaviors over an individual's lifetime including those involving consumption, work, leisure, and savings. (Browning & Crossley, 2001). The HALM is a *health-augmented* version of the lifecycle model in that it incorporates lifetime mortality and morbidity prospects into the utility function and budget constraint, allowing the derivation of expressions for individual WTP for improvements in these prospects. The HALM is preferencist, satisfies the PP, and usable unweighted in CBA and weighted in SWF and EI analyses. I calibrate the HALM to the US setting and demonstrate its use in the valuation of a pediatric vaccine.

2. The health-augmented lifecycle model

2.1. Specification of lifetime utility and the budget constraint

The HALM is a model of lifetime utility maximization subject to a budget constraint, augmented to include health-related measures of mortality and morbidity prospects. Following the specification of Murphy and Topel (2006), the individual solves:

$$\max_{c(a),l(a)} U = \sum\nolimits_{a=0}^{99} \frac{s(a) \times q(a) \times u(c(a), l(a))}{(1+\rho)^a}, \tag{1}$$

subject to the budget constraint:

$$\sum\nolimits_{a=0}^{99} \frac{s(a) \times o(a) +}{(1+r)^a} = A + \sum\nolimits_{a=0}^{99} \frac{s(a) \times i(a)}{(1+r)^a}. \tag{2}$$

Lifetime utility U is the sum across all ages a of life of period utility $s(a) \times q(a) \times u(c(a), l(a))$ discounted at the rate of time preference ρ. I set the maximum lifespan at 100 years, so $a = 0, \ldots, 99$. Age-specific consumption $c(a)$ and non-market time $l(a)$ are the standard goods of microeconomic theory. Non-market time consists of unpaid work and leisure time. $u()$ is the standard utility function of microeconomic theory. I shall refer to it as the "economic utility function" and to $u(c(a), l(a))$ as "economic utility." The age-specific survival probability $s(a)$ is the probability, conditional on being born, that an individual reaches age a (known in the context of demographic life tables as the survival function). Health utility $q(a)$ is a scalar measure of health-related quality of life (HRQoL) taking on values from zero to one, representing death and perfect health respectively (known in CUA as the quality-adjusted life year (QALY) weight). $s(a)$ and $q(a)$ represent mortality and morbidity prospects respectively. Period utility has multiplicative form, implying that survival, health utility, and economic utility are natural complements: the higher the level of one, the larger the marginal impact of the others on period utility.

The budget constraint requires the expected present discounted value (EPDV) of lifetime resource outflows $o(a)$ to equal initial wealth A and the EPDV of lifetime resource inflows $i(a)$. To facilitate empirical quantification of these outflows and inflows over the lifecycle, I follow the National Transfer Accounts (NTA) project in disaggregating the components of such flows (see UNPDDESA, 2013, equation 2.1 and what follows). Outflows $o(a)$ equal the sum of consumption (excluding health and education) $c(a)$, consumption of health and education $c^{he}(a)$, and transfer outflows $\tau^o(a)$. Inflows $i(a)$ are the sum of labor income $y(a)$, transfer inflows $\tau^i(a)$, and net asset-related inflows $k^i(a)$. Labor income $y(a) = w(a)(T - l(a))$ is the product of the hourly wage $w(a)$ and paid work time $T - l(a)$, where T is the time endowment. Transfer outflows $\tau^o(a)$ equal private transfer outflows and public transfer outflows, while transfer inflows $\tau^i(a)$ equal private transfer inflows and public transfer inflows. Private transfers include intra- and inter-household transfers. Public transfers include those related to education, health, pensions, social protection other than pensions, and other in-kind and cash transfers. Taxes do not explicitly appear in the budget constraint, but they determine the magnitude of public transfer outflows. Net asset-related inflows $k^i(a)$ are the sum of private asset income and public asset income. Private asset income comprises private capital income and property income, while public asset income comprises public operating surpluses and public property income. The difference between inflows and outflows is savings $v(a) = i(a) - o(a)$, which is also the sum of private savings and public savings.

I take the economic utility function $u()$ to be a constant relative risk aversion (CRRA) function of a composite commodity z, which is in turn a Cobb-Douglas function of consumption and non-market time:

$$u(z(a)) = \frac{z(a)^{1-\frac{1}{\sigma}} - z_0^{1-\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}}, \tag{3}$$

$$\sigma \geq 0, \sigma \neq 1, \tag{4}$$

$$z_0 > 0, \tag{5}$$

$$z(a) = c(a)^{\alpha} l(a)^{1-\alpha}, \tag{6}$$

$$0 < \alpha < 1. \tag{7}$$

The CRRA function, also called the isoelastic or power function, has two parameters, the elasticity of intertemporal substitution σ (whose reciprocal $1/\sigma$ is the coefficient of relative risk aversion and the income elasticity of marginal utility) and subsistence composite consumption z_0. The advantage of the CRRA form is that it incorporates the elasticity of intertemporal substitution into the economic utility function in a simple way. This elasticity represents a person's tolerance for volatility/uncertainty. As $\sigma \to +\infty$, tolerance increases, and as $\sigma \to 0$, tolerance decreases. We will find that WTP for mortality and morbidity risk reduction is sensitive to this tolerance.

Subsistence composite commodity consumption z_0 is the level of composite consumption at which individuals would be indifferent between life and death. All economic models that value mortality risk reductions must specify the utility of death and we adopt the common

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approach of assuming that this utility is constant and that some positive level of consumption is necessary to make life worth living. The economic utility function above implies that $u(z_0) = 0$, or that the economic utility of death is normalized to zero. The Cobb–Douglas function is homogeneous of degree one and has parameter α reflecting relative preferences for consumption and non-market time.

The budget constraint reflects the assumption of perfect capital markets, including perfect credit markets for saving and borrowing, and perfect annuity markets for insuring consumption against longevity risks.

2.2. Solution and value formulas

The individual takes as given $s(a), q(a), w(a), A, T, c^{he}(a), \tau^o(a), \tau^i(a), k^i(a)$ and maximizes U with respect to $c(a), l(a)$ subject to the budget constraint. (See the Appendix for the Lagrangian and first-order conditions [FOCs].)

2.3. Value of a statistical life year and the value of a statistical health utility

Given a health technology applied to the individual at birth and whose lifetime survival and health utility impacts are $\delta s(a), \delta q(a)$ for all $a \geq 0$, the individual's WTP for this technology can be approximated, using the envelope theorem, by (see the Appendix for derivations):

$$\mathrm{WTP} = \sum_{a=0}^{99} \frac{\mathrm{VSLY}(a) \times \delta s(a) + s(a) \times \mathrm{VSHU}(a) \times \delta q(a)}{(1+r)^a}, \tag{8}$$

where:

$$\mathrm{VSLY}(a) \equiv y^f + c^f \Phi, \tag{9}$$

$$\mathrm{VSHU}(a) \equiv \left(\frac{1}{q}\right) \times c^f(\Phi + 1). \tag{10}$$

Full consumption c^f is the sum of the value of consumption and of non-market time, where each hour of non-market time is valued at the hourly wage:

$$c^f = c + wl. \tag{11}$$

Full income y^f is the sum of net earned and unearned income y^n and the value of non-market time:

$$y^f = y^n + wl. \tag{12}$$

$$y^n = y + \tau^i + k^i - c^{he} - \tau^o. \tag{13}$$

Φ is consumer surplus per unit of z or per dollar of c^f, or equivalently, the monetized value of the excess of the average utility of z over its marginal utility, and is given by:

$$\Phi \equiv \frac{\frac{u}{z} - u_z}{u_z} = \frac{\frac{u}{z}}{u_z} - 1 = \frac{1 - \sigma\left(\frac{z_0}{z(a)}\right)^{1-\frac{1}{\sigma}}}{\sigma - 1}. \tag{14}$$

Thus, WTP for a technology depends on its impacts on survival $\delta s(a)$ and on health utility $\delta q(a)$, as well as on the value of unit improvements in survival probability (summarized by

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the age-specific Value of a Statistical Life Year or $\text{VSLY}(a)$) and the value of unit improvements in health utility (summarized by the age-specific Value of a Statistical Health Utility or $\text{VSHU}(a)$). $\text{VSLY}(a)$ and $\text{VSHU}(a)$ are the fundamental value formulas produced by the HALM. They show how the value of health is affected by a broad range of economic variables related to consumption, non-market time, and earned and unearned income. Since these economic quantities vary with age over the lifecycle, so does the value of health.

