

Behavioral Longevity: The impact of smoking, alcohol consumption, and obesity on life expectancy

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SUMMARY

This paper attempts to contribute to our understanding of human longevity by focusing on the impact of our daily life on longevity. In analyzing cross-sectional data from 174 countries in 2015 that are publicly available, e.g., from the World Health Organization, we assumed a simple linear relationship between life expectancy and behavioral factors when other factors, e.g., medical and environmental factors, are held constant. We estimated the parameter values of the behavioral factors in the equation by representing the relationships using ordinary least squares. With the approximately 89% explanatory power in the variation of longevity in the sample of 174 countries, we conclude that an average person's life expectancy in those 174 countries can increase by more than 3 years if smoking and alcohol consumption is reduced by a half and weight is decreased by 10%.

INTRODUCTION

The human life span has extended over the past decades. According to the World Health Organization (WHO), the average life expectancy at birth has increased from 52.5 years in 1960 to 71.7 years in 2015 (1) (Figure 1).

As life expectancy has extended, the topic of any influencing factors in longevity has featured prominently in research, both for medical, commercial, and public reasons. Research in academia has focused on individual longevity, e.g., why some individuals live longer than others, and on average life expectancy, e.g., what factors contribute to the mean life expectancy of a population (2-4). For individual longevity, a recent National Institute on Aging study identified a broad range of social, behavioral, genetic, and environmental factors that can affect the risk of mortality among older adults (5). Among those factors, it is notable that approximately 15–25% of the overall variation in human longevity can be explained by genetic differences. It is also worth noting that long-lived individuals have fewer chronic diseases, better mental health, and better physical and cognitive function than short-lived members of their age cohort. For the mean longevity of a population, in addition to the factors identified for longer life spans, social and behavioral factors have been emphasized as crucial to the average level of longevity in a given population.

On genetic factors, studies have produced little consensus on the “maximum” achievable lifespan of an individual. The

traditional view held by the scientific community is that the maximum life span has not increased, despite the fact that the average life span has been on the rise for the last several decades. The ideal average life span is approximately 85 years, and the changes in lifestyle that can postpone chronic illness can modify the physiological and psychological markers of aging, causing the morbidity curve to become more rectangular (6). That is, the percentage of the survived in the cohort population decreases slowly for most of the life span, and then drops drastically once it hits a certain point closer to the average life span. On the contrary, other studies have disputed the traditional view, arguing that “maximum” life expectancies can be raised in the future through advances in biomedical research, as well as the reduction of age-related risk factors. It is possible to have a life expectancy of 95 to 100 years with a standard deviation of about 10 years (7). In fact, this view has already been seen in practice in animal research; one study reported that a single mutation in the nematode *Caenorhabditis elegans* genome doubled life span (8).

Several studies that focused on both medical and environmental factors have discussed how life expectancy has increased over time due to different reasons. Most of the gain in life expectancy before 1950 was due to reductions in infant, child, and early adult mortality as a result of improved standards of living, better public health standards, and the

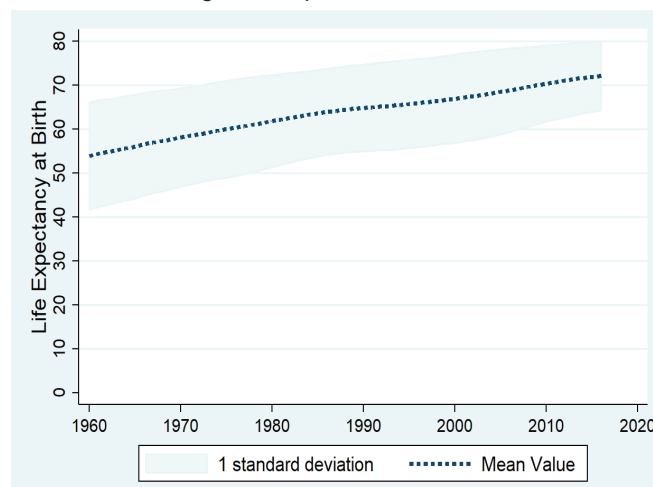


Figure 1: Time trend of life expectancy at birth from 1960 to 2016. The dotted line denotes the mean value of life expectancies of the countries in the world. The shaded area shows one standard deviation of the life expectancies.

advancement of medicine, while the increase in life expectancy since 1950 has largely been due to reductions in mortality at older ages (2, 9). In particular, the role of medical factors in mortality is well documented in comparative studies of several high-income countries (4). In addition to medical factors, average income levels (GDP per capita) and educational environment (e.g., rate of literacy) are closely related to the increase in life expectancy in developing countries (10).

