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ESTIMATING THE WELFARE GAINS FROM ANTI-RETROVIRAL THERAPY IN SUB-SAHARAN AFRICA

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Abstract

Since the start of the century, many countries in Sub-Saharan Africa have experienced large gains in life expectancy and average consumption levels. Around the same time, an unprecedented international effort has taken place to combat HIV/AIDS mortality with the expansion of anti-retroviral therapy (ART) across many of the hardest hit countries. These drugs have been shown to halt the progression of HIV and onset of AIDS. In this paper, I estimate the impact of ART on average welfare over time in 42 countries using the equivalent consumption approach. I decompose the change in welfare to isolate the relative contribution of ART-driven improvements in life expectancy and consumption. Overall, the results indicate that ART has played a key role in improving welfare in many SSA countries, accounting for around one fifth of total welfare growth in SSA between 2000 and 2017. In those countries most affected by HIV/AIDS, this figure rises to almost half. Moreover, the estimates suggest that average welfare in some countries would have declined over time in the absence of the ART expansion.

Keywords: ART; Sub-Saharan Africa; welfare; HIV/AIDS.

JEL classification: I31; J17; O55

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1 Introduction

Sub-Saharan Africa (SSA) is the focal point of the global HIV/AIDS pandemic. At the peak of the crisis, in 2004, the region reported around 1.3 million AIDS related deaths, accounting for almost 80% of the global total (UNAIDS, 2020b). While there is no cure for the disease, the progression of HIV and eventual onset of AIDS can be delayed with antiretroviral therapies (ART). These therapies have transformed HIV/AIDS from a death sentence into a manageable, chronic condition. Moreover, individuals infected with the disease can expect to live a near-normal lifespan, provided that they start ART early (Johnson et al., 2013). Up until the early 2000s, access to ART had been prohibitively expensive for many individuals and governments in SSA. With the development of low-cost generic ARTs at the start of the century, several international and domestic funding streams were set up in response to the crisis, notably through the Global Fund to Fight AIDS, Tuberculosis and Malaria (2001) and the United States President's Emergency Plan For AIDS Relief (PEPFAR) (2003). By the end of 2020, there were over 18 million people receiving ART in SSA due to these efforts (UNAIDS, 2020b). Evidence suggests that the rollout of ART has substantially reduced HIV/AIDS mortality rates and improved life expectancies across the most affected countries (Bendavid and Bhattacharya, 2009; Bor et al., 2013). Furthermore, ART may have contributed to the "African growth miracle" by boosting labour productivity and the accumulation of human capital.[1] Tompsett (2020), for instance, estimates that GDP growth in SSA would have been around a third lower without the expansion of ART coverage at the start of the century.

The aim of this paper is to quantify the relative contribution of ART to changes in welfare over time and across countries in SSA. From the outset, I define welfare in terms of consumption and life expectancy using the equivalent consumption approach (Usher, 1973, 1980).[2] This approach estimates the hypothetical consumption that, if combined with some reference life expectancy, would make a representative agent indifferent to his/her current life (as defined by his actual consumption and survival conditions). The equivalent consumption (or income)

[1] For a discussion of recent growth trends in SSA and the "African growth miracle", see Rodrik (2018). Baranov and Kohler (2018) present recent evidence on the positive impact of ART on educational expenditures and schooling.

[2] While this definition is somewhat narrow, recent empirical contributions (e.g. Jones and Klenow, 2016) suggest that these two components explain the largest share of welfare differences between countries.

has been applied in numerous contexts that are relevant to this paper, including the measurement of the welfare costs of HIV/AIDS (Crafts and Haacker, 2003; Soares, 2007; Fimpel and Stolpe, 2010), the value of health interventions (Murphy and Topel, 2003; Hall and Jones, 2007) and between-country welfare inequality (Becker et al., 2005; Fleurbaey and Gaulier, 2009; Jones and Klenow, 2016).

To measure the contribution of ART to welfare, I construct a counterfactual scenario which describes country-specific trajectories of life expectancy at birth and consumption in the absence of the ART expansion. I employ the demographic and epidemiological modelling tool Spectrum (Stover et al., 2010) to estimate counterfactual "no-ART" life expectancies at birth. This tool is often utilised by statistical agencies, such as the World Health Organisation, to model the impact of HIV/AIDS on mortality in low income countries and has been applied in previous studies assessing the benefits of ART (Forsythe et al., 2019; Lamontagne et al., 2019). I predict counterfactual "no-ART" consumption trajectories using the empirical model of Tompsett (2020), which controls for country- and time-specific fixed effects as well as possible sources of endogeneity bias emanating, for instance, from differences in how effectively countries have expanded ART coverage. Following this, I calculate the equivalent consumption measure under the actual and counterfactual scenarios, which allows me to isolate the relative contribution of ART to welfare in each country.

While several studies have estimated the value of ART-related income gains (Resch et al., 2011; Tompsett, 2020)[3] and/or welfare benefits of mortality reductions (Bor et al., 2013; Forsythe et al., 2019; Lamontagne et al., 2019), this is the first paper, to my knowledge, to directly estimate the contribution of ART to welfare through the combined channels of improved life expectancy and consumption. This is salient because welfare does not depend on income, which is a means to an end, but rather on consumption, which is an end in itself. Consumption may also be a better indicator of long term welfare trends in developing countries.[4] This paper also moves beyond programme-specific cost-benefit analyses of ART (e.g. Resch et al. 2011; Forsythe et al. 2019; Lamontagne et al. 2019) by estimating the contribution of ART to average welfare over time. This perspective is important because it weights the benefits of ART-relative

[3] Resch et al. (2011) also estimate the averted medical and orphan care costs but are extremely small when compared with productivity related income gains.

[4] See Deaton (1997) for a discussion of consumption and income as long term measures of welfare change in low income countries.

to prevailing trends in other factors that affect welfare through life expectancy and consumption. For instance, some countries may have been worse off over time in the absence of the ART expansion, a facet that would not be captured by a standard cost-benefit analysis of an ART programme. Lastly, this paper explores cross-country heterogeneity in the value of ART gains, which may be relevant for comparing countries with different sized HIV epidemics and/or those that have been comparatively more successful in rolling out ART among their populations. It therefore builds on previous works that have been primarily focused on the regional (e.g. SSA) or global benefits of ART.[5]

Regarding the value of ART, this analysis yields several key insights. First, ART has driven large welfare gains within many SSA countries over time. On average, across the region, these welfare gains equate to two additional percentage points of consumption growth per year. This means that ART has contributed to around one fifth of total welfare growth in SSA between 2000 and 2017. Second, there is substantial heterogeneity in the value of ART gains across countries, particularly between those with high and low HIV prevalence rates. In the former, the value of ART-driven improvements in longevity and consumption is equivalent to an additional four percentage points of consumption growth per annum. This compares with just over half a percentage point in countries with low HIV prevalence. Third, the estimates suggest that average welfare would have actually declined or stagnated over time without the expansion of ART in some of the worst affected countries (e.g. Eswatini, Lesotho, South Africa). Lastly, the results imply that the value of ART is chiefly derived from improvements in longevity rather than consumption gains, with the former accounting for over 80% of the total. This further highlights the need to take a multidimensional approach to welfare measurement.

The structure of the paper is as follows. Section 2 introduces the equivalent consumption approach. Section 3 provides an overview of the data and describes the calibration of the model. Section 4 presents the results and the relative contribution of ART to welfare change. Section 5 discusses the strengths and weaknesses of the empirical approach. Section 6 presents some concluding remarks.

[5] The two existing retrospective analyses of Resch et al. (2011) and Forsythe et al. (2019) estimate the benefits of ART at the SSA level and for other regions of the world.