These value formulas have two broad elements. The y^f term reflects the resources (in terms of income and time) that are made available by health and that are transformable into the goods (consumption and non-market time) from which economic utility is directly derived. This term can therefore be interpreted as reflecting the instrumental value of health. The terms involving c^f and Φ reflect the value of health in virtue of its being a direct component of period utility (see Equation (1)) and so can be interpreted as reflecting the intrinsic value of health. This intrinsic value reflects the value of c^f given the natural complementarity between health and c^f, so that the value of health is higher the higher is the value of c^f. This intrinsic value multiplies c^f by the consumer surplus term Φ to reflect the fact that the monetary value of the utility derived from full consumption generally exceeds the price of full consumption itself.

The Φ term in $\text{VSHU}(a)$ has a "+1" while the corresponding term in $\text{VSLY}(a)$ does not. This reflects the fact that improvements in survival impose a cost on the budget constraint that improvements in health utility do not: a living person must consume, so being alive has resource costs equal to the value of full consumption. Such cost must be offset from the value of improvements in survival but not from the value of improvements in health utility.

The fact that $\text{VSLY}(a)$ contains a y^f term while $\text{VSHU}(a)$ does not is an artifact of my specification of the budget constraint, which gives a role to the survival probability in affecting lifetime resources (being alive can both relax the budget constraint by facilitating income and tighten it by requiring consumption) but not to health utility. A more general budget constraint, which could be pursued in future work, could allow for health utility to affect the budget constraint through positive impacts (e.g. higher earnings and lower health expenditures) and negative impacts (e.g. lower transfer inflows). Such budget impacts would introduce a resource-related term into $\text{VSHU}(a)$.

The $\text{VSHU}(a)$ term has a $1/q$ term while the $\text{VSLY}(a)$ term does not. This is because the calculation of the intrinsic value of health requires computing the partial derivative of period utility $s(a) \times q(a) \times u(c(a), l(a))$ with respect to health, and monetizing this period utility gain by dividing by the marginal utility of composite commodity consumption $q(a) \times u_z$ (see Appendix for details). In the case of improvements in survival, this partial derivative is $q(a) \times u(c(a), l(a))$, so that health utility cancels out when dividing by marginal utility. However, in the case of improvements in health utility, this partial derivative is $s(a) \times u(c(a), l(a))$ so that dividing by marginal utility does not cancel out health utility in the denominator. Thus, holding fixed the economic aspects of life, the value of improvement in survival does not depend on baseline health utility, while the value of improvement in health utility does.

Equation (8) for WTP discounts health gains $\delta s(a), \delta q(a)$ at the interest rate r. It is an unresolved and controversial question in health economic evaluation whether to discount such health gains, and if so, whether to do so at the same rate r with which other monetary values are discounted (see, e.g. the discussion in Robinson *et al.*, 2019). I do not make any contribution to this debate. I have adopted the mathematically simplest assumption of applying the rate of time preference ρ to all of period utility including its health and

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consumption elements, which results in a uniform discount rate for health and monetary values. Such uniform discounting conforms to widespread practice and influential reference cases (see, e.g. Neumann *et al.*, 2016; iDSI, 2023).

Following Murphy and Topel (2006), I assume the survival probability $s(a)$ is a function of the mortality hazard $\lambda(j)$ for all ages from birth to age a:

$$s(a) = \exp\left[-\sum_{j=0}^{a}\lambda(j)\right]. \tag{15}$$

The Value of a Statistical Life at age $\overline{a}$, denoted $VSL(\overline{a})$, is the WTP for a small reduction in the mortality hazard $\lambda(\overline{a})$, or equivalently, the marginal rate of substitution between $\lambda(\overline{a})$ and A. For a small enough reduction in the hazard, the envelope theorem provides the following approximation to VSL (see Appendix for details):

$$\text{VSL}(\overline{a}) = \sum_{a=\overline{a}}^{99}\frac{s(a)\times \text{VSLY}(a)}{(1+r)^{a-\overline{a}}}. \tag{16}$$

2.4. Calibration

The fundamental value formulas of the HALM are the age-specific expressions for VSLY and VSHU. Computing these formulas therefore requires expressions for y^f, c^f, Φ. Consumer surplus Φ, in turn, requires estimates of σ and z_0. In what follows, I convert all monetary variables into 2023 US dollars (USD).

2.4.1. Model-based versus data-based values for $c(a), l(a)$

The value formulas for VSLY and VSHU ultimately depend on the values of $c(a), l(a)$. A first way to derive $c(a), l(a)$ is to solve the FOCs for the optimal values for these variables, which will be functions of the exogenous variables and parameters of the model. Given values for these exogenous variables and parameters, we obtain values for optimal consumption and non-market time implied by the theory. A second and alternative way is to estimate these from data and to assume these data have been generated by individuals behaving according to the model. For realism, to facilitate widespread use, and to generate value formulas that reflect real-world patterns of consumption, income, and time use, I follow the second approach.

2.4.2. Consumption c and earned and unearned income y^n

Equations (11) and (12) show full consumption c^f and full consumption y^f to be functions of consumption c and earned and unearned income y^n, respectively. I estimate c and y^n using variables from the National Transfer Accounts Project database (NTA, 2023), which uses microdata to compute how various consumption-, income-, and transfer-related quantities vary by age over the lifecycle. Table A1 shows how I map c and the components of y^n onto NTA variables, as well as the definitions of the NTA variables I rely on. Since NTA values stop at age 90, I extrapolate values to all older ages by assuming that labor income is zero, and that all other values are set to their age 90 values. I convert all NTA data, which is given in 2011 international dollars, to 2023 USD by multiplying by 1.35 (US BLS, 2023a)).

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Table A2 shows the values (in 2023 USD) of the NTA variables I use. The age-specific values of consumption c and earned and unearned income y^n are given in Table A6.

2.4.3. Hourly wages w and non-market time l

Both full consumption and full income require the value of non-market time $w \times l$. For hourly wages w, the US Bureau of Labor Statistics (Table 20 in US BLS, 2023b) provides hourly earnings by age (column 1 in Table A3), but these are limited to workers paid hourly rates who may not be representative of workers as a whole. I thus compute the ratio of the hourly earnings of a particular age group to the hourly earnings across all age groups. For example, this ratio equals 12.06/17.02 for those aged 16–19 (column 2 in Table A3). I then estimate the hourly earnings for this age group across all workers (including those not paid hourly rates) as the product of this ratio and the hourly earnings across all workers, which I take as $33.74 in 2023 USD (Table B-3 in US BLS, 2023c). Thus, for example, for those aged 16–19, the hourly earnings across all workers equals (12.06/17.02) × 33.74 (column 3 in Table A3). Hourly wage data are unavailable for ages 0–15 so I backfill age 16 values to these earlier ages.

I obtain age-specific non-market time from the 2022 results of the American Time Use Survey (US BLS, 2023d, summarized in Table A4). I take unpaid work to consist of the following ATUS activity categories: household activities, purchasing goods and services, caring for and helping household members, caring for and helping non-household members, organizational, civic, and religious activities, telephone calls, mail, and e-mail. I take leisure to consist of the ATUS category "leisure and sports." Thus, age-specific non-market time per year is 365.25 times the sum of the columns in Table A4. Time use data are unavailable for those aged 0–14, so I backfill age 15 values of non-market time to these earlier ages.

The age-specific values of non-market time (combining the value of hourly earnings and non-market time) $w \times l$, full consumption c^f, and full income y^f are given in Table A6.

2.4.4. Health utility

The expression for $VSHU(a)$ depends on health utility in the general population $q(a)$. I obtain these from Szende *et al.* (2014) and report them in Table A5. Health utility values are unavailable for those aged 0–17 so I backfill age 18 values to these earlier ages.

2.4.5. Consumer surplus

The last component of VSLY(a) and VSHU(a) is consumer surplus Φ, which depends on both σ and z_0. I simplify by approximating $\frac{z_0}{z(a)}$ by $\frac{c_0}{c(a)}$ where c_0 is subsistence consumption of goods and services so that:

$$\Phi(a) = \frac{1 - \sigma\left(\frac{z_0}{z(a)}\right)^{1-\frac{1}{\sigma}}}{\sigma - 1} \approx \frac{1 - \sigma\left(\frac{c_0}{c(a)}\right)^{1-\frac{1}{\sigma}}}{\sigma - 1}. \tag{17}$$

I have already quantified $c(a)$ above, so the remaining parameters in (17) are c_0 and σ.

I consider two possible values for c_0: half the annual extreme poverty rate in the US, and half that of the country with the lowest annual extreme poverty rate in the world. I estimate these annual extreme poverty rates based on Allen's (2017) estimate of a daily extreme

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poverty rate in the US and Zimbabwe of \$4.28 and \$1.86 respectively in 2011 international dollars. Half the annual extreme poverty rate in the US and Zimbabwe are therefore 0.5 × 365.25 × 4.28=781.64 and.5 × 365.25 × 1.86=339.68 respectively in 2011 international dollars. Converting this into 2023 USD using the CPI (US BLS, 2023a), given parity between international and US dollars, gives us the following value for c_0: 1057.62 and 459.61 based on the US and Zimbabwe rates respectively.

