CHAPTER 5

Health capital

Kenneth Arrow, Partha Dasgupta, and Kevin Mumford

KEY MESSAGES

Health is an essential characteristic of human well-being.

Health capital is an important part of inclusive wealth.

The economic model of health capital presented in this chapter allows health to affect human well-being through three distinct channels: direct well-being, productivity, and longevity.

Most health capital services influence human well-being directly rather than through the production of goods and services that are counted in GDP.

In the absence of better estimates of the direct and productivity effects, gains in life expectancy should be used as the primary measure of health capital.

Annual gains in health capital in the U.S. are worth approximately US$10,000 per person.

1. Introduction

Attempting to measure human well-being without considering health would be a great oversight. Health is central to our happiness. Health affects our enjoyment of life, our productivity in employment, and our risk of death. Our desire for good health influences our decisions regarding eating, sleeping, exercising, and our demand for medical services. As shown in Table 1, total spending on medical care from both public and private source makes up an important and generally increasing share of national income in many countries.

The improvement in life expectancy at birth has been quite dramatic in most countries over the past 60 years (see Figure 1). Several studies, including Nordhaus (2005), Becker et al. (2005), Murphy and Topel (2006), and Jones and Klenow (2011), have shown that recent gains in life expectancy have been at least as important to human welfare as gains in income. The Inclusive Wealth Report 2012 treated health as a form of wealth by estimating the value of the improvement in life expectancy over a nineteen-year period. However, health capital was treated separately from other forms of capital because it was found that even modest gains in life expectancy outweighed other gains. Though understandable, this is not a theoretically-sound reason to exclude health capital from an inclusive measure of national wealth.

TABLE 1

Total health expenditure (percentage of GDP)

Country	1995	2000	2005	2010
Brazil	6.7	7.2	8.2	9.0
China	3.5	4.6	4.7	5.0
Germany	10.1	10.4	10.8	11.5
India	4.0	4.3	4.2	3.7
United States	13.6	13.6	15.8	17.7

Source: The World Bank (2013), World Development Indicators

2. Health as a capital asset

Health is a multidimensional concept. There is no single standard way to measure the health of an individual or a population group. A physician may examine a patient and measure health along several dimensions including mental health, severity of illnesses, nutrition, body mass index (BMI), risk of disease, and level of pain or discomfort. An individual may track exercise and eating behavior or rate his or her own subjective health along a scale of overall fitness. For a population group, a researcher may use life expectancy, infant mortality rate, availability of healthcare services, or prevalence of preventable diseases as indicators of the health of the group. Our term, health capital, refers to a satisfactory measure of the overall health of an individual or a population. It may be a single all-encompassing measure or perhaps a weighted combination of the health measures described above.

The question of whether it is appropriate to treat health as a capital asset it important. Doubts about treating health as a form of capital arise when one compares health to other forms of capital and notes the obvious differences. Economists generally describe capital as an input into a production function. We think of manufactured capital assets such as machines, equipment, buildings, roads, and ports that are used in the production of goods and services. Manufactured capital assets have value that is equivalent to their future marginal productivity. The productive services can be rented or the capital asset itself can be sold to another individual without destroying its value. Unlike inputs that are consumed as part of the production process, manufactured capital can be employed in the production process multiple times. Manufactured capital may depreciate over time, but it is not consumed in the production of goods and services. To summarize, economists generally think of a manufactured capital asset as (1) a durable object that could be sold to someone else, (2) an input in the production of goods and services, and (3) a store of value to achieve consumption.