2 Measuring welfare change

2.1 The equivalent consumption approach

There is a vast literature exploring the value of reductions in mortality from the theoretical and empirical perspectives (Schelling, 1968; Usher, 1973; Arthur, 1981; Rosen, 1988; Becker et al., 2005; Murphy and Topel, 2006). In line with Usher (1973, 1980), I consider a representative agent who faces uncertainty regarding his/her remaining length of life. If the agent is an expected utility maximiser, his/her welfare can be represented as the sum of utilities U_j derived from each possible length of life j, weighted by the probability of living a life of that particular length p_j:

$$W = \sum_{j=0}^{T} p_j U_j \ , \tag{1}$$

where T is the postulated upper limit on the length of life, $p_j = d_j s_j$ is the probability of living a life of j years, within which d_j is the probability of dying at exact age j and $s_j = \prod_{i=0}^{j}(1-d_i)$ is the conditional probability of surviving to that age, with $s_0 = 1$. In line with the literature, I assume that the utility of a remaining life of i years can be expressed as an additive sum of discounted period utilities:

$$U_j = \sum_{i=0}^{j-1} \frac{u(c_i)}{(1+r)^i} \ , \tag{2}$$

where instantaneous per period utility $u(c_i)$ depends solely on the flow of consumption c_i and r is a discount rate that captures the agent's pure time preference. For empirical tractability, I assume that the representative agent enjoys the current average consumption level c of his/her country in all future periods of life so that $c_i = c$. While this is a strong assumption it can be considered rather conservative at the same time. For instance, if consumption grows over the agent's remaining years of life, his/her lifetime utility will be underestimated, ceteris paribus.[6] By substituting (2) into (1), and using the properties of

[6] See Ponthiere (2011) for an empirical comparison of ex-ante and ex-post lifetime utility measures. While it is possible to extrapolate consumption and survival conditions into the future, Ponthiere (2011) shows that the length of time horizon and the presence of structural breaks in the the trends makes it likely that such extrapolations will lead to bias.

the survival function s_j, lifetime welfare can be re-written as:[7]

$$W(c,l) = \sum_{i=0}^{T-1} \frac{u(c)s_{i+1}}{(1+r)^i} = u(c)A(l) \ , \tag{3}$$

where $A(l) = \sum_{i=0}^{T-1} \frac{s_{i+1}}{(1+r)^i}$ is discounted life expectancy at birth.[8]

Next suppose that the agent's consumption c and life expectancy l increase from to c' and l', respectively. The equivalent consumption is then the hypothetical consumption profile $c^*(c', l'; l)$, that if combined with the initial reference life expectancy l, would leave the agent indifferent to his/her new circumstances given by c' and l':

$$W(c', l') = W(c^*(c', l'; l), l) = W(c' + \delta(l, l'), l) \ , \tag{4}$$

where $\delta(l, l')$ captures the value of life expectancy gains in terms of annual consumption. More specifically, it is the amount of additional consumption that the agent would have to receive in the second period to forego the improvements in life expectancy at birth from l to l'. Using equations (3) and (4), this amount can be implicitly defined as:

$$\delta(l, l') = u^{-1}\left(\frac{u(c')A(l')}{A(l)}\right) - c' \ . \tag{5}$$

The value of life expectancy gains therefore depends on three key elements. First, higher levels of consumption c' increase the value of additional years of life, *ceteris paribus*. This is because consumption and life expectancy are complements within the expected lifetime welfare function (see equation 3). Secondly, the magnitude and timing of longevity gains are important, as indicated by the ratio term $A(l')/A(l)$. Larger relative gains are more valuable, while those that occur further along the temporal horizon are discounted more heavily.[9] Lastly, the curvature of the instantaneous utility function $u(.)$ plays a key role in determining the trade-off between additional years of life and consumption, the details of which are discussed later in this section.

[7] Using the fact that $\sum_{j=0}^{T} p_j = \sum_{j=0}^{T} d_j s_j$ and $s_0 = 1$. See Annex A for the full derivation.

[8] In the empirical application, I assume that $s_i = 1$ for all $i \leq l$, where l is life expectancy at birth, since Spectrum does not provide the underlying survival curves used to generate life expectancy at birth.

[9] In this representative agent framework, time discounting implies that countries with lower initial life expectancies will place additional value on longevity gains.

The growth rate of equivalent consumption is further defined as:

$$g(c^*) = u^{-1}\left(\frac{u(c')A(l')}{A(l)}\right)\frac{1}{c} - 1\,, \tag{6}$$

which can be divided by the total number of years between the two points in time to provide an approximate average annual growth rate.

Figure 1 depicts the equivalent consumption approach using indifference curves defined in the consumption/life expectancy space. The agent's initial bundle is denoted by point A, which provides expected lifetime welfare $W(c, l)$. Point B represents the new situation in which the agent's improved consumption and life expectancy yield a higher level of welfare $W(c', l')$. The equivalent consumption is the hypothetical consumption level $c^*(c', l'; l)$ that provides the same level of welfare as the second period but with the life expectancy observed in the first period. The value of the life expectancy gains in terms of annual consumption is depicted by the vertical distance $\delta(l, l')$.

To estimate $c^*(c', l'; l)$ and $\delta(l, l')$ from the data, a functional form for $u(.)$ must be chosen. In line with the literature (e.g. Becker et al., 2005), I specify instantaneous utility as:

$$u(c) = \frac{c^{1-1/\gamma}}{1-1/\gamma} + \alpha\,, \tag{7}$$

which is determined by two factors: the intertemporal elasticity of substitution γ and a constant term α. The former is a measure of substitutability between different consumption periods and determines the curvature of the utility function in each period. Higher degrees of curvature imply more rapidly diminishing returns to consumption. This in turn increases the value of life expectancy relative to consumption gains, since each additional period of life becomes essential for increasing expected lifetime welfare at higher consumption levels. The constant term α arises because of the normalisation of the death state to zero and determines the hypothetical value of being alive relative to being dead (see Rosen, 1988). Note that if $\gamma < 1$, then the first term on the right-hand side of the equation is negative and α must be positive to yield non-negative utility. With this specified functional form, the closed form solution for $c^*(c', l'; l)$ in equation (4) can be written as:

$$c^*(c', l'; l) = \left[c'^{1-1/\gamma}\frac{A(l')}{A(l)} + \alpha(1-1/\gamma)\left(\frac{A(l') - A(l)}{A(l)}\right)\right]^{\frac{\gamma}{\gamma-1}}\,. \tag{8}$$

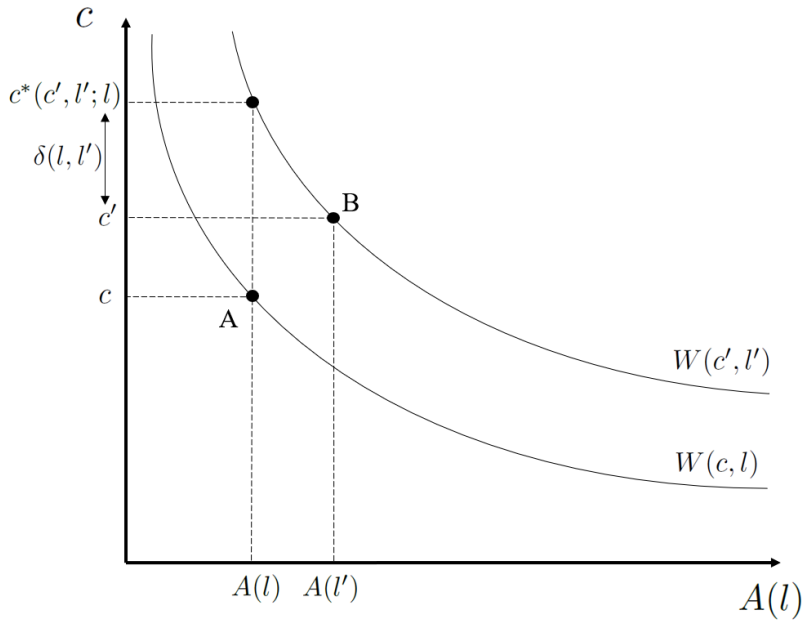


Figure 1: The equivalent consumption approach

I use this formula to estimate the value of longevity gains across countries and time in the following sections.

2.2 Decomposition

It is expected that increases in ART coverage will lead to changes in both consumption and longevity over time within each country, although the direction of the former effect is unclear *a priori* (see Annex C). To isolate the relative contribution of ART to welfare change, I decompose the difference in the equivalent consumption measure over time. Let $\hat{c}$ and $\hat{l}$ define the counterfactual "no-ART" consumption and life expectancy values in the second period. Accordingly, the decomposition can be written as:

$$c^*(c', l'; l) - c^*(c, l; l) = \underbrace{c^*(c', l'; l) - c^*(c', \hat{l}; l)}_{\text{life exp. (ART)}} + \underbrace{c^*(c', \hat{l}; l) - c^*(\hat{c}, \hat{l}; l)}_{\text{cons. (ART)}} +$$

$$\underbrace{c^*(\hat{c}, \hat{l}; l) - c^*(\hat{c}, l; l)}_{\text{life exp. (other)}} + \underbrace{c^*(\hat{c}, l; l) - c^*(c, l; l)}_{\text{cons. (other)}}, \tag{9}$$

where each term in equation (9) is evaluated with respect to the reference life expectancy l in the initial period.[10] This implies that equivalent consumption in the first period is equal to the baseline consumption level, that is $c^*(c, l; l) = c$. The hypothetical consumption level that would provide the agent with the same level of welfare in a counterfactual second period without ART, $W(\hat{c}, \hat{l})$, but with the life expectancy observed in the first period, is given by $c^*(\hat{c}, \hat{l}; l)$. Likewise, $c^*(\hat{c}, l; l)$ and $c^*(c', \hat{l}; l)$ are the equivalent consumption values that yield the welfare levels $W(\hat{c}, l)$ and $W(c', \hat{l})$ respectively. The values of ART-induced changes in life expectancy and consumption are captured by the first and second terms of the right hand side in equation (9). The sum of these two components yields the total value of ART related welfare gains. Note that the decomposition itself is path dependent. An alternative path would be to first isolate the relative contribution of consumption (ART and other factors) to welfare change, followed by the life expectancy components. This route, however, does not provide a consistent decomposition of the difference between equivalent consumption in the actual and counterfactual scenarios, defined by $c^*(c', l'; l)$ and $c^*(\hat{c}, \hat{l}; l)$, respectively.[11] Regardless, the core results in this paper are robust to each decomposition path. For instance, the proportion of welfare growth attributable to ART in SSA (see section 4.1, Table 1) falls by only one percentage point (from 21% to 20%) when using the alternative decomposition route.