I estimate σ by assuming the VSL of a middle-aged American is \$10 million (which is conservative relative to the \$11.4 million estimate for the year 2020 from the US Department of Health and Human Services (2021)) when evaluated at the age equal to half of US life expectancy at birth and backing out the value of σ that makes this equality hold. Combining (9), (16), and (17):

$$\mathrm{VSL}(\overline{a}) = \sum_{a=\overline{a}}^{99} \frac{s(a) \times \left(y^f(a) + c^f(a) \times \dfrac{1 - \sigma\left(\frac{c_0}{c(a)}\right)^{1-\frac{1}{\sigma}}}{\sigma - 1} \right)}{(1+r)^{a-\overline{a}}} = 10M. \tag{18}$$

Given that US life expectancy is about 76 (Arias *et al.*, 2022), I choose $\overline{a} = 38$. I assume $r = \rho = 0.03$. I derive the survival probabilities $s(a)$ using 2020 US lifetables from the National Vital Statistics Report (US CDC, 2022). Thus, the only remaining unknown in Equation (18)) is σ. Backing out the value for σ, I get $\sigma = 2.06$ when $c_0 = 1057.62$ and $\sigma = 2.13$ when $c_0 = 459.61$.

(These σ estimates suggest an estimated coefficient of relative risk aversion of $1/\sigma < 1/2$. There are puzzles regarding such an estimated coefficient that I do not attempt to resolve. On the one hand and reassuringly, my estimates conform to theoretical results suggesting this coefficient should be smaller than the income elasticity of VSL (Kaplow, 2005) and empirical results suggesting this income elasticity is between 0.5 and 0.7 in the US. (Viscusi & Masterman, 2017). On the other hand, and problematically, my estimates also exemplify an empirical puzzle whereby VSL-based estimates of the coefficient of relative risk aversion are significantly smaller than those derived from other economic behaviors and contexts such as financial and labor markets, where the coefficient of relative risk aversion tends to be around 1 (Chetty, 2006; Gandelman & Hernandez-Murillo, 2015) or higher (e.g. between 2 and 10, Kaplow, 2005.)

This completes the calibration of VSLY and VSHU. Table A6 reports values for survival s, Φ^{US} and Φ^{Z} which are the values for Φ corresponding to US and Zimbabwean utility parameter values, and the resulting values for VSLY and VSHU. Figure 1 represents the following values graphically: $y^f, c^f, wl, \mathrm{VSLY}, \mathrm{VSHU}, \mathrm{WTP}_{\mathrm{QALY}}$. The left and right panels are based on the US and Zimbabwean values for c_0 respectively. Note that VSLY and VSHU are very similar across panels, suggesting their robustness with respect to the choice of c_0. The jaggedness of the graphs reflects the jaggedness of the underlying data and can be smoothed away if necessary.

Observe that $y^f, c^f, wl, \mathrm{VSLY}, \mathrm{VSHU}$ share the same general inverse U-shape as a function of age, peaking at age 55. These provide evidence that the economic determinants of the value of health (e.g. c^f and y^f) and therefore the value of health itself (i.e. VSLY, VSHU), are generally not age-invariant. Figure 1 also shows that VSHU is everywhere higher than VSLY. The jump upward in $y^f, c^f, \mathrm{VSLY}, \mathrm{VSHU}$ at age 90 is an artifact of how I

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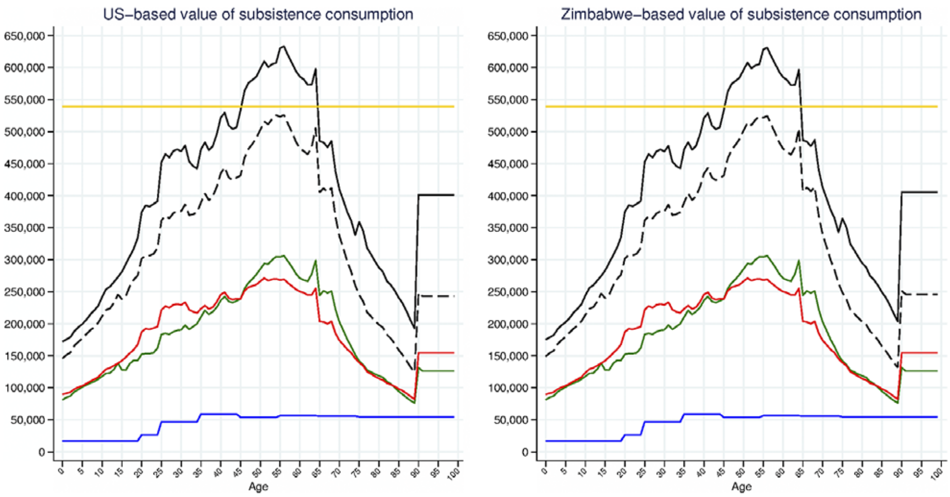

***Figure 1.** Health-augmented lifecycle model results. Value of a statistical disability year (black); Value of a statistical life year (dashed black); Full income (green); Full consumption (red); Monetized value of nonmarket time (blue).*

have filled in missing NTA values in this age group, and I shall improve this feature of this analysis in future work.

2.5. Comparison with CUA

Equation (1) shows what assumptions suffice for lifetime utility U to be multiplicatively separable in lifetime QALYs, given by $\sum_{a=0}^{99} \frac{s(a) \times q(a)}{(1+\rho)^a}$, and economic utility, given by $u(c(a), l(a))$, as assumed by CUA: lifetime utility must be additively separable in period utility; period utility must be multiplicatively separable in survival probability, health utility, and economic utility; and $c(a)$ and $l(a)$ must be constant throughout the lifetime. While the first and second of these are standard in the literature, the third, the age-invariance of consumption and non-market time, is implausible in light of the evidence in Figure 1, suggesting the empirical falsity of the assumptions imposed by CUA on preferences. In Figure 1, I have also for comparison with my VSLY and VSHU estimates, graphed $WTP_{QALY} = 539{,}083$, which is my estimate of CUA's central measure of the value, the WTP per QALY, given a VSL of \$10 million and given my estimate of the discounted quality-adjusted life expectancy (QALE) of a 38-year-old of 18.55 (using the s values in Table A6, renormalized so they equal 1 for a 38-year-old; the q values in Table A5; and a 3 % discount rate).

2.6. Application

To show how to use the VSLY and VSHU value formulas to compute WTP for a vaccine, I take an example from Sevilla *et al.* (2022). That paper performed a prospective evaluation of introducing a pediatric 13-valent Pneumococcal Conjugate Vaccination (PCV13) program into Egypt's national immunization program and vaccinating 100 successive birth cohorts over the period from 2016 to 2115. Egypt is a PCV-naïve country, so the paper used an incidence

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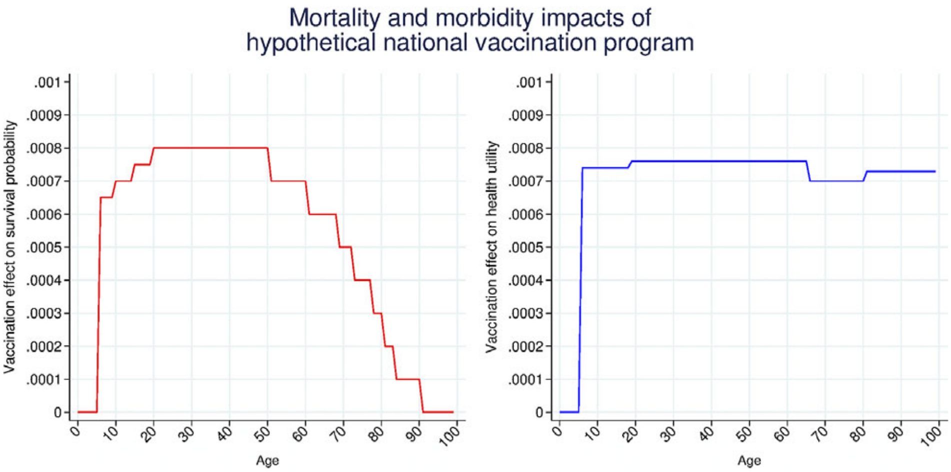

Figure 2. *Mortality and morbidity impacts of pediatric vaccination program.*

rate projection model to estimate the impact of PCV13 on the incidence of various serotypes or groups of serotypes of pneumococcal disease. It used a multiple-cohort static Markov model of Streptococcus Pneumoniae to estimate PCV13's impact (relative to no vaccination) on lifetime survival probabilities and health utility conditional for each of the 100 birth cohorts. These impacts are what are denoted in Equation (8) as $\delta s(a)$ and $\delta q(a)$. That paper's calculated impacts for the first birth cohort are summarized in their Figure 6 (Sevilla et al., 2022), which, through visual inspection, I approximate graphically in Figure 2 and numerically in the final two columns of Table A6. Equation (8) shows how to combine $\delta s(a)$ and $\delta q(a)$ with $\mathrm{VSLY}(a)$, $\mathrm{VSHU}(a)$, $s(a)$, and r to obtain WTP for the vaccine. Sevilla *et al.* (2022) calculate Egyptian values for $\mathrm{VSLY}(a)$ and $\mathrm{VSHU}(a)$, which they combine with estimates of $\delta s(a)$ and $\delta q(a)$ to derive Egyptian WTP for PCV13. I combine their estimates of $\delta s(a)$ and $\delta q(a)$ with my estimates of $\mathrm{VSLY}(a)$ and $\mathrm{VSHU}(a)$ for the US to estimate US WTP for these survival and health utility gains. Using the US and Zimbabwe values for the extreme poverty rate, the US WTP for these gains are \$13,481 and \$13,508 respectively.