On social and behavioral factors, several studies have identified that individual behavior in smoking, drinking alcohol, and eating also affects longevity. First, the harms of smoking have been near universally acknowledged by many authorities, like the Center for Disease Control and Prevention (11), the Royal College of Physicians (12), and the International Agency for Research on Cancer (13). It was speculated as early as 1938 that smoking was associated with a shortening of duration of life and that the degree of this decrease increased as the amount of smoking increased, although tobacco was not supposed to further harm those who had survived to 70 or more (14). A 2014 report from the U.S. Surgeon General concluded that more than 20 million premature deaths can be attributed to smoking (15). Life expectancy among smokers is much shorter than life expectancy among those who never smoke (16). Even among centenarians, smoking is still incompatible with successfully attaining long life (17). And even those who quit smoking in old age, like 65 years of age, can gain 1.4 to 3.7 years in life (18).

Second, unlike smoking cigarettes, alcohol has been recognized as having a U-shaped or J-shaped relation to mortality (19). That is, mortality rate decreases as alcohol consumption increases from zero (i.e., abstinence) to

Variable	Description (Unit)	Mean	Std. Dev	Min	Max
Longevity	Life Expectancy (Years)	71.2	8.4	48.9	83.7
Smoking	No. of cigarettes per person per day	18.2	12.2	1	108.9
Alcohol	Liters of pure alcohol per capita per year	6.2	4.1	0.1	17.4
BMI	Body Mass Index (Kg/m ²)	25.63	2.23	20.50	32.90
Overweight	Prevalence of Overweight and obese (% of adults)	47.12	16.08	17.70	78.30
Disease	Cause of Death by Communicable Disease (% of death)	22.3	19.9	1.4	65.6
Injury	Cause of Death by Injury (% of death)	9.0	4.1	2.7	29.3
HDI	Human Development Index (between 0 and 1)	0.698	0.155	0.352	0.949

Table 1: Summarized Statistics of Data. Data Sources: Longevity, BMI, Overweight, Disease, and Injury are from the World Health Organization, Smoking and Alcohol are from the Our World in Data, and HDI is from the United Nations Development Program.

moderate drinking, and then it increases to a higher level as alcohol consumption increases further to heavy drinking. Various health benefits and risks (i.e., cardiovascular or blood pressure, etc.) have been discussed for the relationship between alcohol consumption and longevity (20- 22).

Third, it is now quite well known that obesity causes adverse impacts on health, like diabetes, heart disease, high blood pressure, and some cancers, and thus reduces life expectancy (4). The negative effects of an increase in body mass index (BMI) would overwhelm the positive effects of a decline in smoking, and it is predicted that obesity would shorten life expectancy by 0.71 years between 2005 and 2020 (23) The world-wide phenomenon of an increase in obesity is traced to advancements in technology and an increasingly sedentary lifestyle that have lowered the real price of food as well as the physical expenditure of calories per hour worked, both in market and household production (24).