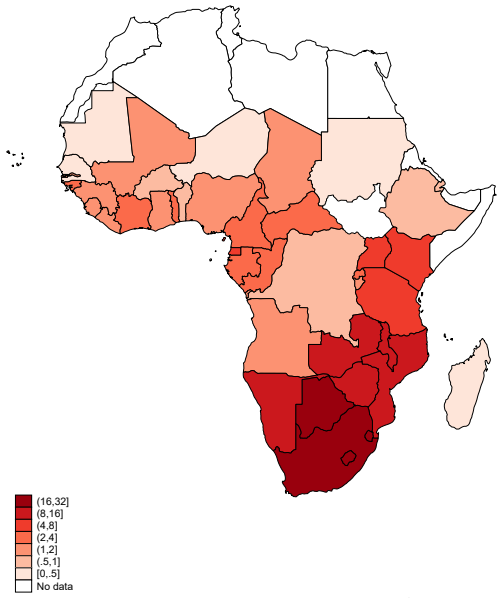
3 Data and calibration

3.1 The HIV/AIDS epidemic in SSA

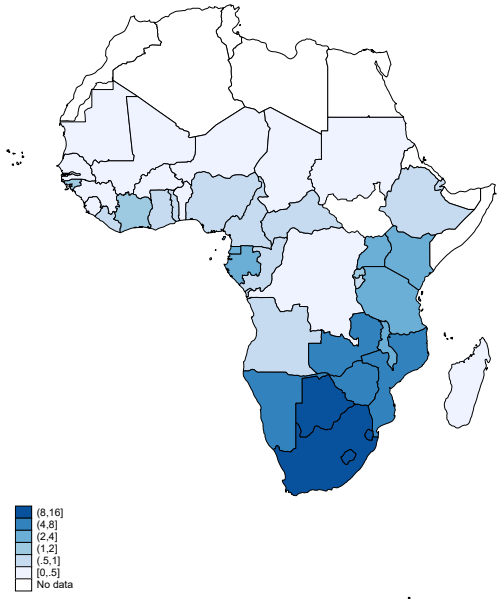
While SSA is the region in the world most affected by HIV/AIDS, there is a substantial amount of geographical variation in the scale of the epidemic. More precisely, the HIV/AIDS epidemic is concentrated within the eastern and southern countries of SSA (see Figure 2a). In Eswatini, Lesotho and Botswana,

[10] An alternative approach is to calculate $c^*(c', l'; l)$ using a single fixed reference life expectancy for all countries (see Fleurbaey and Gaulier, 2009; d'Albis and Bonnet, 2018). However, this would require additional assumptions regarding the appropriate value for the SSA context (e.g. regional or global maximum, single- or multi-year reference). I therefore follow the literature in setting the reference value as life expectancy in the base year of the analysis.

[11] More specifically, the difference between equivalent consumption in the actual and counterfactual scenario is the sum of the ART-related consumption and life expectancy components. This is not the case if the decomposition first isolates the consumption (ART and other factors) component then life expectancy.



(a) HIV prevalence (% aged 15-49)



(b) ART coverage (% of total population)

Figure 2: The HIV/AIDS epidemic in SSA, 2017. *Sources: a) World Bank Development Indicators b) author's calculations using UNAIDS data in Spectrum.*

for example, more than one in five individuals aged 15-49 years are infected with HIV. Very high prevalence rates of 10% or above are also observed in South Africa, Zimbabwe, Mozambique, Namibia and Zambia. In contrast, prevalence rates in western and central SSA are generally below 5% and, in several cases, even below 1%. Thus, in the following sections, I divide countries into high and low HIV groups. High HIV countries are defined as those with prevalence rates equal to or above 5% at the start of the analysis period in the year 2000. Low HIV countries are defined as having prevalence rates below this threshold.

Evidence suggests that the expansion of ART in the early 2000s reversed the upwards trends in AIDS mortality that prevailed throughout many countries in SSA during the 1990s.[12] As noted by Tompsett (2020), ART is likely to have a substantial impact on life expectancy or economic outcomes when a large proportion of the population are receiving treatment. Thus, looking at the standard indicator of ART coverage, measured as a percentage of the individuals living with HIV, is likely to yield few insights. Note that a country may have low HIV prevalence but full ART coverage while the opposite could also be true. Figure 2b presents ART coverage as a percentage of the population in 2017. Several countries in southern SSA have a substantial proportions of populations receiving ART. In Eswatini, for example, around 15% of its population in 2017 was receiving ART. Similar orders of magnitude are are found in Lesotho (12%) and Botswana (12%), followed by South Africa (9%) and Zimbabwe (7%). It is therefore expected that ART will have contributed to large welfare gains in these countries. Again, the proportions receiving ART in the western and central countries is low, with most reporting less than 1% of their population as receiving ART.

3.2 Scenario construction

I consider two scenarios to estimate the welfare gains from ART. The retrospective scenario describes the actual trends in life expectancy at birth and consumption per capita within 42 SSA countries over the period 2000-2017. Life expectancy at birth is taken from the UN World Population Prospects.[13] Real consumption per capita is obtained from the Penn World Tables (version 9.1) and defined as the sum of personal expenditures, measured in 2011 prices

[12] See, for example, Bendavid et al. (2012), Bor et al. (2013) and Tompsett (2020).

[13] This is data is preloaded within the Spectrum software. See UN (2019) for underlying data.

at purchasing power parities (PPP).[14]

The counterfactual scenario defines country specific trends of life expectancy and consumption in absence of ART over the same period. To calculate the former of these trends, I utilise the Spectrum (version 5.87) modelling package (Stover et al., 2010). This software includes the AIDS Impact Model (AIM), which estimates the demographic and epidemiological impacts of HIV/AIDS (e.g. number of HIV infections, AIDS deaths at each age) given specific assumptions on ART coverage.[15] For the counterfactual scenario, I assume ART is not available for the treatment of adults/children or the prevention of mother-to-child transmission. I then use Spectrum to generate counterfactual life expectancies at birth for 42 countries in SSA. Further details on the underlying data within Spectrum can be found in Annex B. To estimate the counterfactual consumption levels in the absence of ART, I utilise the same empirical strategy and model as Tompsett (2020) but use consumption rather than income as the dependent variable (see Annex C). Using this model, I estimate the impact of ART on growth in consumption controlling for time and country fixed effects as well as country specific linear time trends. Interestingly, the estimated coefficients are almost identical to those reported by Tompsett (2020) and display a higher level of statistical significance. More specifically, the results suggest that a 1 percentage point increase in ART coverage of the total population leads to a 1.35 (95% CI: 0.20-2.51) percentage point increase in the growth rate of consumption.[16] I utilise this result to isolate the proportion of consumption growth due to ART over the period and to generate counterfactual consumption levels in the absence of ART.

Figures 3 and 4 present the actual and counterfactual "no-ART" trends in average life expectancy and consumption per capita for 14 high HIV countries in the sample.[17] The upper and lower bounds of counterfactual consumption are based on the 95% confidence interval of the estimated coefficient.[18] The wide bounds imply a large amount of uncertainty regarding the true impact of ART

[14] I do not include government expenditures, since it is likely that these capture expenditures on health and education, which can be considered investments to some extent.

[15] AIM country files contain the most recent demographic, epidemiological and ART programme data. The files are frequently updated and validated by UNAIDS.

[16] The corresponding estimate of Tompsett (2020) for the case of GDP per capita is 1.25 percentage points.

[17] Average differences between the two scenarios are much less pronounced for the remaining low HIV countries and are provided in the Annex.

[18] Unfortunately, Spectrum life expectancy outputs are not provided with a confidence interval.