(The reason the US WTP for the vaccine is relatively invariant with respect to the value of c_0 is that the estimate of σ adjusts in response to maintain a VSL of \$10M. The change in c_0 and the offsetting change in σ do not fully offset each other in $\mathrm{VSLY}(a)$ and $\mathrm{VSHU}(a)$, so WTP does vary with the value of c_0. But they offset sufficiently that the variation is slight.)

2.7. Generalization to other countries

Applying the HALM to other countries requires country-specific estimates of $c(a)$ and $y^n(a)$ (which can be obtained from NTA (2023)), $w(a)$ (which can be obtained from labor force data), and $l(a)$ (which can be obtained from time use surveys). Under the assumption of identical global preferences (discussed further below), the values of c_0 and σ derived from the Zimbabwean extreme poverty rate can be used for any country in the world. (Using these values for c_0 and σ for countries other than the US does not imply extrapolating the \$10 million US VSL to that other country, since the VSL in that other country, as Equations (9)

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and (16) show, will depend not just on the values for c_0 and σ but also on its own levels of full consumption and full income.) An even simpler way to apply the HALM to another country is to simply take my computed VSLY and VSHU values and scale them by the ratio of per capita GDP in that other country to that of the US. Applying the HALM also requires estimates of $s(a), q(a), \delta s(a), \delta q(a)$, but these are required or would be generated by any model of health technology impact.

2.8. Conservative simplification

VSLY and VSHU are positive functions of consumer surplus Φ, which is itself typically positive. Also, the utility function parameters z_0 and σ only affect VSLY and VSHU through Φ. These along with Equations (9) and (10) suggest an approximation that is both conservative and avoids the challenge of having to estimate utility function parameters: approximate VSLY and VSHU by y^f and c^f/q respectively.

3. Conclusion

The HALM is preferencist and therefore satisfies the PP. It incorporates health into economic evaluation by augmenting a workhorse of microeconomic and macroeconomic theory, the lifecycle model, which is perhaps the most foundational and widely used utility-theoretic framework for the economic evaluation of policies in general, health-related or not. This makes it an apt framework for preferencist economic evaluation involving health.

The HALM also provides a flexible preference-based framework for policy evaluation. By "flexible" I mean that it imposes relatively fewer empirically false restrictions on preferences than other preference-based approaches like CUA. (Another approach that incorporates features of lifecycle models and QALY-centric CUA is taken by Cookson *et al.* (2021), which proposes a measure of lifetime utility that is additive in lifetime QALYs. However, it exemplifies the problem that although it is convenient (and congenial to CUA) to specify lifetime utility as separable in lifetime QALYs and economic utility, such separability requires imposing implausible restrictions on preferences or economic behaviors. As I discussed above, multiplicative separability requires age-invariant consumption and non-market time. Cookson *et al.* (2021) achieve additive separability with the assumption that health and consumption are perfect substitutes/non-complementary. This is implausible given that, intuitively, the marginal utility of leisure time, books, movies, and so on depends on whether one is depressed, has good vision, has physical mobility, and conversely the marginal utility of vision and mobility depends on whether one has access to books and movies and leisure time, as they themselves acknowledge using similar examples.) The HALM's relative flexibility allows it to reflect true preferences more accurately, which promotes its ability to satisfy the PP.

While I have focused on a benchmark specification of the HALM, other versions are possible. One important area for future work is to drop the assumption of perfect capital markets and to allow for budget constraints allowing for borrowing constraints, and imperfect insurance and annuity markets. Another area worth examining is how to extend the HALM to accommodate dimensions of well-being beyond health and economics, for example, by incorporating hedonic, eudaimonic, or social well-being.

The HALM shows that the value of health reflects not just its impact on earned income, but also on unearned income and the value of non-market time, which in turn consists of the value of unpaid work and leisure. This demonstrates the limitations of the human capital approach that values health solely in terms of its impact on (typically paid) work, ignoring leisure (and typically, unpaid work).

The HALM expresses the value of health as functions of traditional economic quantities like consumption, paid and unpaid work, leisure, health expenditures, and public and private transfers. This may give it an advantage relative to a recent approach to broad valuation centered on the WELLBY (Frijters, 2021), which evaluates policies through their joint impact on self-reported overall life satisfaction (OLS) as quantified over a 0 to 10 scale and on longevity. Cognitive limitations likely prevent individuals from being able to translate policy impacts on the above economic quantities into ultimate impacts on OLS, so it is useful to be able to value health directly in terms of those economic quantities.

There is some controversy regarding whether the value of health gains, especially of mortality risk reductions, should net out such economic costs such as future consumption, future health services consumed, and future pension costs (see, e.g. Basu, 2016). Equations (9), (11)–(13) shed light on this issue and show that the value of mortality risk reduction depends on the value of savings $v(a)$, which is indeed a function of consumption of goods and services, consumption of health services, transfers including pensions, along with all other savings determinants.

An issue of concern in the literature is how to address preference heterogeneity. We can distinguish two questions. The first question is intrapersonal and wholly empirical: what is the functional dependence of WTP on preferences, and how therefore does WTP vary with preferences? The second question is interpersonal and irreducibly normative: how aggregate the WTP of individuals with different preferences? There are at least three competing answers to this second question. CBA simply adds up WTP across individuals with different preferences, while SWF and EI analysis can account for these differences through differential weighing of WTP (for SWF-based approaches to preference heterogeneity, see Adler (2019), and for the EI-based approach, see Fleurbaey *et al.* (2013)). Both questions are essential, but they are separate questions. The HALM addresses only the first question and should not be relied on to supplant the consideration of interpersonal aggregation, distribution, and fairness required by the second question. But regardless of the answer to the second question, we need expressions for WTP as functions of preference parameters – these, after all, are what are to be aggregated given some answer to the second question--and the HALM provides such expressions.

The HALM generates expressions for WTP that can be used in either CBA, utilitarian or prioritarian SWFs, or EI, which differ from each other in whether and how to weigh the WTP of the worse off relative to the better off, or whether and how to weigh the WTP of individuals with different preferences. Thus, the HALM can be used within any of these three frameworks. However, the HALM can make an even further contribution to the implementation of SWF-based approaches. Utilitarian- and prioritarian SWFs respectively weigh individuals' WTP wholly or partially in proportion to their marginal utility of income. The HALM facilitates the construction of such weights, and therefore the operationalization of SWF approaches: the Lagrange multiplier serves as an estimate of that marginal utility that is directly comparable among individuals with identical preferences and that can be adjusted using the methods described in Adler (2019) to render them comparable among individuals with different preferences.

Competing interest. JS is employed as a health economist at Data for Decisions, LLC, and as a Research Associate at the Harvard T.H. Chan School of Public Health. Through these employers or personal consulting fees, he has received financial support from vaccine- and medical device manufacturers including Pfizer, GSK, Merck, Sanofi, Bavarian-Nordic, Johnson & Johnson, Janssen, and Edwards Life Sciences. Through these employers or personal

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A. Appendix

A.1. HALM mathematical details

Denoting the Lagrangian by L, the individual solves:

$$\max_{c(a),l(a),\mu} L = \sum_{a=0}^{99} \frac{s(a) \times q(a) \times u(c(a), l(a))}{(1+\rho)^a} + \mu\left[A + \sum_{a=0}^{99} \frac{s(a) \times v(a)}{(1+r)^a}\right]. \tag{A1}$$

The FOCs are:

$$\frac{\partial L}{\partial c(a)} = 0 \rightarrow \mu = q \times u_z \times z_c \times \left(\frac{1+r}{1+\rho}\right), \tag{A2}$$

$$\frac{\partial L}{\partial l(a)} = 0 \rightarrow \mu \times w = q \times u_z \times z_l \times \left(\frac{1+r}{1+\rho}\right), \tag{A3}$$

$$\frac{\partial L}{\partial \mu} = 0 \rightarrow A + \sum_{a=0}^{99} \frac{s(a) \times v(a)}{(1+r)^a} = 0, \tag{A4}$$

where $u_z, z_c,$ and z_l are the partial derivatives of u with respect to composite commodity consumption and the partial derivatives of composite commodity consumption with respect to consumption and nonmarket time, respectively.