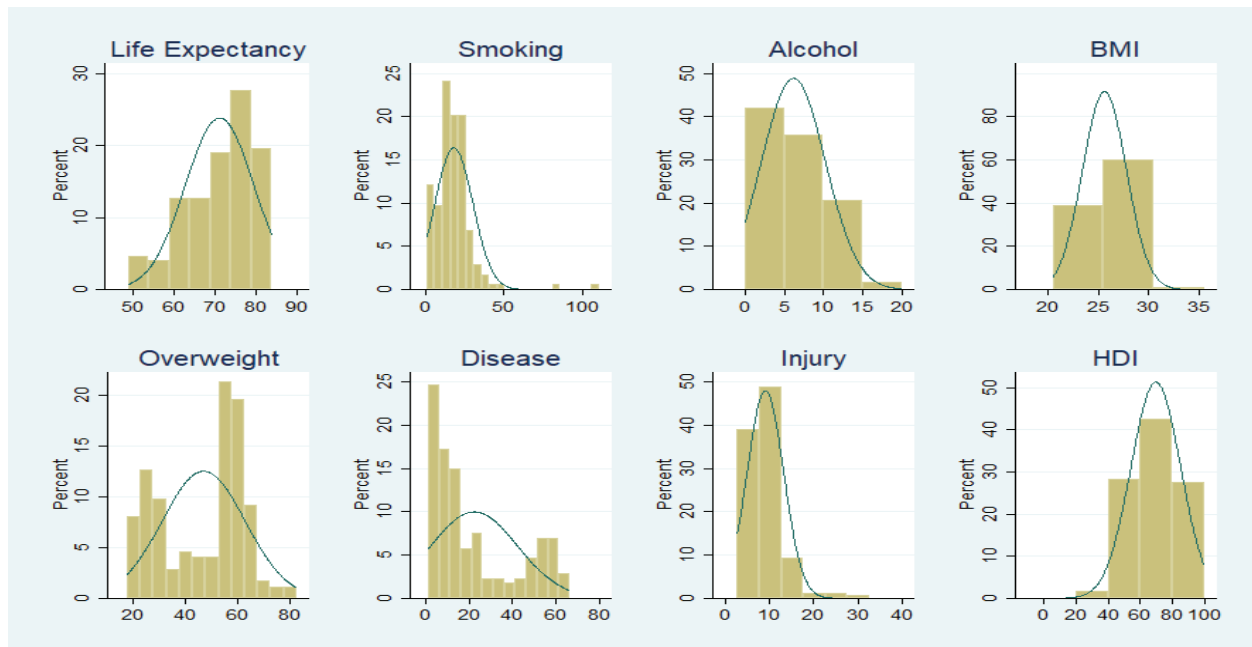


Figure 2: Histograms of data. Histogram shows how a variable is distributed. Bar in each panel indicates what percentage of the countries are clustered in the range of each variable. Line in each panel indicates the normal distribution of each variable.