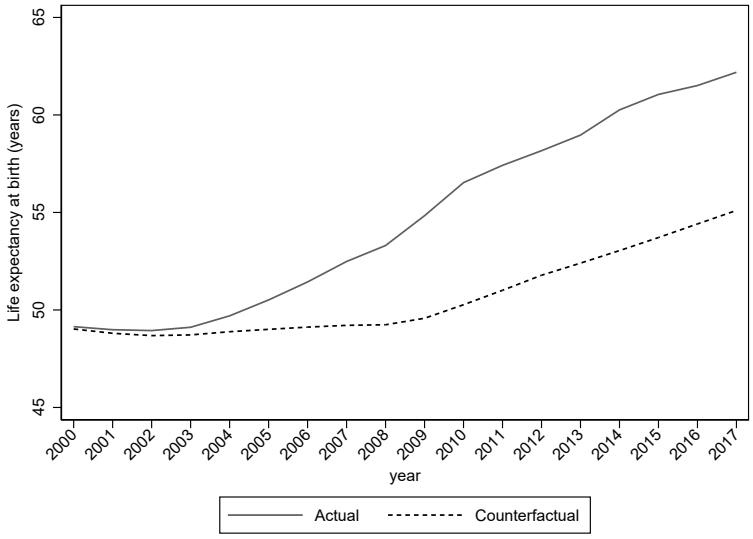


Figure 3: Actual and counterfactual "no-ART" life expectancy at birth (high HIV countries only), 2000-2017. *Sources: Author's estimates using the Spectrum model.*

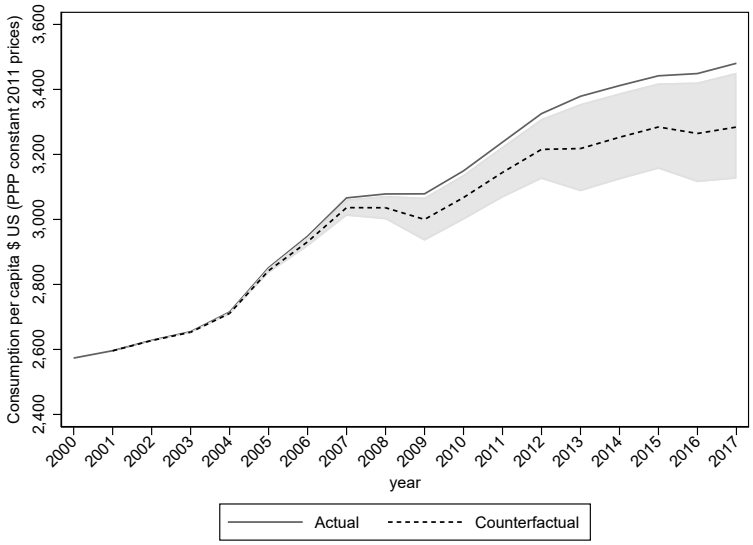


Figure 4: Actual and counterfactual "no-ART" consumption per capita (high HIV countries only), 2000-2017. *Note: 95% confidence interval shaded.. Sources: Author's estimates based on PWT (v 9.1) and UNAIDS data.*

on consumption. Each graph demonstrates a divergence between the actual and counterfactual measures from around 2003-2005 onwards, coinciding with the rapid expansion of ART across countries.

3.3 Parameter calibration

The estimation of $c^*(c', l'; l)$ requires that the parameters γ and α are set within reasonable bounds. The extensive literature on the intertemporal choice indicates that plausible values of γ range from 0.5 to just above 1 (Hall, 1988; Browning et al., 1999; Havranek et al., 2015). The available empirical evidence also suggests relatively smaller values of γ in low income countries due to subsistence requirements and reduced opportunities for intertemporal substitution (Atkeson and Ogaki, 1996; Havranek et al., 2015; Ogaki et al., 1996). Given the uncertainty surrounding this parameter, I follow Murphy and Topel (2006) in setting $\gamma = 0.8$, which corresponds to around halfway between estimates used in previous studies on the value of longevity (Becker et al., 2005; Hall and Jones, 2007).

While there is a well established empirical literature concerning γ, there are, to my knowledge, no direct estimates of α. Instead, its value is often inferred from estimates of the value of statistical life (VSL) for a given γ (see Ponthiere, 2008). To observe how such estimates can be utilised for the calibration, first note that the VSL is the marginal rate of substitution between current mortality risk and consumption. Using equation (1), this can be expressed formally as:

$$VSL = -\frac{\partial W/\partial d_0}{\partial W/\partial c_0} = \frac{\frac{A(l)}{s_0}\left[\frac{c^{1-1/\gamma}}{1-1/\gamma} + \alpha\right]}{s_0(c_0)^{-1/\gamma}} \,. \tag{10}$$

where, as before, $A(l)$ is discounted life expectancy at birth. The value of α can be then solved for using estimates of VSL and γ alongside data on life expectancy at birth and consumption.[19] While reliable estimates of the VSL are lacking for many SSA countries, the extensive literature on how the VSL varies with income across countries allows for an approximation of the average population value in each country. Recent meta-analyses suggest that this elasticity is close or equal to unity (Viscusi and Masterman, 2017; Masterman and Viscusi, 2018), which implies a constant VSL-income ratio across countries. To proceed, I assume that the VSL is 170 times consumption per capita, based on

[19] I assume that $s_0 \approx 1$, i.e. the individual is alive in the first period.

the recent cross-country VSL estimates of Viscusi and Masterman (2017). This is just below the threshold adopted by Lancet Global Commission on Investing in Health (180 times GDP per capita) to measure the value of longevity gains in low income countries (Jamison et al., 2013), which has also been employed by previous works on the benefits of ART (Lamontagne et al., 2019; Forsythe et al., 2019). Nevertheless, it cannot be understated that there is a considerable amount of uncertainty regarding the appropriate VSL income elasticity to be applied in low income country contexts. This is because most meta-analyses primarily rely on VSL studies from high and upper middle income countries. I therefore present additional results adopting a lower threshold of 100 times consumption per capita in Annex D.[20]

Finally, I assume a discount rate of 5%, that is $r = 0.05$. This adheres to the recent recommendations of Haacker et al. (2020) for the analysis of health benefits in low and middle income countries. Since $\delta(l, l')$ corresponds to a measure of equivalent variation, I calibrate country specific α parameters using the 2017 values of consumption and discounted life expectancy. These calibrations imply a set of indifference curves for each country within the consumption/life expectancy space. Figure 5 presents the resulting indifference curves for one particular country, Botswana, which intersect with the observed consumption and discounted life expectancy values in the years 2000 and 2017. The dashed indifference curve passes through the estimated counterfactual values of consumption and life expectancy in 2017. The indifference map demonstrates that there has been an increase in welfare over time in Botswana, the magnitude of which would have been reduced in the absence of ART. Note that the curves also are non-homothetic. More specifically, the weight placed on life expectancy increases as consumption rises. This is a natural implication of the diminishing marginal utility of consumption (or equivalently a low degree of intertemporal substitution) as discussed in section 2.1.

[20] Robinson et al. (2019), for instance, suggest considering thresholds between 100 to 160 times income per capita, to address concerns regarding the limited resources available for mortality reductions in low and middle income countries.

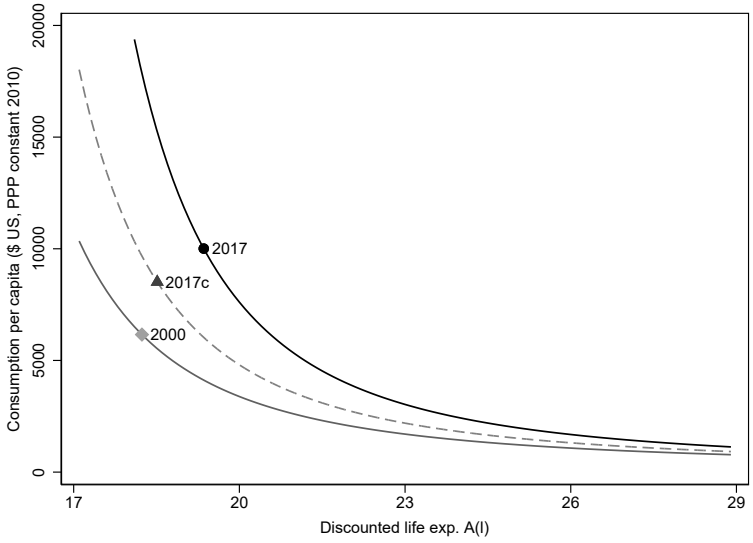


Figure 5: Indifference map for Botswana, 2000 and 2017 (actual and counterfactual), $\gamma = 0.8$ and $\alpha = 1.28$. *Note: 2017c denotes for the counterfactual outcomes in 2017.*