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Given a health technology applied to the individual at birth and whose lifetime survival and health utility impacts are $\delta s(a), \delta q(a)$ for all $a \geq 0$, the individual's WTP for this technology can be approximated, using the envelope theorem, by $WTP = \frac{\delta L}{\mu}$ where:

$$\mathrm{WTP} = \frac{\delta L}{\mu} = \frac{1}{\mu}\left(\sum_{a=0}^{99} \frac{\partial L}{\partial s(a)} \delta s(a) + \frac{\partial L}{\partial q(a)} \delta q(a)\right). \tag{A5}$$

Equations (A1) and (A2) imply:

$$\frac{1}{\mu}\frac{\partial L}{\partial s(a)} = \frac{1}{\mu}\frac{q \times u}{(1+\rho)^a} + \frac{v}{(1+r)^a} = \frac{\frac{u}{u_z \times z_c} + v}{(1+r)^a}, \tag{A6}$$

$$\frac{1}{\mu}\frac{\partial L}{\partial q(a)} = \frac{1}{\mu}\frac{s \times u}{(1+\rho)^a} = \frac{s \times \left(\frac{1}{q}\right) \times \frac{u}{u_z \times z_c}}{(1+r)^a}. \tag{A7}$$

We can rewrite $\frac{u}{u_z \times z_c}$ as follows. The Cobb-Douglas function's homogeneity of degree one implies (suppressing a for notational compactness):

$$kz = z(kc, kl) \rightarrow \frac{\partial (kz)}{\partial k} = z_c \frac{\partial (kc)}{\partial k} + z_l \frac{\partial (kl)}{\partial k} \rightarrow \mathrm{z} = z_c c + z_l l \rightarrow \frac{z}{z_c} = c + \frac{z_l}{z_c} l. \tag{A8}$$

Combining (A2) and (A3) yields:

$$w = \frac{z_l}{z_c}. \tag{A9}$$

Equations (A8), (A9), and (10) imply:

$$\frac{z}{z_c} = c^f, \tag{A10}$$

which in turn implies:

$$\frac{u}{u_z \times z_c} = c^f(\Phi + 1), \tag{A11}$$

where Φ is given by (14).

We also have:

$$v = i - o = y^n - c, \tag{A12}$$

and:

$$\frac{u}{u_z \times z_c} + v = c^f(\Phi + 1) + (y^n + wl) - (c + wl) = y^f + c^f \Phi, \tag{A13}$$

where y^f and y^n are given by (12) and (13).

Substituting all the above into (A5) yields (8).

Equation (15) implies, for $a \geq \overline{a}$:

$$\frac{\partial s(a)}{\partial \lambda(\overline{a})} = -s(a). \tag{A14}$$

For a small enough reduction in the hazard, the envelope theorem provides the following approximation to VSL (relying on (A1), (A2), and (A6)):

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$$\mathrm{VSL}(\overline{a}) = \frac{\frac{\partial L}{\partial \lambda(\overline{a})}}{\frac{\partial L}{\partial A}} = \left(\frac{1}{\mu}\right)\frac{\partial L}{\partial \lambda(\overline{a})} = \left(\frac{1}{\mu}\right)\sum_{a=\overline{a}}^{99}\frac{\partial L}{\partial s(a)}\frac{\partial s(a)}{\partial \lambda(\overline{a})} = \sum_{a=\overline{a}}^{99}\frac{s(a)\times \mathrm{VSLY}(a)}{(1+r)^{a-\overline{a}}}. \tag{A15}$$

Table A1. *HALM variables and National Transfer Accounts equivalents*

HALM variable	Definition	NTA-based measure of HALM variable and NTA variable definitions
c	Consumption of goods and services, excluding health and education	NTA-based measure of HALM variable: CFX+CGX NTA variable definitions: CFX: Private consumption other than health and education CGX: Public consumption other than health and education
c^{he}	Consumption of health and education	NTA-based measure of HALM variable: CFH+CFE +CGH+CGE NTA variable definitions: CFH: Private consumption, health CFE: Private consumption, education CGH: Public consumption, health CGE: Public consumption, education
y^n	Earned and unearned income	NTA-based measure of HALM variable: YL+YAF +YAG+TFI+TGI-CFH-CFE-CGH-CGE-TFO-TGO NTA variable definitions: see below
y	Labor income	NTA-based measure of HALM variable: YL NTA variable definition YL: Labor Income
τ^o	Transfer outflows	NTA-based measure of HALM variable: TFO+TGO NTA variable definitions: TFO: Private transfers outflow TGO: Public transfers outflow
τ^i	Transfer inflows	NTA-based measure of HALM variable: TFI+TGI NTA variable definitions TFI: Private transfers inflow TGI: Public transfers outflow
k^i	Net asset-related inflows	NTA-based measure of HALM variable: YAF+YAG NTA variable definitions: YAF: Private asset income YAG: Public asset income

Source: Author's definitions and NTA (2023).

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Table A2. *NTA variables*

a	CFX	CGX	CFH	CFE	CGH	CGE	YL	YAF	YAG	TFI	TGI	TFO	TGO
0	44,315	28,289	7,357	0	11,877	0	0	0	−555	43,093	46,226	503	4,767
1	45,972	28,314	7,331	0	11,627	0	0	0	−581	46,946	45,910	494	4,983
2	47,651	28,349	7,307	1,468	11,381	0	0	0	−606	50,868	45,626	486	5,202
3	51,333	29,284	7,547	4,893	11,494	0	0	0	−656	60,397	46,860	328	5,631
4	54,137	29,425	7,660	2,971	11,302	0	0	0	−694	62,098	46,888	334	5,958
5	56,684	29,178	7,730	3,589	10,976	55,640	0	0	−728	65,573	103,863	521	6,247
6	59,978	29,088	7,881	1,145	10,758	55,465	0	0	−770	66,407	103,490	0	6,609
7	63,806	29,146	8,145	481	10,663	55,573	0	0	−818	69,674	103,616	364	7,022
8	67,095	28,932	8,373	1,501	10,540	55,159	0	0	−860	74,489	102,648	907	7,377
9	70,676	28,807	8,659	1,522	10,507	54,918	0	0	−905	78,386	102,142	0	7,762
10	76,600	29,520	9,277	0	10,828	56,269	0	0	−980	83,388	104,716	1,583	8,412
11	81,969	29,962	9,844	0	11,126	57,101	0	0	−1,050	89,619	106,258	2,379	9,010
12	84,550	29,453	10,052	1,159	11,141	56,108	0	0	−1,084	93,155	104,739	3,203	9,307
13	88,101	29,439	10,428	1,127	11,377	56,037	0	0	−1,131	96,664	104,926	0	9,722
14	91,677	29,491	10,792	13,469	11,638	56,055	0	0	−1,179	119,430	105,503	229	10,146
15	95,461	29,687	11,146	1,746	11,913	56,293	605	70	−1,274	104,446	107,052	8,069	11,043
16	100,568	30,319	11,644	15,038	12,176	57,123	4,963	571	−1,479	118,766	109,638	12,458	13,492
17	105,695	30,943	12,172	10,812	12,221	58,029	13,184	1,218	−1,691	122,342	110,962	15,728	16,527
18	111,080	31,426	12,566	21,805	11,950	69,880	23,265	2,816	−1,945	132,782	126,367	21,057	20,146
19	118,171	32,269	13,047	28,147	11,366	24,744	36,622	4,142	−2,282	130,456	86,567	27,544	24,893
20	127,784	32,838	13,370	29,104	10,964	27,186	53,545	5,890	−2,912	126,714	90,467	34,909	32,553
21	132,762	32,808	13,483	26,108	10,416	28,095	72,925	8,229	−3,427	117,267	90,755	41,513	39,477
22	133,215	31,517	13,032	20,280	9,581	26,701	91,730	10,001	−3,905	106,632	85,349	47,573	45,915
23	135,778	30,799	12,924	14,769	9,038	26,643	112,800	11,710	−4,495	96,364	83,139	54,713	53,561
24	138,432	30,298	12,970	11,458	8,684	25,848	134,233	13,626	−5,127	95,339	80,596	62,971	61,606
25	144,186	30,479	13,395	9,216	8,600	25,565	157,509	15,009	−5,826	87,039	82,264	72,288	70,439