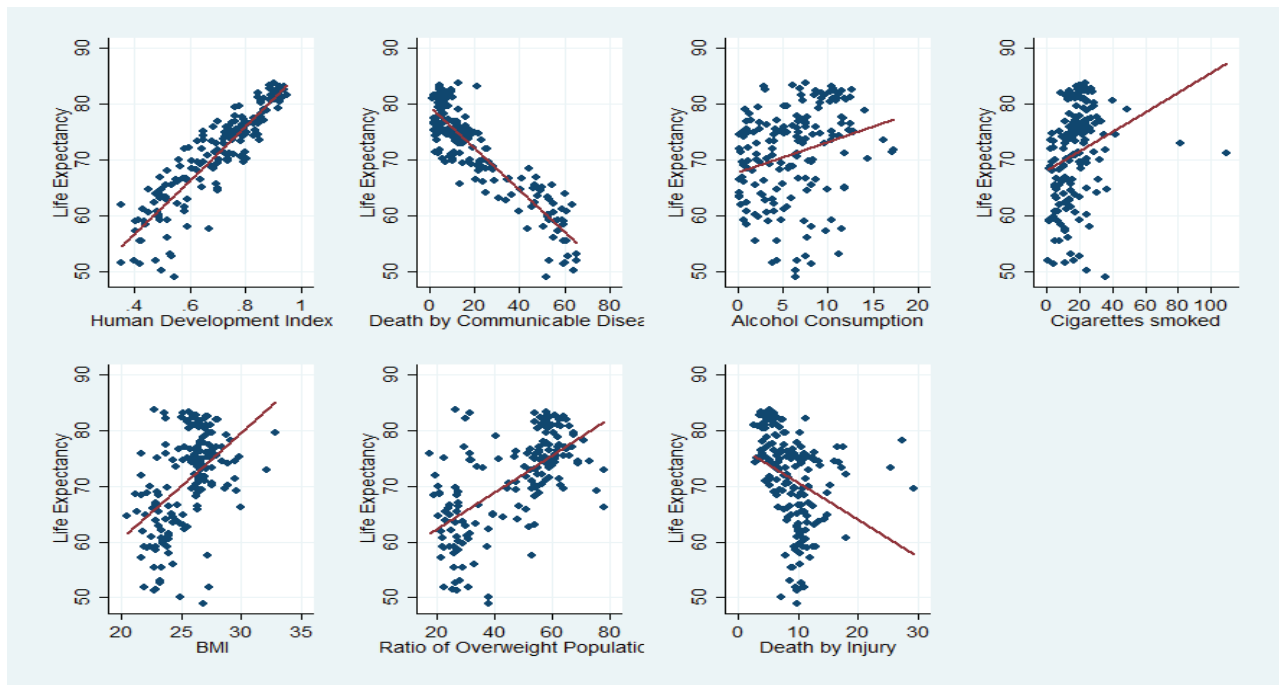


Figure 3: Relationship between life expectancy and contributing factors. Each panel shows how life expectancy and a factor is correlated. The line in each panel shows the linear trend line.

Due to the volume of existing research on longevity, it is important to summarize what is already known about the factors of longevity and determine the importance of behavioral factors on longevity. People eat and drink. Some smoke cigarettes, among other risk factors. However, it is hypothesized that obesity, alcohol consumption, and cigarettes are harmful to longevity. From this hypothesis, this paper will attempt to quantify the consequences of our daily behaviors on longevity. By quantifying any impacts, inferences can be made regarding the relationship between longevity and the behavioral variables of interest, such as alcohol consumption, obesity, and cigarette smoking.

RESULTS

Following the literature review on the behavioral determinants of longevity, we chose 3 behavioral factors, i.e., alcohol consumption, smoking cigarettes, and obesity, and collected data on the factors as well as other variables, i.e., life expectancy, death by disease, death by injury, and the Human Development Index (HDI). The data, collected from 3 different sources (WHO, United Nations Development Program, and Our World in Data), were combined in a way that a country with any missing observations is dropped from our analysis. These data cover 174 countries in 2015 (Table 1). As of 2015, the average life expectancy of 174 countries (the mean of Longevity) is 71.2 years, and the world population deviates, on average, 8.4 years from the mean and skewed to the left as more countries clustered on the right side of the mean value (Figure 2). The table also shows that an adult smokes 18.2 cigarettes a day (slightly less than one pack of cigarettes a day) and drinks 6.2 liters of alcohol a year (approximately one bottle of beer a day), although

there is a huge variation among countries. For obesity, it is somewhat striking that the global average BMI is 25.63 kg/m², which is outside normal range (18.5–25.0 kg/m²), and falls into the category of overweight, and that almost one half of the entire adult population (47.12%) is either overweight or obese. In some countries, most notably Kiribati and Tonga, this ratio even approaches 80% (Figure 3).

For the variables whose effects on longevity must be separated, 22.3% and 9.0% of all deaths are caused by communicable diseases and injuries, respectively. The average HDI is 0.698, which means that the world, on average, achieves 69.8% of the arbitrarily defined level of standard living.

We then analyzed how the behavioral factors are correlated to each other. It turns out that the correlation coefficients, measuring the degree of correlation between variables, range 0.135~0.318 that are statistically significant at the level of 0.05 except the correlation between Alcohol and BMI (Table 2). The correlation between Alcohol and BMI

	<i>Smoking</i>	<i>Alcohol</i>	<i>BMI</i>	<i>Overweight</i>
<i>Smoking</i>	1.000			
<i>Alcohol</i>	0.1791 (0.018)	1.000		
<i>BMI</i>	0.3178 (0.000)	0.135 (0.076)	1.000	
<i>Overweight</i>	0.3060 (0.000)	0.2279 (0.003)	0.8647 (0.000)	1.000

Table 2: Correlation coefficient (ρ) and p-values for the test: the null hypothesis (ρ=0) vs. the alternative hypothesis (ρ≠0). Bold numbers represent the correlation coefficients that are statistically significant at 0.05, meaning that zero correlation is as unlikely as less than the probability of 0.05.