4 Results

4.1 Contribution of ART to welfare growth across countries and time

Table 1 presents the growth rates of consumption (column 1) as well as welfare in the actual and counterfactual no-ART (columns 2 and 3) scenarios. Going from column (1) to (2), the average annual growth rate in the SSA region more than doubles when gains in life expectancy are considered alongside consumption. The relative increase is smaller when population weights are included (second row). Still, the average growth rate of equivalent consumption is almost eight percentage points higher than the corresponding consumption-only rate. This implies that the true magnitude of the "African growth miracle" is not fully captured by changes in consumption alone. Comparing columns (2) and (3), the results suggest that average welfare growth in SSA would have been almost 2 percentage points lower in the absence of the ART expansion. In high HIV countries, this difference rises to over 4 percentage points. Columns (5)-(8) decompose welfare growth over time using equation (9). At the SSA level,

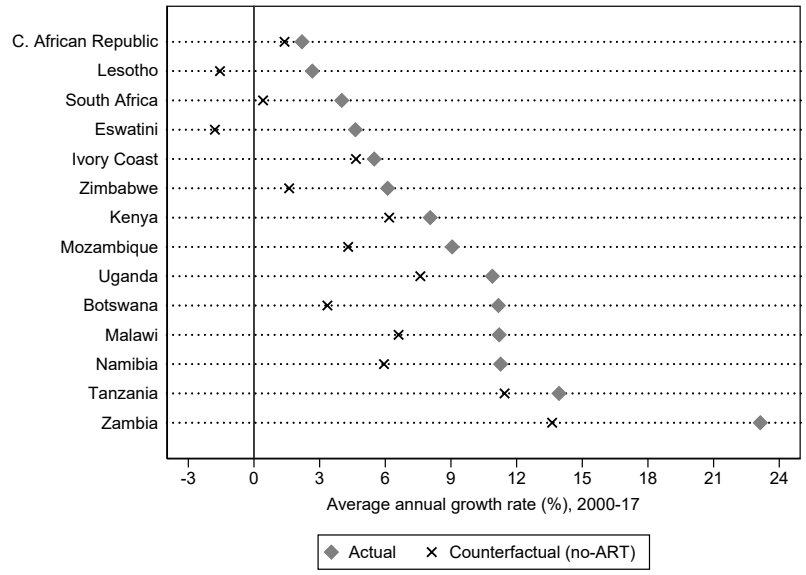
Table 1: Welfare growth statistics, 2000-2017

	Average annual growth rates				Decomposition of welfare growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Cons.	Welfare	Welfare (c.f.)	Diff.	Life exp. ART	Cons. ART	Life exp. other	Cons. other
SSA	4.09	8.71	6.84	1.86	1.57	0.29	3.04	3.80
SSA (w)	10.94	18.62	16.46	2.17	1.87	0.29	5.80	10.65
Std. dev.	6.53	10.04	9.37	2.35	2.01	0.38	3.56	6.49
High HIV	3.14	8.84	4.55	4.29	3.61	0.69	2.09	2.46
Low HIV	4.57	8.64	7.98	0.65	0.56	0.10	3.51	4.47

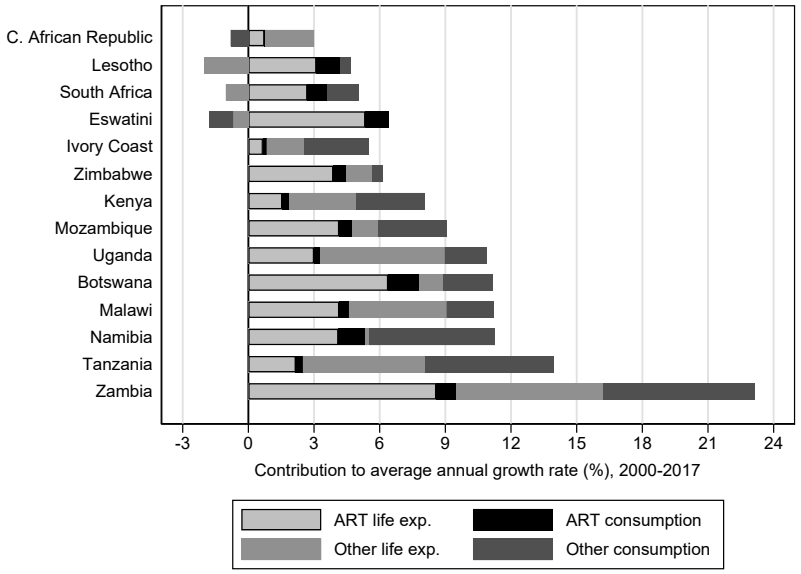
Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Cons. stands for consumption per capita. All figures are reported in percentages. Welfare defined as equivalent consumption. Column (3) gives the growth rate of equivalent consumption in the no-ART scenario. Column (4) reports the difference between columns (2) and (3). Columns (5) and (6) may not always sum to the difference in (4) due to rounding. Second row figures for SSA are weighted by country population size. High HIV countries defined as those with prevalence rates (% aged 15-49 years) greater than 5% in 2000.

the unweighted estimates imply that about one fifth of total welfare growth is attributable to ART. Other factors have led to large improvements in life expectancy and consumption (columns 5 and 6) and account for the remaining four fifths of total welfare growth over the period. This proportion rises even further when population weighting is included, mainly due to the substantial growth rates observed in Nigeria, SSA's most populous country. In high HIV countries, however, ART related gains in life expectancy and consumption have accounted for almost half of the growth (48.5%) in welfare over time. Gains in life expectancy due to ART make the largest contribution to the welfare growth rate in these countries, adding 3.6 percentage points. Meanwhile, ART consumption gains contribute around 0.7 percentage points. The estimates in Table 1 are also reasonably robust to calibrations of α based on lower VSL estimates equal to 100 times consumption per capita (see Table 6 in Annex D). Under this assumption, the contribution of ART to welfare growth in SSA is reduced by 5 percentage points from 21% to 16%. The corresponding reductions for high and low HIV countries are 7.5 (from 48.5% to 41%) and 2 percentage points (7.5% to 5.5%).

Figure 6 reveals a substantial amount of heterogeneity in the the contribution of ART to welfare growth rates in high HIV countries. Panel a) compares average annual growth rates of equivalent consumption with and without ART. Several



(a) Average annual growth rates in welfare



(b) Decomposition of average annual growth rates

Figure 6: Welfare growth rates and decomposition, high HIV countries, 2000-2017.

high HIV countries would have observed substantial reductions in these growth rates without the rollout of ART. Zambia, for instance, would lose the equivalent of 9.5 percentage points of consumption growth in the no-ART scenario. Similar orders of magnitude are reported for Botswana (7.8 percentage points) and Eswatini (6.4 percentage points). In fact, the estimates suggest that Lesotho and Eswatini would have experienced a reduction in average welfare over the period in the absence of the ART expansion, each displaying negative average annual growth rates in the counterfactual scenario. South Africa would have also seen its average annual growth rate reduced from 4% to 0.4%.

Panel b) decomposes the estimated growth rates of equivalent consumption into the relative contributions of ART and other factors. The largest relative contributions of ART are observed in Lesotho and Eswatini, where the negative growth rates are reversed through ART related improvements in consumption and life expectancy. ART also accounts for large proportions of welfare growth in South Africa (90%), Zimbabwe (74%) and Botswana (70%), all of which are among the countries worst hit by HIV/AIDS. Relatively smaller ART contributions are observed for the Central African Republic, Ivory Coast, Kenya and Tanzania. While, these countries have experienced comparatively smaller HIV epidemics than other countries in the graph,[21] some have also been far less successful in expanding ART to individuals living with HIV in their populaton. For instance, the Central African Republic and Uganda had very similar HIV prevalence rates at the start of the century, but vastly different ART coverage rates (% of individuals living with HIV) of 35% and 69% in 2017 UNAIDS (2020b), respectively.

4.2 The value of ART-related gains in life expectancy and consumption

Table 2 presents average changes in life expectancy and per capita consumption due to ART at the regional level and the value of these gains in terms of annual per capita consumption. Columns (1) and (2) demonstrate that the ART has led to improvements in life expectancy at birth and consumption of 3.7 years and $165, respectively. These figures are slightly reduced when country population

[21] In 2000, HIV prevalence rates (% of population aged 15-49 years) in these countries were: Central African Republic (7.1%), Côte d'Ivoire (6.2%), Kenya (8.9%) and Tanzania (6.2%). Vastly higher rates are observed in the same year for Eswatini (22.1%), Lesotho (23.3%) and Botwana (26.1%).