Table A2. *Continued*

a	CFX	CGX	CFH	CFE	CGH	CGE	YL	YAF	YAG	TFI	TGI	TFO	TGO
26	149,847	30,792	13,885	8,601	8,630	0	179,443	15,687	−6,489	85,227	55,852	81,667	78,793
27	148,213	29,862	13,856	7,457	8,340	0	191,238	15,988	−6,803	82,354	53,805	87,406	82,886
28	152,290	30,395	14,455	7,117	8,509	0	210,025	16,598	−7,357	82,155	55,422	96,184	89,866
29	153,495	30,455	14,804	5,652	8,515	0	224,386	16,610	−7,778	79,626	55,867	101,839	95,073
30	152,407	30,175	14,934	4,827	8,395	0	234,851	17,038	−8,073	77,531	54,579	105,262	98,721
31	155,916	30,833	15,512	3,885	8,501	0	251,756	18,595	−8,602	78,565	55,804	111,924	105,205
32	146,179	28,952	14,796	4,984	7,950	0	247,072	19,252	−8,391	74,746	51,163	109,177	102,585
33	143,341	28,410	14,740	3,212	7,774	0	252,145	21,810	−8,553	75,266	49,994	111,816	104,424
34	141,853	28,157	14,886	3,488	7,719	0	259,421	25,362	−8,785	77,129	49,879	116,517	107,132
35	137,169	27,357	14,788	3,371	7,572	0	261,481	28,790	−8,903	75,864	48,260	119,685	108,137
36	141,117	28,246	15,705	3,334	7,890	0	279,931	34,307	−9,576	80,976	50,500	131,493	115,803
37	136,680	27,394	15,742	2,831	7,705	0	280,304	37,737	−9,660	76,672	48,389	135,205	116,244
38	139,056	27,861	16,667	3,192	7,976	0	292,968	42,425	−10,128	78,922	49,610	144,552	121,462
39	146,083	29,164	18,283	3,600	8,497	0	312,375	48,539	−10,857	82,400	51,759	157,219	129,788
40	155,899	30,891	20,428	2,731	9,165	0	334,039	55,587	−11,643	87,320	55,104	171,433	138,999
41	158,926	31,328	21,978	3,131	9,500	0	340,482	60,460	−11,899	91,497	56,085	176,508	141,884
42	151,629	29,723	22,209	2,478	9,226	0	323,005	61,114	−11,359	87,401	53,730	168,674	135,240
43	149,585	29,141	23,233	2,471	9,203	0	316,084	63,934	−11,286	86,652	52,605	165,144	133,872
44	150,910	29,213	24,773	2,764	9,427	0	317,262	67,973	−11,506	87,368	53,046	164,495	135,843
45	154,972	29,805	26,837	2,198	9,847	0	325,084	73,945	−11,981	89,369	54,666	166,704	140,694
46	165,905	31,647	30,132	2,476	10,777	0	346,705	84,243	−13,040	95,278	58,815	175,644	152,175
47	170,736	32,282	32,364	2,295	11,392	0	355,949	92,237	−13,591	97,045	60,374	178,206	157,819
48	172,703	32,307	33,944	1,880	11,835	0	358,382	98,084	−13,814	97,058	61,485	177,802	159,901
49	174,948	32,288	35,360	1,805	12,268	0	358,801	104,524	−13,984	99,335	61,869	176,436	161,463
50	179,762	32,733	37,160	1,937	12,909	0	363,707	111,734	−14,304	100,919	63,745	177,502	164,943
51	184,328	33,057	38,664	1,979	13,448	0	366,142	118,092	−14,516	103,073	65,241	176,720	167,314

Table A2. *Continued*

a	CFX	CGX	CFH	CFE	CGH	CGE	YL	YAF	YAG	TFI	TGI	TFO	TGO
52	181,463	31,994	38,348	1,328	13,347	0	353,552	118,958	−14,147	100,467	63,868	167,690	162,856
53	183,646	31,850	38,914	1,385	13,629	0	351,034	124,462	−14,225	100,525	64,674	163,305	163,362
54	184,775	31,543	39,165	1,376	13,817	0	347,547	128,460	−14,230	99,720	64,730	158,111	163,031
55	181,343	30,456	38,251	1,350	13,631	0	333,544	128,454	−13,863	97,090	63,168	148,841	158,324
56	182,727	30,237	38,280	998	13,891	0	327,066	130,727	−13,856	97,054	63,646	144,062	157,751
57	178,205	29,045	36,910	1,010	13,829	0	306,269	128,985	−13,340	94,680	62,250	134,735	151,374
58	174,377	27,990	35,618	1,001	13,906	0	284,638	127,046	−12,789	93,313	61,688	126,618	144,710
59	170,331	26,954	34,245	654	14,146	0	260,466	125,824	−12,178	91,607	61,673	119,042	137,392
60	167,633	26,176	33,170	577	14,647	0	238,590	125,952	−11,647	90,949	62,553	112,273	131,016
61	166,304	25,615	32,362	394	15,303	0	217,916	130,992	−11,213	90,558	64,218	107,017	125,576
62	163,640	24,909	31,330	410	15,995	0	196,230	137,433	−10,732	88,358	67,341	101,189	119,572
63	163,992	24,708	29,487	467	21,925	0	178,096	149,499	−10,506	87,224	82,933	96,993	117,009
64	172,813	25,800	29,021	442	29,555	0	168,431	171,349	−10,816	88,836	101,618	97,568	120,507
65	128,758	19,101	20,092	266	27,056	0	111,103	140,357	−7,916	63,750	86,505	69,756	88,208
66	128,091	18,890	18,208	293	33,494	0	96,894	150,051	−7,703	60,882	100,139	66,543	86,282
67	125,569	18,461	17,397	199	35,010	0	82,552	153,604	−7,325	57,112	103,571	62,687	82,051
68	129,016	18,945	17,678	220	36,605	0	73,531	161,965	−7,276	55,867	108,607	61,717	81,423
69	112,674	16,574	15,421	182	32,670	0	55,360	143,201	−6,118	46,082	96,966	51,927	68,532
70	102,814	15,202	14,150	209	30,641	0	43,887	129,089	−5,318	39,613	90,518	45,961	59,875
71	96,784	14,440	13,489	144	29,855	0	35,987	118,895	−4,773	35,551	87,213	41,677	54,119
72	90,351	13,651	12,903	133	29,062	0	29,356	108,878	−4,273	31,098	83,349	37,855	48,838
73	85,537	13,135	12,655	129	28,879	0	24,418	100,210	−3,865	28,106	80,972	35,219	44,606
74	77,681	12,175	11,891	114	27,705	0	19,631	89,260	−3,381	24,747	75,807	31,510	39,407
75	73,022	11,697	11,692	96	27,638	0	16,305	82,751	−3,078	22,550	73,607	29,177	36,223
76	68,572	11,288	11,638	79	27,746	0	13,647	78,416	−2,831	20,538	71,863	27,151	33,595
77	60,255	10,214	10,892	56	26,243	0	10,717	71,088	−2,459	17,593	66,104	23,612	29,392

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Table A2. *Continued*

a	CFX	CGX	CFH	CFE	CGH	CGE	YL	YAF	YAG	TFI	TGI	TFO	TGO
78	56,977	9,955	11,039	39	26,915	0	8,900	69,405	−2,307	15,960	65,732	22,013	27,772
79	53,526	9,592	11,197	24	27,357	0	7,427	67,285	−2,165	14,189	64,831	20,189	26,192
80	50,449	9,226	11,346	16	27,796	0	6,355	66,226	−2,065	12,403	63,926	18,753	25,010
81	48,440	8,940	11,797	9	28,634	0	5,555	64,755	−1,981	11,181	63,778	17,371	24,016
82	44,319	8,166	11,694	5	27,891	0	4,678	58,935	−1,790	9,634	60,108	15,180	21,704
83	42,529	7,748	12,105	2	28,190	0	4,222	55,774	−1,687	8,758	58,855	14,057	20,426
84	40,058	7,177	12,297	1	27,745	0	3,676	50,980	−1,540	8,039	56,264	12,880	18,633
85	36,991	6,492	12,223	1	26,564	0	3,026	44,861	−1,360	7,441	52,444	11,379	16,464
86	34,531	5,960	12,075	0	25,511	0	2,546	40,283	−1,224	6,899	49,348	10,493	14,819
87	31,050	5,293	11,355	0	23,435	0	2,105	35,172	−1,070	6,175	44,657	9,366	12,958
88	27,117	4,592	10,242	0	20,801	0	1,751	30,223	−920	5,382	39,237	8,153	11,143
89	23,695	3,998	9,171	0	18,452	0	1,490	26,184	−797	4,703	34,518	7,103	9,658
90	85,424	14,363	33,855	0	67,514	0	5,232	93,596	−2,850	16,951	125,279	25,533	34,537
91	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
92	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
93	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
94	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
95	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
96	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
97	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
98	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537
99	85,424	14,363	33,855	0	67,514	0	0	93,596	−2,850	16,951	125,279	25,533	34,537

Source: NTA (2023).