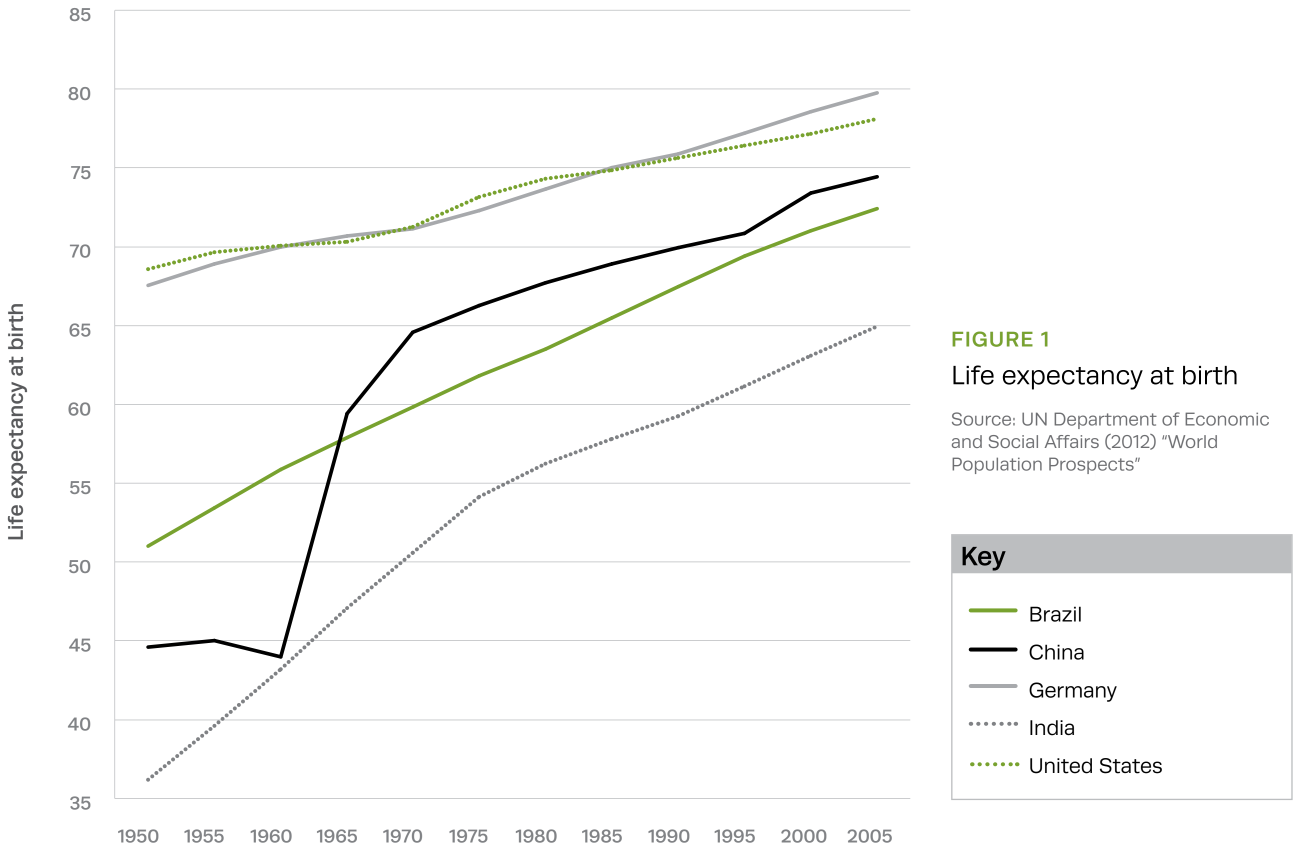


FIGURE 1

Life expectancy at birth

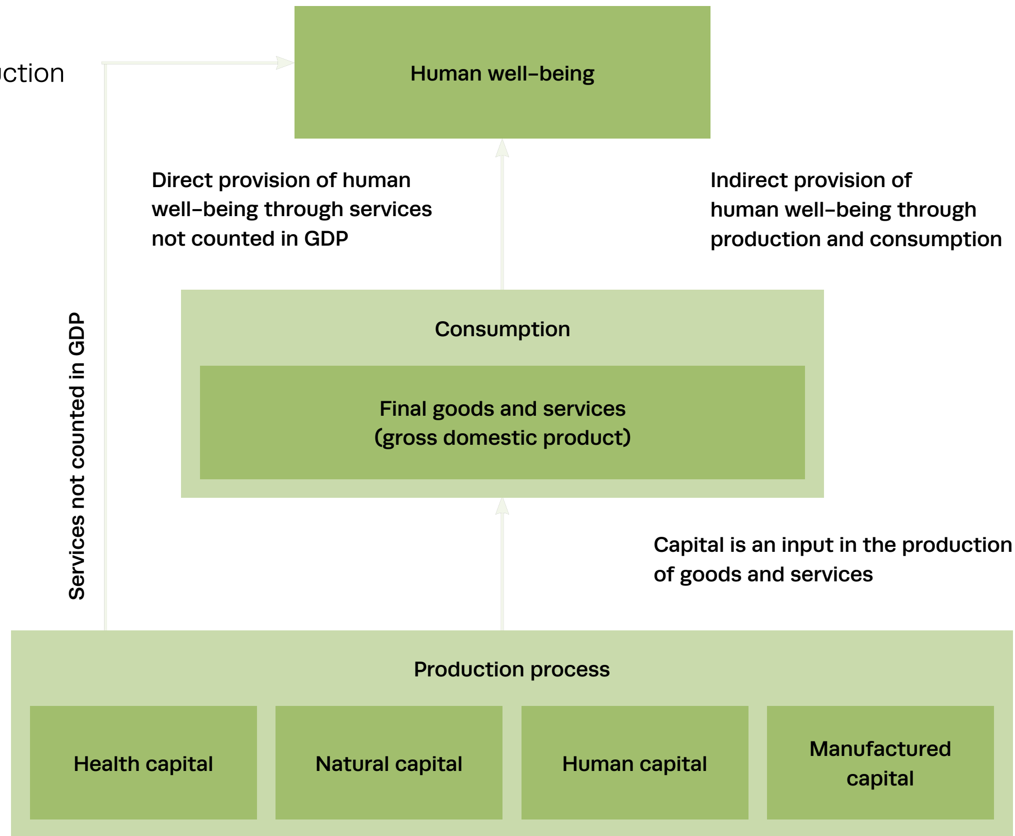
Source: UN Department of Economic and Social Affairs (2012) "World Population Prospects"

Like manufactured capital, health is durable. A person's health is relatively constant over time. Health depreciates, but it is not consumed as it provides current well-being. At times, health may depreciate rapidly due to some illness, similar to the risk of some catastrophe reducing the value of a manufactured capital asset. Unlike a manufactured capital asset, health capital cannot be directly purchased from a health-rich person. One cannot rent the well-being services that flow from health nor can one sell health to another individual. However, the ability to transfer a capital asset to another individual does not seem to be an essential characteristic of capital. The knowledge, skills, and abilities that make up what is commonly called "human capital" cannot be directly transferred from one person to another and this does not cause economists to question if human capital can be considered a capital asset.

Health is not commonly thought of as an input in the production of final goods and services. The evidence suggests that improvements in health do lead to productivity gains, particularly in low-income countries (Bhargava et al. 2001). The estimates suggest that large increases in health cause only small increases in GDP growth rates and there is little evidence for productivity gains from health in developed countries. However, health does provide health services – greater enjoyment of current consumption and longer life – directly to the individual. That these health services are not part of measured gross domestic product does not mean that they have no value. To the contrary, health is of great value to humans and is an essential characteristic of well-being. Our view is that health capital is similar to consumer durables (e.g., houses, consumer electronics, furniture, home appliances, and sports equipment) that provide well-being to consumers, but are

FIGURE 2

Use of capital in production



not generally direct inputs in the production of a final good or service that is counted as part of gross domestic product.

Figure 2 illustrates the point that capital assets can both directly and indirectly (through the production process) affect human well-being. Machines and business equipment primarily increase human well-being through the production process. Forests have both a direct influence on human well-being through ecological and recreational services as well as an indirect influence through the consumption of final goods for which timber is an input. Similarly, health capital has a direct influence on human well-being as well as an indirect affect through increased productivity. That health increases human well-being primarily through a direct channel rather than through the indirect production/consumption channel does not raise any concerns about its treatment as a capital asset.

To summarize, health is (1) durable and nontransferable, (2) both an input in the production of goods and services and the source of a flow of services which increase human well-being, and (3) a store of value to achieve the consumption of health services. Services from capital assets, which are not counted as part of GDP, including health services, have value. Therefore, the value of the capital asset itself is equal to the present discounted value of the future services. From the point of view of an economist, health is a form of capital. This chapter seeks to measure the stock of health capital, estimate its value, and measure the value of the change in health capital for several countries over a period of five years.