Table 2: Value of ART-related gains in consumption and life expectancy, summary statistics, 2000-2017

			Value of ART in terms of annual cons.		
	(1)	(2)	(3)	(4)	(5)
	Gain in life exp. due to ART	Gain in cons. due to ART	Value of ART life exp. gains	Total value of ART gains	% of mean cons. 2017
SSA	3.7	165	724	890	20.0
SSA (w)	3.0	102	441	543	15.5
Std. dev.	4.5	359	1,518	1,869	26.0
High HIV	8.7	433	1,882	2,315	48.3
Low HIV	1.2	32	145	177	5.4

Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Cons. stands for consumption per capita. Second row SSA values are weighted by country population size. Columns (3) and (4) measured in $US (PPP constant 2010 prices). High HIV countries defined as those with prevalence rates (% aged 15-49 years) greater than 5% in 2000.

weights are included in the second row. As before, there are vast differences between high and low HIV countries. The former have experienced large ART-related increases in life expectancy of almost 9 years, compared with 1.2 years in the latter group. Similarly, average improvements in consumption due to ART have been sizeable in high HIV countries, at $433 or equivalently 10% of mean consumption per capita in 2019. Column (3) presents the value of ART longevity improvements in terms of annual per capita consumption using equation (5). Column (4) gives the total value of ART gains in longevity and consumption, which is the sum of columns (2) and (3). This represents the amount a representative agent would have to be compensated by in 2017 to forgo the ART-driven changes in life expectancy and consumption over the period 2000-2017. To provide some perspective on these values, column (5) presents the total value of ART gains as a percentage of the mean consumption level in 2017. The average per capita value of ART gains in SSA varies between $543 and $890, with and without population weights. This means that a representative agent would have be compensated by around 15-20% of his/her annual consumption per capita in 2017 to forego the improvements in longevity and consumption due to ART. Once more, these values are much larger in high HIV countries, reflecting the large increases in life expectancy and consumption attributable to ART (columns 1 and 2).

Table 3 presents the same results for individual high HIV countries. Across coun-

Table 3: Value of ART gains over time, high HIV countries, 2000-17

			Value of ART in terms of annual cons.		
	(1)	(2)	(3)	(4)	(5)
Country	Gain in life exp. due to ART	Gain in cons. due to ART	Value of ART life exp. gains	Total value of ART gains	% of mean cons. 2017
Botswana	16.7	1,495	6,685	8,179	81.7
C. A. R	2.0	10	110	120	15.5
Ivory Coast	1.8	55	214	269	9.3
Eswatini	16.4	1,317	6,519	7,836	109.4
Kenya	4.8	103	486	589	20.1
Lesotho	11.0	523	1,462	1,986	56.6
Malawi	8.0	61	573	634	54.2
Mozambique	9.4	68	466	534	49.4
Namibia	9.4	919	3,106	4,025	41.5
South Africa	11.6	1,062	3,175	4,237	43.7
Tanzania	4.2	49	330	379	20.6
Uganda	5.8	52	534	586	40.7
Zambia	9.7	171	1,586	1,758	69.2
Zimbabwe	10.5	177	1,103	1,279	64.6

Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Cons. stands for consumption per capita. Second row SSA values are weighted by country population size. Columns (3) and (4) measured in $US (PPP constant 2010 prices). C.A.R. stands for Central African Republic.

tries, the largest gains in life expectancy (column 3) and consumption (column 4) due to ART have taken place in Botswana, Eswatini, and South Africa, all of which have large HIV epidemics and high proportions of their population receiving ART (see Annex B, Table 7). ART has also led to large gains in life expectancy of over 10 years in Lesotho and Zimbabwe. Overall, the table sheds light on a substantial amount of cross-country heterogeneity in the value of ART gains. In absolute terms, the largest values are reported in Botswana, Eswatini, South Africa and Nambia. These reflect not only the magnitude of the ART related gains in life expectancy and consumption within these countries, but also their relatively high consumption per capita levels compared with other countries in the table. Recall from equation (1) that the level of consumption is a direct determinant of the value of longevity gains. In column (5), the relative value of ART gains are highest in Eswatini. In fact, a representative agent in this country would have to be compensated by 109% of his/her consumption level in 2017, to forego the gains from ART over the period 2000-17. Large

proportions are also reported for Botswana, Zambia, Zimbabwe, Lesotho and Malawi, within which the consumption value of ART gains is more than 50% of per capita consumption in 2017.

Table 4 presents the corresponding estimates for low HIV countries. As shown in columns (3) and (4), these countries have experienced much smaller increases in life expectancy at birth and consumption due to ART. Consequently, the values of ART gains are much lower than in the most of the high HIV countries. Notable countries include Equatorial Guinea, Gabon, Guinea Bissau and Rwanda, which have experienced ART-related gains in life expectancy of around 3 years. In these countries the value of ART gains are sizeable at around 10-15% of per capita consumption. Nevertheless, for the majority of low HIV countries, the values of ART gains are relatively small. This is to be expected since these countries have smaller HIV epidemics and proportions of their populations receiving ART. Thus, ART has had a reduced impact on macro-level indicators such as life expectancy at birth and per capita consumption.

Going further, the results allow for a "back-of-the-envelope" comparison of the benefits of ART with respect to the costs of provision. Tompsett (2020) calculates that the current cost of ART provision in SSA to be around $9.4 per capita per year for every 1% of the population treated with ART. On average, Spectrum reports that 1.7% of the population within the 42 countries included in this study are receiving ART. Using the population weighted average value of ART gains from Table 2 yields a benefit-cost ratio of 34:1 for the SSA region in 2017. This is almost double the benefit-cost ratio of 18:1 reported by Forsythe et al. (2019), which only considers changes in mortality.[22] It is also worth noting that the estimated ART-related gains in consumption alone would outweigh the costs of ART by a factor of 6:1. Under the assumption of a lower VSL across countries (see Table 7 in Annex D), the benefit cost ratio is 21:1.

5 Discussion

This section highlights some of the strengths and weaknesses of the equivalent consumption approach employed within this study. One of the key advantages of this approach is that it incorporates specific preference parameters regarding the intertemporal elasticity of substitution γ and the hypothetical consumption

[22] Author's own calculations using the combined results for East and Southern Africa, and West and Central Africa from Exhibit 2 in Forsythe et al. (2019).

Table 4: Value of ART gains over time, low HIV countries, 2000-17

			Value of ART in terms of annual cons.		
	(1)	(2)	(3)	(4)	(5)
Country	Gain in life exp. due to ART	Gain in cons. due to ART	Value of ART life exp. gains	Total value of ART gains	% of mean cons. 2017
Angola	1.0	38	186	224	7.1
Benin	0.9	10	44	54	3.1
Burkina Faso	0.6	7	37	44	3.0
Burundi	1.0	6	34	40	4.7
Cape Verde	0.8	31	64	95	1.6
Cameroon	2.1	33	212	245	9.2
Chad	0.8	5	47	52	4.1
Comoros	0.0	1	1	2	0.1
Congo	1.4	20	104	124	5.7
D.R.C	0.7	2	20	22	3.2
Eq. Guinea	3.6	328	1,382	1,710	15.5
Ethiopia	0.9	10	38	48	4.3
Gabon	3.2	155	448	603	10.7
Gambia	1.4	16	93	110	4.5
Ghana	1.2	41	133	175	4.3
Guinea	1.0	15	86	101	4.5
Guinea-Bissau	2.3	25	158	183	10.3
Liberia	1.2	5	36	41	5.1
Madagascar	0.1	0	3	4	0.2
Mali	0.7	10	81	91	3.6
Mauritania	0.3	5	19	24	0.9
Niger	0.3	1	10	11	1.4
Nigeria	1.4	41	322	363	9.7
Rwanda	2.9	41	230	271	15.1
Senegal	0.4	7	23	30	1.1
Sierra Leone	0.9	9	160	169	10.9
Sudan	0.1	1	9	10	0.4
Togo	1.8	20	85	105	7.0

Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Cons. stands for consumption per capita. Second row SSA values are weighted by country population size. Columns (3) and (4) measured in $US (PPP constant 2010 prices). D.R.C. stands for Democratic Republic of Congo.

level at which a representative agent is indifferent between being alive or dead, determined by the constant term α. The paper therefore builds on previous works regarding the benefits of ART, which remain agnostic on these parameters and instead apply VSL estimates directly to changes in age-specific mortality rates (Forsythe et al., 2019; Lamontagne et al., 2019). However, as discussed by Ponthiere (2008), several different combinations of γ and α may be consistent with the same VSL estimate, each yielding different conclusions on the value of longevity gains. Moreover, these approaches implicitly assume that any life is worth living regardless of the consumption level, which may be a strong assumption if we assume that there exists subsistence level of consumption at which an individual would be indifferent between life and death (see Rosen, 1988). This paper attempts to resolve the first uncertainty by turning to the available literature on intertemporal choice and the VSL income elasticity. It addresses the second issue by calibrating country specific values of α, with the goal of providing a more accurate estimation of the true value of ART longevity gains.