	Specification A		Specification B	
	Coefficient	(p-value)	Coefficient	(p-value)
Smoking	-0.038	(0.032)	-0.046	(0.027)
Alcohol	-0.279	(0.000)	-0.262	(0.000)
Overweight			-0.059	(0.001)
BMI	-0.568	(0.000)		
Disease	-0.206	(0.000)	-0.201	(0.000)
Injury	0.029	(0.559)	0.014	(0.787)
HDI	34.645	(0.000)	37.753	(0.000)
R^2	0.891		0.885	
Adjusted R^2	0.888		0.881	

Table 3: Results of estimating the relation between life expectancy (dependent variable) and contributing factors (independent variables). () denotes p -values. The difference of Specifications A and B is what variable is used for obesity. Specification A has BMI for obesity and Specification B has Overweight for obesity.

is statistically significant only at the level of 0.1. The degrees of the correlation are weak, but positive. Thus, we can say that a country in higher consumption in smoking tends to show more consumption in alcohol and to a higher level of obesity.

The estimated results for the relationship between longevity and several other factors are shown in **Table 3**. The results, based upon the ordinary least squares method that estimates the parameters of the variables in a way to minimize the squares of the estimation errors, explain 88.5% (for the model called Specification B where Overweight is included for obesity) or 89.1% (for the model called Specification A where BMI is included for obesity) of the variation in Longevity, as given by the R^2 value. This means that 10.9% or 11.5% of the variation in Longevity is not explained by the factors that are used in the estimation. The unexplained portion in the variation of longevity may be due to genetic factors or something else that is not in the estimation. The adjusted R^2 , when the numbers of explanatory variables and observations are considered, merely budged and thus provides the similar explanation.

	Developed Economies 50 countries		Developing Economies 97 countries		Undeveloped Economies 27 countries	
Smoking	0.016 (0.660)	0.012 (0.757)	-0.041 (0.059)	-0.044 (0.046)	0.078 (0.354)	0.081 (0.355)
Alcohol	-0.044 (0.647)	-0.022 (0.832)	-0.318 (0.000)	-0.316 (0.000)	-0.362 (0.087)	-0.275 (0.194)
BMI	-0.477 (0.046)		-0.329 (0.031)		-1.178 (0.072)	
Overweight		0.011 (0.754)		-0.046 (0.055)		-0.140 (0.159)
Disease	0.053 (0.527)	0.117 (0.240)	-0.251 (0.000)	-0.253 (0.000)	-0.189 (0.070)	-0.218 (0.048)
Injury	-0.039 (0.607)	-0.084 (0.295)	0.131 (0.079)	0.129 (0.086)	-0.235 (0.565)	-0.321 (0.454)
HDI	53.193 (0.000)	57.022 (0.000)	29.836 (0.000)	30.318 (0.000)	45.785 (0.011)	40.767 (0.023)
R^2	0.716	0.689	0.841	0.839	0.675	0.654
Adjusted R^2	0.676	0.645	0.830	0.828	0.578	0.550

Table 4: Empirical Results by different groups. () denotes p -values. Note: the sample of 174 countries is divided into 3 groups (developed, developing, and undeveloped economies) based upon the classification of the World Bank.

For the parameter values, the p -values of all variables except Injury, which indicate the probability that the null hypothesis that the parameter is zero, are low. That is, the p -values of Alcohol, BMI (or Overweight), Diseases, HDI are less than 0.01 while the p -value of Smoking is 0.027~0.032 that is marginally significant. Thus these parameter values can be used to explain the impact on longevity.

For the variables that are controlled to separate the impact of behavioral factors on longevity, a reduction in the deaths by communicable disease (Disease) is sure to increase life expectancy (that is, an 0.2-year increase in life expectancy by lowering the deaths by communicable disease by 1%), while it is unclear that altering the parameter value for death by injury (Injury) would affect longevity. Any improvement in our standard of living (denoted by HDI) also increases life expectancy, as expected.