3. The value of health capital

We begin with a stylized model to illustrate the role of health capital in providing human well-being. We propose a rather simple two-period model as it is sufficient for providing general intuition about how to measure and value health capital. The model is an expanded version of the Arrow et al. (2013) model. We assume that the economic agent is alive in period 1 with certainty, but there is uncertainty about being alive in period 2. The agent's expected lifetime utility is given by

EQUATION 1

$$\text{Expected Lifetime Utility} = U(H, c_1) + \pi(H)\, U(H, c_2)$$

where H is health capital, c_1 is consumption in period 1, c_2 is consumption in period 2, and $\pi(H)$ is the probability of survival to the second period. We assume that the probability of survival depends on the amount of health capital where more health increases the probability of being alive in period 2, though diminishing returns imply that each additional unit of health capital has less of a positive effect on the probability of survival. The current utility (felicity) depends both on the level of health capital and the amount of consumption. There are diminishing marginal returns to both health capital and consumption. The utility function is the same in both periods and for simplicity we assume that the agent does not discount the future, though this could easily be relaxed.

The agent is endowed with financial wealth given by $W(H)$. We assume that an increase in health causes an increase in the agent's wealth. The mechanism we have in mind is that a healthier agent is more productive and earns higher wages. Alternatively, we could assume that a healthier agent is able to work more hours and thus has a higher income. However, to keep the model focused on health, we abstract from the labor-leisure decision and simply assume that the agent is directly endowed with wealth. Making wealth a function of health capital embeds the productive impacts of health in a straight-forward way. By assumption, there are diminishing returns to additional health capital. The increase in the agent's wealth caused by an additional unit of health capital is much smaller for a healthy agent than for a malnourished one.

The agent's lifetime budget constraint is given by

EQUATION 2

$$c_1 + pc_2 + h \leq W(H)$$

where wealth can be spent on either consumption in period 1, consumption in period 2, or investing in health. In our notation, an investment in health is given by h and we assume that health capital, H, is increasing in h. We have normalized the price of consumption in period 1 to one. Survival to period 2 is uncertain, so the agent can purchase a contract granting consumption in period 2 at price p which is less than one. If the probability of survival is very low, the contingent price for consumption in period 2 would also be low. We will assume that the agent can purchase period 2 consumption at the actuarially-fair price of $p = \pi$.

We should consider the difference between an investment in health, h, and consumption, c. Purchasing a pain reliever, like Aspirin, should be treated as consumption. A short-term pain reliever provides a health service, but it has no effect on health capital, H, because the effect is temporary. The resulting reduction in pain increases current well-being, but the effect does not carry over into other periods. In this model, the primary characteristic of an investment in health is that it increases the stock of health capital. Therefore, many healthcare services and medicines would be categorized as consumption rather than health investment. A true investment in health would increase future health services.

The agent wants to maximize expected utility given by Equation (1) subject to the budget constraint given by Equation (2). With no discounting, the agent will choose to perfectly smooth consumption by selecting $c_1 = c_2$. Thus we can rewrite Equation (1) as

EQUATION 3

$$\text{Expected Lifetime Utility} = U(H(h), c) + \pi(H(h))\, U(H(h), c)$$

where consumption, $c = c_1 = c_2$, is the same in both periods and health capital, *H(h)*, is written as a function of health investment *h*. The first order condition with respect to health investment is given by:

EQUATION 4

$$\underbrace{(1+\pi)\frac{\partial U(H,c)}{\partial H}\frac{\partial H}{\partial h}}_{\text{Direct Wellbeing}} + \underbrace{\frac{\partial U(H,c)}{\partial c}\frac{\partial W}{\partial H}\frac{\partial H}{\partial h}}_{\text{Productivity}} + \underbrace{U(H,c)\frac{\partial \pi}{\partial H}\frac{\partial H}{\partial h}}_{\text{Longevity}} = \frac{\partial U(H,c)}{\partial c}$$

Equation (4) illustrates the trade-off between using wealth for consumption or health. The additional utility from an increase in consumption is given by the right-hand side of Equation (4). The expected-utility-maximizing agent invests in additional health up to the point where, at the margin, the value of additional health is equal to the marginal value of consumption. The value of additional health has three components: well-being, productivity, and longevity as given by the three terms on the left-hand side of Equation (4). We will examine each of these three components in greater detail.