At the same time, applying a single set of preference parameters to the population of each country simplifies the problem considerably. Individual preferences for mortality reductions may differ according to a range of factors, including age, sex, religion and culture (Robinson et al., 2019).[23] Taking these factors into account would require detailed surveys designed to elicit preference parameters at the individual level, which at present are unavailable for most countries in SSA. In addition, information on the "average" values of these parameters is far from conclusive due to the lack of empirical studies on γ and the VSL in SSA. Still, the estimates presented in this paper can be considered relatively conservative given the available evidence. As discussed in section 3.3, recent meta-analyses point to an average value of $\gamma = 0.5$ across countries (see Havranek et al., 2015) and perhaps even lower values in low income countries where opportunities for intertemporal substitution of consumption are limited. Setting γ below the base value of 0.8 would dramatically increase the value of ART related longevity gains reported in this paper. Moreover, the baseline VSL consumption ratio utilised for the calibration of α is slightly lower than the one used in previous ART cost-benefit analyses (e.g. Forsythe et al. 2019; Lamontagne et al. 2019). Applying a higher ratio would also increase the value of ART related welfare gains within each country. Lastly, the sensitivity analysis (see Annex D) demonstrates

[23] See León and Miguel (2017) for empirical evidence suggesting that the VSL may be correlated with income and fatalistic attitudes in African countries.

that even under more strictive assumptions regarding the VSL, the core finding remains: ART has made a substantial contribution to welfare across SSA.

6 Conclusion

In this paper I estimate welfare gains from ART over time and across a set of SSA countries using the equivalent consumption approach. The results suggest that ART-related improvements in longevity and consumption have led to large welfare gains across the region, particularly in those countries most affected by HIV/AIDS. In some instances, the gains from ART have outweighed the welfare losses due to other factors influencing life expectancy and consumption. The results also indicate a substantial amount of heterogeneity concerning the value of ART gains across SSA countries, reflecting relative differences in the severity of the HIV epidemic and abilities to expand ART coverage. Lastly, ART-related gains in life expectancy far outweigh those related to improvements in consumption. This result persists when using more conservative assumptions regarding the VSL.

Overall, the findings contribute to the ongoing debate regarding the HIV/AIDS funding gap, which has emerged in recent years. International funding for HIV/AIDS in low- and middle-income countries has fallen in recent years and future contributions remain uncertain amid the current COVID-19 pandemic (UNAIDS, 2020a). At the same time, many SSA countries remain heavily reliant on external funding for their HIV/AIDS programmes. UNAIDS (2020a) reports current funding gaps of 9% and 32% in eastern and southern Africa, and western and central Africa regions, respectively. Provision of ART presents governments with an efficiency/fairness dilemma. On the one hand, it creates a large, long term fiscal burden for the most affected countries, as individuals must continue to receive treatment for the rest of their lives. On the other hand, ART undoubtedly improves the lives of those affected by HIV/AIDS and discontinuing treatment would be equivalent to an 'act of commission' that ends the lives of identifiable people (Collier et al., 2015). This fiscal burden will continue to grow across SSA as the number of people living with HIV/AIDS increases and ART coverage expands (ibid). Failure to address these funding concerns risks undoing much of the progress made thus far, which, as this analysis has shown, could have significant repercussions for welfare across countries.

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A Derivation of equation (3)

First note that equation (1) can be re-written, using (2), as:[24]

$$W = u(c_0)(d_1 s_1 + d_2 s_2 + ... + d_T s_T) + \frac{u(c_1)}{1+r}(d_2 s_2 + d_3 s_3 + ... + d_T s_T) + \\ ... + \frac{u(c_{T-2})}{(1+r)^{T-2}}(d_{T-1} s_{T-1} + d_T s_T) + \frac{u(c_{T-1})}{(1+r)^{T-1}}(d_T s_T) \ . \tag{11}$$

By definition, the first term of the right hand side is equal to $u(c_0)(1 - d_0 s_0)$, which is further simplified to $u(c_0)(1-d_0)$ by assuming $s_0 = 1$. The second term of this expression can also be re-defined as $[u(c_1)/1+r] \cdot (1 - d_0 - d_1 s_1)$. Using the fact that $s_1 = s_0(1 - d_0)$ and the assumption that $s_0 = 1$, this term can be further simplified as $[u(c_1)/1+r] \cdot (1-d_0)(1-d_1)$. Lastly, assuming that $d_T = 1$ means that the last term in the equation is multiplied by s_T. Applying these operations successively, expression 11 can be re-specified as:

$$W = u(c_0)(1 - d_0) + \frac{u(c_1)}{1+r}(1 - d_0)(1 - d_1) + \frac{u(c_2)}{(1+r)^2}(1 - d_0)(1 - d_1)(1 - d_2) + \\ ... + \frac{u(c_{T-2})}{(1+r)^{T-2}} s_{T-1} + \frac{u(c_{T-1})}{(1+r)^{T-1}} s_T \ . \tag{12}$$

Using the definition of the survival function $s_i = \prod_{j=0}^{i-1}(1 - d_j)$, allows us to re-write equation 12 as:

$$W = u(c_0)s_1 + \frac{u(c_1)}{1+r} s_2 + \frac{u(c_2)}{(1+r)^2} s_3 + ... + \frac{u(c_{T-2})}{(1+r)^{T-2}} s_{T-1} + \frac{u(c_{T-1})}{(1+r)^{T-1}} s_T \\ = \sum_{i=0}^{T-1} \frac{u(c_i) s_{i+1}}{(1+r)^i} \ , \tag{13}$$

which is equivalent to equation 3 after assuming $c_i = c$.

[24] This is a shortened and altered version of the derivation provided in the Annex of Ponthiere (2004).

B Notes on data used in Spectrum

Concerning the underlying data, many countries in SSA lack complete vital registration systems, which hinders the accurate estimation of mortality rates. Spectrum therefore calculates life expectancy at birth using model life tables, which conform with best available estimates of infant and adult mortality in each country. The impact of HIV/AIDS mortality, which occurs predominantly at adult ages, is then factored in using the AIDS Impact Model (AIM). Model life tables are used by almost all major reporting institutions to generate estimates of life at expectancy at birth in low income countries and can therefore be considered the best available approximation of the actual mortality experience within a country.

Figure 7 charts the change of ART coverage as a proportion of the total population between 2000-2017 across all countries in the main sample. ART coverage is recorded by AIM as zero for all years preceding 2000. As noted by Tompsett (2020), ART is likely to have a greater impact on country-level outcomes when the proportion of the population receiving ART is higher. Several countries have witnessed large expansions of ART across their populations during the period 2000-2017. These tend to be the countries that have been hardest hit by the HIV/AIDS epidemic, which are mainly located in eastern and southern Africa. Examples include Eswatini (Swaziland), Botswana and Lesotho, each of which have over 10% of their total populations receiving ART.

The absolute differences in life expectancies at birth between the years 2000 and 2017 are presented in Figure 8. Across all countries in the two panels, almost half (45%) of the countries experienced a gain in life expectancy at birth of more than 10 years. However, for high HIV countries (panel a) many of these gains would have be largely reduced or reversed completely under the no-ART counterfactual scenario. For instance, three countries (Eswatini, South Africa, and Lesotho) would have had lower life expectancies in 2017 than in 2000 without the introduction of ART. In addition, Botswana would have seen its 20 year gain in life expectancy substantially reduced to 3.8 years under the counterfactual scenario. These reductions are not borne out to the same extent in low HIV countries (panel b). Nevertheless, there are sizeable differences between the actual and counterfactual scenarios of around 3 years in countries such as Equatorial Guinea, Gabon and Rwanda.