Table A3. *Hourly wages, 2023 USD*

Age	Hourly earnings, hourly rate workers (1)	Ratio (2) = (1)/17.02	Hourly earnings, all workers (3)=(2) × 33.74
16+	17.02		
16–19	12.06	0.70857814	23.9074266
20–24	14.76	0.86721504	29.2598355
25–34	17.65	1.03701528	34.9888954
35–44	18.97	1.11457109	37.6056287
45–54	19.12	1.12338425	37.9029847
55–64	19.21	1.12867215	38.0813984
65+	16.47	0.96768508	32.6496945

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Table A4. *Nonmarket Time use (hours per day)*

Age group	Household activities	Purchasing goods and services	Caring for and helping household members	Caring for and helping non-household members	Organizational, civic, and religious activities	Telephone calls, mail, and email	Leisure and sports
15–19	0.79	0.43	0.13	0.09	0.18	0.15	0.20
20–24	1.16	0.51	0.22	0.09	0.14	0.17	0.21
25–34	1.68	0.58	0.82	0.11	0.16	0.11	0.21
35–44	1.80	0.62	1.21	0.13	0.16	0.12	0.25
45–54	1.98	0.69	0.48	0.15	0.27	0.14	0.19
55–64	2.13	0.82	0.18	0.30	0.28	0.16	0.19
65–74	2.61	0.79	0.08	0.31	0.46	0.25	0.19
75+	2.54	0.71	0.13	0.17	0.48	0.29	0.27

Table A5. *US general population health utilities*

Age	Health utility
18–24	0.899
25–34	0.883
35–44	0.851
45–54	0.809
55–64	0.773
65–74	0.752
75+	0.676

Source: Szende *et al.* (2014).

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Table A6. *HALM quantities*

a	s	c	y^n	$w \times l$	c^f	y^f	Φ^{US}	$VSLY^{US}$	VHQ^{US}	Φ^Z	$VSLY^Z$	VHQ^Z	δs	δq
0	1.000	72,603	64,261	17,202	89,806	81,464	0.7228	146,380	172,104	0.7553	149,292	175,344	0.00000	0.00000
1	0.995	74,286	67,840	17,202	91,488	85,042	0.7254	151,411	175,592	0.7568	154,283	178,786	0.00000	0.00000
2	0.994	76,001	70,043	17,202	93,203	87,246	0.7280	155,095	179,147	0.7584	157,926	182,296	0.00000	0.00000
3	0.994	80,617	76,707	17,202	97,819	93,909	0.7344	165,749	188,720	0.7622	168,467	191,743	0.00000	0.00000
4	0.994	83,563	80,067	17,202	100,765	97,270	0.7382	171,659	194,832	0.7645	174,304	197,774	0.00000	0.00000
5	0.994	85,863	84,005	17,202	103,065	101,207	0.7411	177,588	199,605	0.7662	180,175	202,484	0.00000	0.00000
6	0.994	89,066	87,269	17,202	106,268	104,471	0.7449	183,626	206,255	0.7685	186,133	209,044	0.00065	0.00074
7	0.994	92,953	90,224	17,202	110,155	107,426	0.7492	189,952	214,329	0.7710	192,359	217,006	0.00065	0.00074
8	0.993	96,027	92,421	17,202	113,230	109,623	0.7524	194,818	220,717	0.7730	197,145	223,305	0.00065	0.00074
9	0.993	99,483	96,256	17,202	116,686	113,458	0.7558	201,655	227,901	0.7750	203,891	230,387	0.00065	0.00074
10	0.993	106,121	100,754	17,202	123,323	117,956	0.7620	211,926	241,705	0.7787	213,983	243,993	0.00070	0.00074
11	0.993	111,931	105,368	17,202	129,133	122,570	0.7669	221,601	253,798	0.7816	223,499	255,909	0.00070	0.00074
12	0.993	114,003	105,841	17,202	131,205	123,043	0.7685	223,880	258,111	0.7826	225,721	260,159	0.00070	0.00074
13	0.993	117,540	111,768	17,202	134,743	128,971	0.7713	232,894	265,480	0.7842	234,635	267,416	0.00070	0.00074
14	0.993	121,168	121,426	17,202	138,370	138,628	0.7739	245,719	273,038	0.7858	247,357	274,860	0.00070	0.00074
15	0.992	125,147	110,689	17,202	142,350	127,891	0.7767	238,460	281,333	0.7874	239,984	283,028	0.00075	0.00074
16	0.992	130,886	110,526	17,202	148,089	127,728	0.7805	243,317	293,301	0.7897	244,674	294,810	0.00075	0.00074
17	0.992	136,638	120,524	17,202	153,840	137,727	0.7841	258,354	305,303	0.7918	259,540	306,623	0.00075	0.00074
18	0.991	142,506	125,880	17,202	159,709	143,082	0.7875	268,855	317,554	0.7938	269,865	318,678	0.00075	0.00074
19	0.990	150,440	125,763	17,202	167,642	142,966	0.7918	275,705	334,128	0.7964	276,472	334,981	0.00075	0.00076
20	0.990	160,622	125,618	26,718	187,340	152,336	0.7968	301,613	374,435	0.7994	302,086	374,962	0.00080	0.00076
21	0.989	165,570	126,657	26,718	192,288	153,374	0.7991	307,031	384,810	0.8007	307,338	385,152	0.00080	0.00076
22	0.988	164,732	126,725	26,718	191,450	153,443	0.7987	306,357	383,053	0.8005	306,693	383,426	0.00080	0.00076
23	0.987	166,578	127,870	26,718	193,296	154,587	0.7995	309,136	386,923	0.8010	309,409	387,227	0.00080	0.00076
24	0.985	168,730	135,129	26,718	195,448	161,847	0.8005	318,302	391,438	0.8015	318,503	391,662	0.00080	0.00076
25	0.984	174,665	136,491	46,901	221,567	183,393	0.8030	361,313	452,420	0.8030	361,313	452,419	0.00080	0.00076

Table A6. *Continued*

a	s	c	y^n	$w \times l$	c^f	y^f	Φ^{US}	$VSLY^{US}$	VHQ^{US}	Φ^Z	$VSLY^Z$	VHQ^Z	δs	δq
26	0.983	180,638	138,143	46,901	227,540	185,045	0.8054	368,310	465,237	0.8044	368,085	464,983	0.00080	0.00076
27	0.982	178,075	136,637	46,901	224,976	183,539	0.8044	364,510	459,736	0.8038	364,381	459,591	0.00080	0.00076
28	0.980	182,685	140,711	46,901	229,586	187,613	0.8062	372,709	469,628	0.8049	372,407	469,287	0.00080	0.00076
29	0.979	183,950	142,829	46,901	230,852	189,730	0.8067	375,959	472,344	0.8052	375,609	471,949	0.00080	0.00076
30	0.977	182,582	143,786	46,901	229,484	190,688	0.8062	375,692	469,409	0.8049	375,394	469,071	0.00080	0.00076
31	0.976	186,749	151,091	46,901	233,650	197,993	0.8078	386,726	478,351	0.8058	386,271	477,836	0.00080	0.00076
32	0.974	175,130	144,350	46,901	222,032	191,251	0.8032	369,588	453,418	0.8031	369,570	453,398	0.00080	0.00076
33	0.972	171,751	148,697	46,901	218,652	195,599	0.8018	370,912	446,167	0.8023	371,021	446,290	0.00080	0.00076
34	0.970	170,010	153,262	46,901	216,911	200,164	0.8010	373,919	442,431	0.8018	374,093	442,628	0.00080	0.00076
35	0.969	164,525	151,938	58,925	223,451	210,863	0.7986	389,316	472,272	0.8004	389,716	472,742	0.00080	0.00076
36	0.967	169,363	161,914	58,925	228,288	220,839	0.8008	403,644	483,071	0.8017	403,853	483,316	0.00080	0.00076
37	0.965	164,074	155,716	58,925	222,999	214,641	0.7984	392,687	471,264	0.8003	393,106	471,756	0.00080	0.00076
38	0.962	166,917	159,947	58,925	225,842	218,872	0.7997	399,477	477,611	0.8010	399,783	477,971	0.00080	0.00076
39	0.960	175,247	166,828	58,925	234,172	225,753	0.8033	413,852	496,206	0.8032	413,829	496,178	0.00080	0.00076
40	0.958	186,791	177,651	58,925	245,716	236,576	0.8078	435,059	521,973	0.8058	434,579	521,409	0.00080	0.00076
41	0.956	190,254	183,624	58,925	249,179	242,549	0.8091	444,148	529,704	0.8066	443,530	528,979	0.00080	0.00076
42	0.953	181,352	176,064	58,925	240,277	234,989	0.8057	428,580	509,833	0.8046	428,315	509,522	0.00080	0.00076
43	0.950	178,726	174,066	58,925	237,651	232,991	0.8047	424,219	503,971	0.8040	424,058	503,782	0.00080	0.00076
44	0.948	180,123	176,842	58,925	239,048	235,767	0.8052	428,252	507,090	0.8043	428,036	506,836	0.00080	0.00076
45	0.945	184,776	184,803	53,992	238,768	238,794	0.8070	431,484	533,322	0.8054	431,092	532,838	0.00080	0.00076
46	0.942	197,552	200,796	53,992	251,544	254,788	0.8116	458,948	563,293	0.8081	458,060	562,194	0.00080	0.00076
47	0.938	203,017	209,938	53,992	257,009	263,930	0.8135	472,998	576,115	0.8092	471,897	574,753	0.00080	0.00076
48	0.935	205,010	215,834	53,992	259,002	269,825	0.8141	480,683	580,791	0.8096	479,504	579,332	0.00080	0.00076
49	0.931	207,235	223,214	53,992	261,227	277,206	0.8148	490,063	586,013	0.8100	488,796	584,447	0.00080	0.00076
50	0.927	212,495	231,349	53,992	266,487	285,341	0.8165	502,923	598,354	0.8110	501,450	596,533	0.00080	0.00076
51	0.922	217,385	239,905	53,992	271,377	293,897	0.8180	515,873	609,830	0.8118	514,208	607,773	0.00070	0.00076