3.1 Direct well-being

The first term on the left-hand side of Equation (4) is the direct utility from additional health capital. Consider a health investment that offers no increase in productivity and no increase in longevity. For example, a surgical procedure that offers long-lasting pain reduction, but does not improve the agent's ability to work nor does it offer any reduction in the risk of mortality. This hypothetical surgery's only effect is to permanently reduce the agent's chronic pain. The reduction in pain directly makes the agent better off and may also increase the agent's enjoyment of consumption. Because the pain reduction is long-lasting, the surgery is an investment which increases health capital. Given our assumption that the surgery has no impact on the agent's productivity or longevity, the entire marginal benefit of this investment in health is captured by the direct improvement in well-being given by the first term of Equation (4):

EQUATION 5

$$(1+\pi)\frac{\partial U(H,c)}{\partial H}\frac{\partial H}{\partial h}$$

The term $(1 + \pi)$ above represents the lasting impact of the investment in health as the increase in utility occurs in both period 1 and period 2. Surviving to period 2 is uncertain, so the increase in expected utility reflects that the agent will only be alive for period 2 with probability π. The rest of this expression is the additional utility or current well-being that the agent enjoys because the level of health capital is higher. It is of particular interest to note that the demand for health investment, *h*, will be larger if the probability of survival to period 2, π, is larger. The intuitive explanation is that long-lasting medical intervention that improves well-being is more valuable to those who expect to live longer. Holding other things constant, as mortality rates decline, the demand for medical services that offers only short-term improvements in well-being will also decline as individuals substitute towards medical services that offer long-term improvements.

We are not familiar with any empirical estimates of the consumption equivalent value of this direct increase in well-being. One approach would be to estimate the willingness to pay for a medical service similar to the hypothetical surgery discussed above. The key would be to identify treatments that have no effect on either productivity or longevity. Calculating the willingness to pay for any health intervention which also affects these other two components would produce upwardly biased estimates.

3.2 Productivity

The second term on the left-hand side of Equation (4) is the productivity gains from additional health capital:

EQUATION 6

$$\frac{\partial U(H,c)}{\partial c}\frac{\partial W}{\partial H}\frac{\partial H}{\partial h}$$

The health investment increases the stock of health capital which increases the agent's wealth. The agent values the additional wealth because it can be spent on additional consumption, c, the marginal value of which is given by the first term in the above expression. The assumption that wealth increases as health capital increases, with diminishing returns, is a simple way to represent the increase in productivity from health.

There is a strong correlation between income and health (see FOGEL 1994). We generally assume that the causal relationship is that additional income allows an individual to make health investments which increase health. However, there is strong evidence for a causal relationship running the other direction. An increase in health causes higher labor productivity through fewer lost workdays, greater physical energy at work, and greater mental focus and ability.[1]

Leibenstein (1957) first proposed that workers with low levels of calorie intake would have lower productivity. There is strong evidence that improvements in nutrition lead to productivity gains in agriculture for those with low levels of calorie intake (STRAUSS 1986). Similarly, there is strong evidence that an increase in birthweight, reflecting an increase in intrauterine nutrient intake, causes an increase in future labor market income (BEHRMAN AND ROSENZWEIG 2004). The evidence shows only productivity gains for low calorie intake. Thomas and Strauss (1997) find evidence only for a positive impact of additional calories below 2,000 calories per day.

Evidence for a causal effect of health on productivity in developed countries is weaker. Several papers have shown that increases in average life expectancy in a country lead to increases in GDP growth (see BLOOM, CANNING, AND SEVILLA 2004). However, we are not aware of convincing micro evidence in developed countries that worker productivity is increasing in health. The evidence that workplace wellness programs increase productivity is mixed. While these programs generally increase worker health as measured by increased physical activity, reduction in tobacco use, and decreased body mass index, there is little evidence of productivity gains (OSILLA ET AL. 2012). The strongest evidence seems to be that an exogenous increase in worker health reduces absenteeism (BAICKER ET AL. 2010).

3.3 Longevity

The defining characteristic of this simple model is that life expectancy is not fixed. We assume that an investment in health increases the probability of survival to the second period. It is clear from Equation (1) that an exogenous increase in the probability of survival, π, increases the expected lifetime utility. How much does the agent value an increase in the probability of survival to the second period? Note that the rate of increase in the expected lifetime utility when π is increased marginally is $U(H,c)$. This means that the value of the increase in the probability of survival depends on the living standard of the agent. An agent with better health and more consumption will place a higher value on an increase in the probability of survival.

The same point is clear from the third term on the left-hand side of Equation (4):

1 Jayachandran and Lleras-Muney (2013) point out that health indirectly affects productivity through education. As longevity increases, so does the return on investments in education. This encourages additional education which makes workers more productive. We do not consider this indirect relationship because improvements in education (even if motivated by increased longevity) are already included in inclusive wealth via the measurement of human capital.