To see if the above results are robust to social and environmental factors, we divided the whole sample (174 countries) into 3 groups (developed, developing, and undeveloped economies) based upon the country classification of the World Bank (25) among other classifications such as the United Nations Development Program and the International Monetary Fund. The difference in the classification hinges on the definition of development (26). There are 50 countries in the developed economies, 97 countries in developing economies, and 27 countries in undeveloped economies in our data sample. Then, the same estimation method is employed to show the results in the **Table 4**.

Table 4 shows that the significance of behavioral factors to longevity is robust to the developing economies and resembles that in the sample of 174 countries. That is, Smoking, Alcohol, and BMI (and Overweight) all decrease life expectancy in a similar fashion. However, the significance of behavioral factors to longevity weakens in the developed and undeveloped economies. Of these factors, only BMI is significant to longevity in developed economies, while Alcohol and BMI are significant to longevity in the undeveloped economies. A weaker significance of behavioral factors is coupled with a weaker explanatory power of the estimation. The overall explanatory power of the estimation, denoted by R^2 , is 65.4% or 84.1%, which is lower than R^2 in the whole sample, when smaller observations are used for estimation. On the contrary, HDI, which gives the standard of living, is significant for all 3 groups, indicating that any improvement in the standard of living is essential to longer life expectancy. Similarly, a decrease in the death by communicable (Disease) is also important to longer life expectancy in both developing and undeveloped economies.

DISCUSSION

Decades of research have shown that human longevity is a complicated result of many different influences, including medical, genetic, environmental, social, and behavioral factors. Here, we focused on behavioral factors such as

smoking cigarettes, alcohol consumption, and obesity to investigate how these factors affect life expectancy and to what extent. By using cross-sectional data from 174 countries in 2015, a simple linear relationship between life expectancy and behavioral factors was assumed when other factors, like medical and environmental factors, were separated.

First, a decrease of one cigarette in daily smoking increases life expectancy by an estimated 0.038 or 0.046 years. Simply speaking, if a person smokes only one half of what he or she currently smokes, the person could live 0.35 or 0.42 years (4.2 or 5.0 months) longer. Second, a reduction of one liter of alcohol in yearly alcohol consumption increases life expectancy by 0.262 or 0.279 years. If a person skips a bottle of beer every other day, the person could live 1.09 or 1.30 years (13 or 15.6 months) longer. Third, a decrease in body weight also leads to longer life spans: a decline in one unit of BMI could extend life spans by 0.568 years. If a person is 175 cm tall, the person could live 6.8 months longer by simply losing 3 kg in weight. If the same person (175 cm tall) loses 10% of his or her weight, that person could live 17.5 months longer. Similarly, the life expectancy of a country could increase by 0.95 years (11.3 months) if a country's ratio of overweight or obese residents declines by its standard deviation (16.1%). In summary, the estimation results predict that life expectancy can increase by more than 3 years if behaviors in smoking cigarettes, drinking alcohol, and eating too much are changed.

Although this study clearly shows the importance of human behavior on longevity, it must be acknowledged that there may be many more factors affecting longevity, such as peace of mind, regular exercise, etc., as human life is very complex and the nature of life is still not completely known. As evidenced in the subsequent estimation by different groups of economies, the significance of behavioral factors diminishes in developed countries and undeveloped countries and the explanatory power of the estimation weakens as a smaller number of countries is analyzed. This empirical evidence humbles our understanding of human life. In this respect, we suggest that the results on the magnitude of behavior's impact be interpreted in a relative sense, not in an absolute sense.

Our study on longevity emphasizes the importance of our daily life in longevity. A change in our daily life in order to smoke fewer cigarettes, drink less alcohol, and prevent obesity does not only extend our life span, but it also reduces a cost of individual and public burden of healthcare. For this reason, any public policies or initiatives discouraging drinking and smoking and preventing obesity should be encouraged. Potential policy interventions might include restricting the marketing of alcohol or tobacco products, mandating simple and informative nutritional labelling on all food products, increasing taxes on tobacco and alcohol products, and launching a public initiative to encourage daily physical exercise.