Table A6. *Continued*

a	s	c	y^n	$w \times l$	c^f	y^f	Φ^{US}	$VSLY^{US}$	VHQ^{US}	Φ^Z	$VSLY^Z$	VHQ^Z	δs	δq
52	0.918	213,457	239,130	53,992	267,449	293,122	0.8168	511,568	600,612	0.8111	510,057	598,745	0.00070	0.00076
53	0.913	215,496	245,873	53,992	269,488	299,865	0.8174	520,142	605,396	0.8115	518,552	603,430	0.00070	0.00076
54	0.907	216,318	250,728	53,992	270,310	304,720	0.8176	525,736	607,325	0.8116	524,113	605,319	0.00070	0.00076
55	0.901	211,799	247,998	56,471	268,271	304,469	0.8163	523,450	630,338	0.8108	521,991	628,450	0.00070	0.00076
56	0.895	212,964	249,654	56,471	269,435	306,125	0.8166	526,153	633,200	0.8110	524,648	631,253	0.00070	0.00076
57	0.888	207,250	240,985	56,471	263,722	297,457	0.8148	512,347	619,162	0.8100	511,068	617,507	0.00070	0.00076
58	0.880	202,367	232,042	56,471	258,839	288,513	0.8133	499,014	607,166	0.8091	497,927	605,760	0.00070	0.00076
59	0.872	197,285	221,911	56,471	253,756	278,383	0.8115	484,315	594,681	0.8080	483,428	593,533	0.00070	0.00076
60	0.864	193,809	214,715	56,471	250,280	271,187	0.8103	473,995	586,143	0.8073	473,244	585,172	0.00070	0.00076
61	0.855	191,919	211,818	56,471	248,390	268,290	0.8097	469,400	581,500	0.8069	468,723	580,625	0.00060	0.00076
62	0.845	188,549	210,133	56,471	245,020	266,605	0.8084	464,686	573,223	0.8062	464,142	572,519	0.00060	0.00076
63	0.834	188,700	221,365	56,471	245,171	277,836	0.8085	476,054	573,595	0.8062	475,504	572,883	0.00060	0.00076
64	0.823	198,613	242,324	56,471	255,084	298,796	0.8120	505,922	597,944	0.8083	504,983	596,729	0.00060	0.00076
65	0.812	147,858	188,422	55,930	203,788	244,351	0.7904	405,434	485,201	0.7956	406,480	486,591	0.00060	0.00076
66	0.800	146,981	195,443	55,930	202,911	251,373	0.7900	411,667	482,985	0.7953	412,746	484,421	0.00060	0.00070
67	0.787	144,031	192,170	55,930	199,960	248,099	0.7884	405,741	475,535	0.7943	406,936	477,124	0.00060	0.00070
68	0.774	147,961	195,050	55,930	203,891	250,979	0.7905	412,154	485,459	0.7956	413,196	486,844	0.00060	0.00070
69	0.760	129,248	166,758	55,930	185,178	222,688	0.7795	367,030	438,191	0.7891	368,806	440,553	0.00050	0.00070
70	0.745	118,016	146,952	55,930	173,946	202,881	0.7716	337,104	409,798	0.7844	339,326	412,753	0.00050	0.00070
71	0.729	111,224	133,588	55,930	167,154	189,518	0.7663	317,610	392,615	0.7812	320,106	395,933	0.00050	0.00070
72	0.712	104,002	119,616	55,930	159,932	175,545	0.7601	297,108	374,328	0.7775	299,898	378,038	0.00050	0.00070
73	0.695	98,672	108,353	55,930	154,602	164,283	0.7551	281,016	360,818	0.7745	284,027	364,823	0.00040	0.00070
74	0.676	89,856	95,436	55,930	145,785	151,366	0.7458	260,087	338,440	0.7690	263,473	342,943	0.00040	0.00070
75	0.656	84,719	87,308	54,737	139,457	142,045	0.7397	245,199	358,892	0.7654	248,779	364,188	0.00040	0.00070
76	0.634	79,860	81,424	54,737	134,597	136,161	0.7334	234,875	345,135	0.7616	238,670	350,749	0.00040	0.00070
77	0.611	70,469	72,847	54,737	125,206	127,584	0.7194	217,662	318,467	0.7532	221,893	324,726	0.00040	0.00070

Table A6. *Continued*

a	s	c	y^n	$w \times l$	c^f	y^f	Φ^{US}	$VSLY^{US}$	VHQ^{US}	Φ^Z	$VSLY^Z$	VHQ^Z	δs	δq
78	0.587	66,932	69,913	54,737	121,669	124,650	0.7134	211,451	308,389	0.7496	215,856	314,905	0.00030	0.00070
79	0.561	63,118	66,607	54,737	117,855	121,344	0.7064	204,593	297,491	0.7454	209,191	304,294	0.00030	0.00070
80	0.533	59,675	63,924	54,737	114,412	118,661	0.6994	198,684	287,626	0.7412	203,465	294,699	0.00030	0.00070
81	0.505	57,380	61,462	54,737	112,117	116,200	0.6945	194,061	281,033	0.7382	198,968	288,292	0.00020	0.00073
82	0.475	52,484	55,092	54,737	107,221	109,829	0.6828	183,037	266,907	0.7312	188,228	274,587	0.00020	0.00073
83	0.443	50,276	51,143	54,737	105,013	105,880	0.6769	176,968	260,504	0.7277	182,296	268,386	0.00020	0.00073
84	0.411	47,235	45,863	54,737	101,972	100,600	0.6682	168,743	251,649	0.7224	174,268	259,822	0.00010	0.00073
85	0.377	43,483	39,781	54,737	98,220	94,518	0.6563	158,977	240,650	0.7152	164,765	249,211	0.00010	0.00073
86	0.342	40,491	34,955	54,737	95,228	89,692	0.6455	151,166	231,807	0.7087	157,181	240,705	0.00010	0.00073
87	0.308	36,343	29,924	54,737	91,080	84,661	0.6285	141,906	219,417	0.6984	148,271	228,832	0.00010	0.00073
88	0.273	31,709	25,334	54,737	86,446	80,071	0.6056	132,424	205,325	0.6845	139,243	215,411	0.00010	0.00073
89	0.238	27,693	21,714	54,737	82,430	76,451	0.5812	124,363	192,813	0.6697	131,652	203,595	0.00010	0.00073
90	0.204	99,788	76,769	54,737	154,525	131,507	0.7561	248,349	401,431	0.7752	251,292	405,784	0.00010	0.00073
91	0.172	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
92	0.142	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
93	0.114	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
94	0.090	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
95	0.069	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
96	0.051	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
97	0.037	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
98	0.026	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073
99	0.017	99,788	71,538	54,737	154,525	126,275	0.7561	243,118	401,431	0.7752	246,060	405,784	0.00000	0.00073