TABLE 2

Estimated value of the average annual increase in life expectancy in the U.S.

Study	Time period	Value of increase
Nordhaus (2005)	1975 – 2000	US$52,000
Becker, Philipson, and Soares (2005)	1960 – 2000	US$2,000
Murphy and Topel (2006)	1970 – 2000	US$40,000
Jones and Klenow (2011)	1980 – 2000	US$60,000
Arrow et al. (2012)	2000 – 2005	US$11,400
Inclusive Wealth Report (2012)	1990 – 2008	US$7,000

EQUATION 7

$$U(H,c)\frac{\partial \pi}{\partial H}\frac{\partial H}{\partial h}$$

The marginal value of an increase in π depends on the utility the agent would realize in the second period. To express *U(H,c)* in dollar terms, economists divide by the marginal utility of consumption and call the resulting object the value of a statistical life or VSL (Ashenfelter 2006). It is important to note that economists do not claim that VSL is the value of life. Instead, one should think of VSL as the amount people would be willing to collectively spend in order to reduce the number of expected deaths by 1.

The value of a statistical life can be inferred from individual choices. For example, workers who wash the windows of skyscrapers face a higher risk of death and are paid more than workers who wash the windows of single-story businesses. The additional compensation from assuming the additional risk of death reflects the workers' willingness to pay to reduce mortality risk. There are many similar opportunities for economists to observe a group's willingness to pay for a reduction in mortality risk. In a survey of country-level VSL estimates, Viscusi and Aldy (2003) found that VSL is approximately equal to US$12,000 multiplied by GDP per capita raised to the 0.6 power. This implies a 2014 VSL of US$8.3 million in the United States, US$2.5 million in China, and US$315,000 in Malawi.

The large VSL estimates imply that investments in health that result in even a small reduction in mortality risk have great value. Many studies have estimated the value of the increase in life expectancy in the U.S. including Nordhaus (2005), Becker et al. (2005), Murphy and Topel (2006), Jones and Klenow (2011), Arrow et al. (2012), and the Inclusive Wealth Report 2012. Table 2 reports the estimated value of the increase in life expectancy from each study. The time frame for each study is different, so we report the total estimated increase in value divided by the number of years. This results in an average increase in value per year. Differences across studies therefore are due both to differences in methods but also in the time period studied.

The estimate of the value of the average annual increase in life expectancy by Becker et al. (2005) is far lower than the other estimates. The time period they considered did not have smaller gains in life expectancy, so the difference comes from their methods. Their model implies a value of a statistical life from the other parameters of the model. Rather than going to the literature for a VSL estimate, they calibrate the other parameters of the model and the resulting VSL is fairly small. The Nordhaus (2005), Murphy and Topel (2006), and Jones and Klenow (2011) studies use similar methods and find large estimates. The Inclusive Wealth Report 2012 follows the Arrow et al. (2012) methods. Both consider a more recent time period and find similar results.

The Arrow et al. (2012) approach is to calculate the expected discounted years of life remaining for each age- and gender-specific group in the population in each year. The population-weighted average of the group-specific changes in the expected discounted year of life remaining over the period is then multiplied by the value of a statistical life year (VSLY) for that country. The VSLY is the VSL divided by the expected discounted years of life remaining and thus represents a per-year valuation of the reduction in risk of mortality.[2] Note that population aging mechanically decreases the average expected discounted years of life remaining, but that the increase in longevity for the old have outpaced this mechanical decrease (see Appendix 1 for the details of this method). The Arrow et al. (2012) approach is straight-forward requiring only life expectancy data combined with an estimate of the VSL for the country. It makes no attempt to adjust the VSL for age or cohort effects as in Aldy and Viscusi (2008). In the model presented here, an agent with higher wealth should have a higher VSL. This is consistent with the cross-country VSL estimates. However, this also suggests that where the life expectancy increases occur within the wealth distribution within a country should matter in calculating the value of the improvement in health. Our method does not account for this.