METHODS

A main goal of this study was to quantify the extent to which behavioral factors, on average, influence longevity. For this purpose, simple linear relations between life expectancy (representing longevity) and each factor is assumed:

$$\text{Longevity} = b_0 + b_1 \times \text{Factor}_1 + \dots + b_n \times \text{Factor}_n + e \quad (1)$$

where $b_0 \dots b_n$ are the parameters (n is the number of the factors), and e represents any errors that cannot be attributed to the factors affecting longevity. By assuming a linear relation, the magnitude of the behavioral factors on longevity can be represented by the values of the parameters in the above equation. While the factors affecting longevity are identified by the real data, the value of the parameters must be estimated. One method to scientifically guess the value is to estimate the parameters in a way that minimizes any errors.

For this purpose, an ordinary least squares method was used to find the value of parameters (b_0, \dots, b_n) in a way that minimized the squares of e that represents any errors where

$$e = \text{Longevity} - b_0 - b_1 \times \text{Factor}_1 - \dots - b_n \times \text{Factor}_n \quad (2)$$

For example, the value of e^2 is calculated by inserting some arbitrary values, e.g., $b_0 = 1, \dots, b_3 = 1$, given the data on the factors. A scientific guess would be to choose the parameter values to minimize the value of e^2 among many other values of e^2 that are calculated from the different values of parameters.

To use this ordinary least squares method, the factors affecting longevity must be identified. It is known, from the literature review as explained in the Introduction of this paper, that human longevity is affected by factors such as genetic, social and behavioral, medical, and environmental factors. Behavioral factors that are related to our daily life, in particular, are of interest: obesity, tobacco use, and alcohol consumption. Data on smoking cigarettes and tobacco products (a.k.a. Smoking) and drinking alcohol (a.k.a. Alcohol) were obtained from an organization, Our World in Data (<https://ourworldindata.org>), which compiles various data such as population, health, food, energy, etc. Smoking and Alcohol were retrieved from the menu, research by topic, health, in its website. Smoking shows the number of cigarettes and other tobacco products per person per day, and Alcohol shows the average amount (liters) of pure alcohol per person over a year. For obesity data that were collected from the Global Health Observatory data at WHO (<http://apps.who.int/gho/data/node.imr>), two different data are used; BMI and Overweight. BMI indicates an average body mass index of a population; body mass index is calculated from a person's weight in kilograms divided by the square of the person's height in meters (kg/m^2). Overweight indicates the percentage of adults who are either overweight or obese. A person with a BMI equal to or more than 25 is considered overweight, and a person with a BMI of 30 or more is considered obese.

The linear equation, shown above in (1), can be better explained when the impact of other factors on longevity, such as medical and environmental, are separated from the impact of behavioral factors on longevity. For this purpose, the following factors are included in the equation: death by communicable disease, death by injury, and standard of living.

The factors of death by communicable disease (or Disease) and death by injury (or Injury) are collected from the Global Health Observatory data at WHO. Disease represents the percentage of all deaths by communicable diseases, while Injury represents the percentage of deaths by injury. The standard of living is represented by the HDI is obtained from the United Nations Development Program (hdr.undp.org/en/data), which includes the Gross National Income per capita (representing income) and years of schooling (representing education), among other factors.

In the equation above, Longevity is the dependent variable. Life expectancy at birth, which was chosen to be a proxy for Longevity, is also collected from the Global Health Observatory data at WHO. It indicates the predicted average number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.

Given this information, the following equation is estimated by the ordinary least squares:

$$\begin{aligned} \text{Longevity} = & b_0 + b_1 \times \text{Smoking} + b_2 \times \text{Alcohol} + b_3 \\ & \times \text{BMI (or Overweight)} + b_4 \times \text{Disease} + b_5 \times \text{Injury} \\ & + b_6 \times \text{HDI} + e \end{aligned} \quad (3)$$

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