Hamilton (2012) suggests that the Arrow et al. (2012) estimates are implausibly large and claims that this must be due to double counting. He correctly points out that VSL reflects the value of all good things that come with living, not only good health. He then argues that if we have already measured the value of natural, manufactured, and human capital, wouldn't it be double counting to then add the value of health capital as the VSL depends on the living standards which are themselves a function of the other forms of capital? This concern is understandable but incorrect. Living is complementary with consumption. Even if health offered no direct increase in well-being or an increase in productivity, health would still have value simply because it extends life and allows a person to enjoy living longer. The model presented here illustrates the important point that the value of health capital does and should depend on the level of well-being and thus by extension on the levels of the other forms of capital and on the state of technology. Note that the term $U(H,c)$ appears in the expression for the value of increased longevity from an increase in health. That utility term represents the value of all good things that come with living.

3.4 Combined value of health capital

The value of an increase in the stock of health capital is the summation of all three components: direct well-being, productivity, and longevity. Accepted empirical estimates of the first two components are lacking, so economists have relied on the third alone to estimate the value of health capital. This is fine, but it should be recognized that the resulting estimates are biased downward. The large value of health capital reported in this chapter is probably too small rather than too large.

An additional issue is how to measure health capital itself. Recall that there are various measures of health and not clear theoretical justification for selecting any particular measure. Restricting the value of health capital to the longevity component makes it easy to justify

2 There are alternative methods for calculating the value of a statistical life year (VSLY). Our method implies a constant VSLY for all individuals within a country but allows for differences across countries.

using expected discounted remaining years of life expectancy as the measure of the stock of health capital. However, assume that we wish to add the productivity component to the value of health capital. Also assume that we have a convincing estimate of the effect of some measure of health, say BMI, on productivity. With this estimated effect we can value the productivity gains or losses from a change in BMI. However, it would be incorrect to refer to this as the value of the change in BMI as this would only be the productivity component. It would also be incorrect to calculate the effect of a change in BMI on longevity and then use this to supplement our longevity valuation. That would be double counting.

The Inclusive Wealth Report 2012 and Arrow et al. (2012) decision to include total factor productivity (TFP) as a measure of technological progress introduces an issue here. TFP growth is included as growth in an additional form of technological capital or time capital. Suppose that a change in BMI causes an increase in productivity. This would be picked up in the TFP growth measure as coming from technological change, when in reality it was the result of an improvement in health. This suggests that it may be appropriate to exclude the productivity component from our valuation of health capital if TFP growth is included in the measure of inclusive wealth. The health effect on productivity should already be captured by the change in TFP.

4. Conclusion

Measuring health capital using only data on life expectancy seems appropriate given the measurement challenges and lack of empirical estimates for the direct welfare and productivity components of the value of health capital. That the value of the change in health capital is large is not surprising given the large willingness to pay for reductions in mortality rates. Health capital should no longer be relegated to the appendix when measuring inclusive wealth. It is likely the most important form of capital in producing human well-being. Health services primarily affect human well-being directly rather than passing through the production process to generate goods and services.

REFERENCES

ALDY, J.E. & VISCUSI, W.K. (2008). Adjusting the Value of a Statistical Life for Age and Cohort Effects. *The Review of Economics and Statistics*, 90(3), 573-581.

ARROW, K.J., DASGUPTA, P., GOULDER, L.H., MUMFORD, K.J. & OLESON, K. (2012). Sustainability and the Measurement of Wealth. *Environment and Development Economics*, 17(3), 317-353.

ARROW, K.J., DASGUPTA, P., GOULDER, L.H., MUMFORD, K.J. & OLESON, K. (2013). Sustainability and the Measurement of Wealth: Further Reflections. *Environment and Development Economics*, 18(4), 504-516.

ASHENFELTER, O. (2006). Measuring the Value of a Statistical Life: Problems and Prospects. *The Economic Journal*, 116(510), C10-C23.

BAICKER, K., CUTLER, D. & SONG, Z. (2010). Workplace Wellness Programs Can Generate Savings. *Health Affairs*, 29(2), 1-8.

BECKER, G.S., PHILIPSON, T.J. & SOARES, R.R. (2005). The Quantity and Quality of Life and the Evolution of World Inequality. *American Economic Review*, 95(1), 277-291.

BEHRMAN, J.R. & ROSENZWEIG, M.R. (2004). Returns to Birthweight. *Review of Economics and Statistics*, 86(2), 586-601.

BHARGAVA, A., JAMISON, D.T., LAU, L.J. & MURRAY, C.J.L. (2001). Modeling the Effects of Health on Economic Growth. *Journal of Health Economics*, 20(3), 423-440.

BLOOM, D.E., CANNING, D. & SEVILLA, J. (2004). The Effect of Health on Economic Growth: A Production Funciton Aproach. *World Development*, 32(1), 1-13.

FOGEL, R. (1994). Economic Growth, Population theory and Physiology: the Bearing of Long-Term Process on the Making of Economic Policy. *American Economic Review*, 84(3), 369-395.

HAMILTON, K. (2012). Comments on Arrow et al., 'Sustainability and the measurement of wealth'. *Environment and Development Economics*, 17(3), 356-361.

JONES, C.I. & KLENOW, P.J. (2011). *Beyond GDP? Welfare across Countries and Time.* (NBER Working Paper no. 16352).

LEIBENSTEIN, H. (1957). *Economic Backwardness and Economic Growth: Studies in the Theory of Economic Development.* New York: Wiley & Sons.

MURPHY, K.M. & TOPEL, R.H. (2006). The Value of Health and Longevity. *Journal of Political Economy*, 114(5), 871-904.

NORDHAUS, W.D. (2005). Irving Fisher and the Contribution of Improved Longevity to Living Standards. *American Journal of Economics and Sociology*, 64(1), 367-392.

OSILLA, K.C., VAN BUSUM, K., SCHNYER, C., LARKIN, J.W., EIBNER, C. & MATTKE, S. (2012). Systematic Review of the Impact of Worksite Wellness Programs. *The American Journal of Managed Care*, 18(2), 68-81.

STRAUSS, J. (1986). Does Better Nutrition Raise Farm Productivity. *Journal of Political Economy,* 94(2), 297-320.

THOMAS, D. & STRAUSS, J. (1997). Health and Wages: Evidence on Men and Women in Urban Brazil. *Journal of Econometrics*, 77(1), 159-86.

UNITED NATIONS, DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, POPULATION DIVISION (2014). World Population Prospects: The 2012 Revision, Methodology of the United Nations Population Estimates and Projections, *Working Paper No. ESA/P/WP.235*.

VISCUSI, W.K. & ALDY, J.E. (2003). THE VALUE OF A STATISTICAL LIFE: A CRITICAL REVIEW OF MARKET ESTIMATES THROUGHOUT THE WORLD. *JOURNAL OF RISK AND UNCERTAINTY*, 27(1), 5-76.

WORLD BANK. 2013. *World Development Indicators 2013*. Washington, DC: World Bank. doi: 10.1596/978-0-8213-9824-1.

APPENDIX 1:

Methodology for valuing the longevity component of health

This appendix provides a description of the methodology employed in Arrow et al. (2012) as well as the Inclusive Wealth Report 2012.

Let *f(t)* be the density of age of death, *F(t)* the cumulative distribution of age of death, and $f(t|t \geq a)$ the conditional density of age of death given survival to age *a*. We obtain an estimate of the number of people who survive to age *t* out of a starting cohort of 100,000 (column l(x) of life tables) for each year and each country. From this, we calculate the unconditional number of deaths by age and divide by 100,000 to give f(t), the density of age of death. From $f(t) = f(t|t \geq 0)$ we calculate *F(t)*:

EQUATION 1

$$F(t) = \sum_{a=0}^{t} f(a)$$

The conditional density of age of death is obtained from f(t) and F(t):

EQUATION 2

$$f(t\,|\,t \geq a) = [1 - F(a)]^{-1} f(t)$$

Future years are discounted at a constant rate d, assuming that the value of an additional year is independent of age. The health capital of an individual of age a is the discounted expected year of life remaining:

EQUATION 3

$$H(a) = \sum_{t=a}^{100} f(t\,|\,t \geq a) V(a,t)$$

where V(a,t) is given by:

EQUATION 4

$$V(a,t) = \sum_{u=0}^{t-a} (1-\delta)^{u}$$

The total health capital of all individuals of age a in a country is calculated by multiplying *H(a)* by the number of people of age a in that country, *P(a)*. Thus, the total health capital (measured in discounted life-years) of a country is:

EQUATION 5

$$H = \sum_{a=0}^{100} H(a)P(a)$$

The value of a unit of health capital is the value of a statistical life-year or VSLY. Thus, the value of the total stock of health capital is simply *H* multiplied by the VSLY.