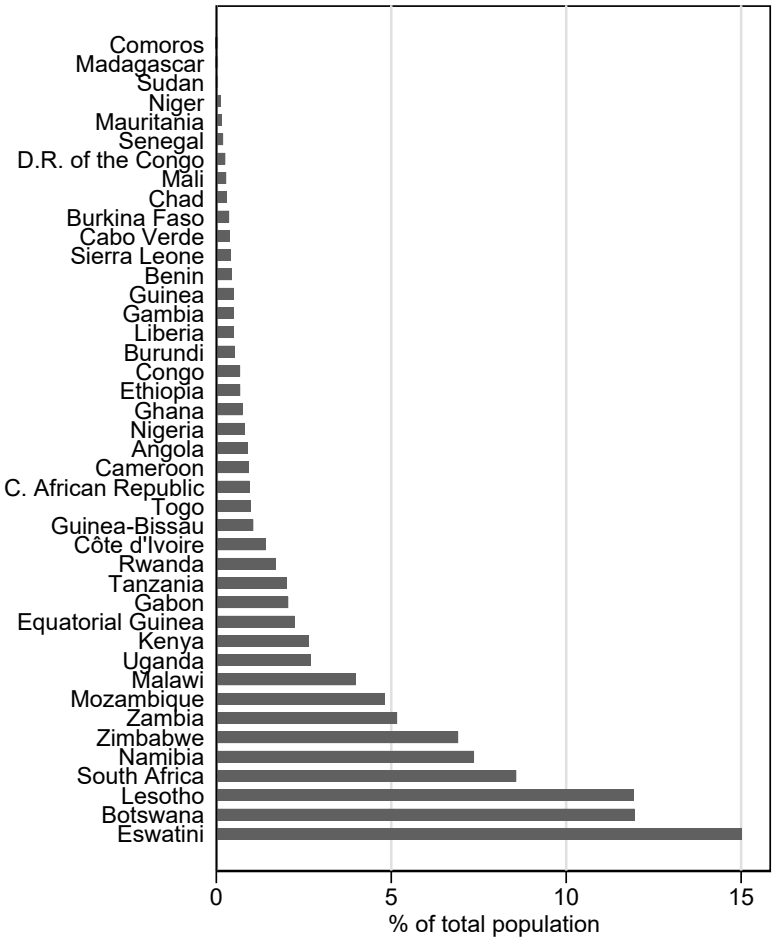
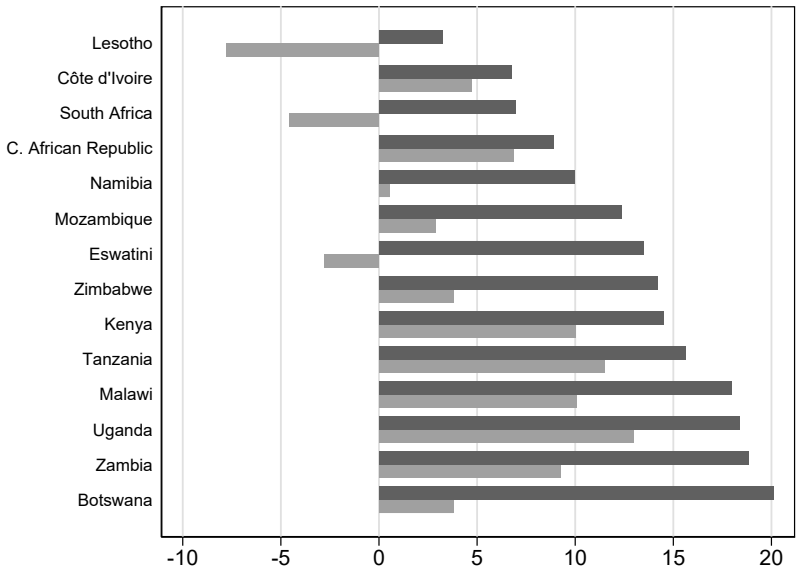


Figure 7: Change in ART coverage between 2000 and 2017

a) High HIV countries



b) Low HIV countries

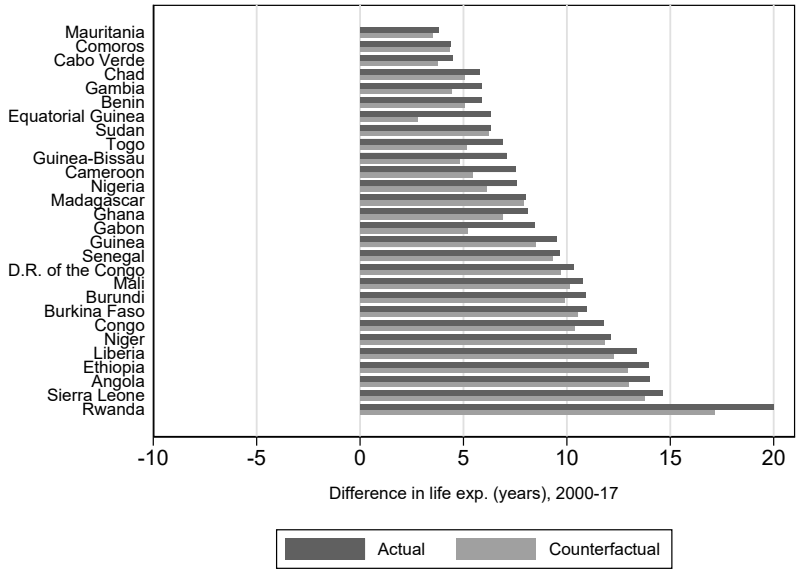


Figure 8: Absolute differences in actual and counterfactual life expectancy at birth, 2000-17

C Estimating counterfactual consumption levels

A priori, the effect of ART on average consumption per capita is ambiguous. On one hand, ART may directly improve productivity and increase levels of human capital accumulation, resulting in higher consumption levels. On the other hand, ART reduces mortality rates and thus leads to population growth. This demographic effect may reduce average consumption per capita in the short run. The relative balance of these two effects will determine the overall impact of ART on consumption.

To derive the counterfactual consumption level that would arise in the absence of ART coverage, I follow Tompsett (2020) and estimate the following equation:

$$\Delta lnc_{nt} = \pi ART_{nt} + a_n + \delta_t + \zeta_n t + \varepsilon_{nt} \,, \tag{14}$$

where Δlnc_{nt} is change in log consumption per capita in country n at time t and ART_{nt} is the proportion of the country n's population receiving ART at time t. The terms a_n and δ_t are country specific and time fixed effects respectively. Country specific linear trends are captured by ζ_n. The idiosyncratic error terms is denoted by ε_{nt}.

The estimation of π via OLS may be biased due to the correlation of unobserved factors in ε_{nt} with $ART_{n,t}$, that is $cov(ART_{nt}, \varepsilon_{nt} \neq 0)$. Tompsett (2020) highlights several sources bias in the context of income growth that are also relevant for the consumption case. First, international assistance for ART programmes may be focused in countries with lower consumption growth prospects, which would tend to downwardly bias π. Second, countries that are more successful at expanding ART programmes may also be performing well on other aspects that improve future consumption prospects, such as institutional quality. This would tend to bias the estimate of π upwards. Third, the expansion of ART coverage may be correlated with other changes that occured during the same time, such as booms in resource exports and simultaneous efforts to combat Malaria.[25]

To proceed, I employ the same empirical strategy as Tompsett (2020) to estimate equation 14. This involves using predicted ART coverage as an instrument for the observed changes in ART coverage, thereby exploting the variation in ART_{nt} that is uncorrelated with unobserved factors in ε_{nt}. Predicted ART coverage is

[25] Tompsett (2020) finds no evidence to suggest that the impact of ART on growth can be explained by trends in Chinese trade/capital flows, petroleum/export booms or Malaria ecology.

calculated as HIV prevalence in 2001 ($HIV_{n,2001}$), the time at which ART prices dropped precipitously and ART became more widely available, multiplied by the proportion of individuals living with HIV receiving ART across all low and middle income countries at time t, denoted by $\overline{ART}_t$. It therefore represents a situation in which the global expansion of ART was evenly distributed across all HIV positive individuals in low and middle income countries, while taking into account the baseline distribution of HIV prevalence. The first stage equation is then given as:

$$ART_{nt} = \zeta ART_{nt,pred} + \widetilde{a}_n + \widetilde{\delta}_t + \widetilde{\zeta}_n t + v_{nt} \, ,$$

where

$$ART_{nt,pred} = \varphi HIV_{n2001} \times \psi \overline{ART}_t \, . \tag{15}$$

This equation shows that the only variation in predicted ART arises from the baseline distribution of HIV prevalence. It therefore excludes variation due to differences in how effectively countries expand ART coverage, which could violate the assumption of $cov(ART_{nt}, \varepsilon_{nt} = 0)$.[26]

Table (5) presents the estimates of π in equation (14). The coefficients for the are remarkably similar to those estimated by Tompsett (2020), who uses GDP per capita instead of consumption, and exhibit a higher degree of statistical significance. Overall, the estimates suggest that a 1 percentage point increase in ART coverage leads to a 1.35 (95% CI: 2.51-0.20) percentage point increase in the growth rate of consumption. The corresponding estimate of Tompsett (2020) for the case of GDP per capita is 1.25 percentage points. Still there is a considerable amount of uncertainty as exhibited by the relatively large standard errors in the IV case.

To calculate the counterfactual consumption level $\hat{c_{nt}}$, I utilise the coefficient in column (2) to recover the proportion of growth due to ART coverage and reverse the first differencing of log consumption:

$$\hat{c_{nt}} = exp(lnc_{nt} - (\hat{\pi} ART_{nt})) \, , \tag{16}$$

[26] As required for a valid instrument, there is a strong association between predicted and observed ART coverage. See Tompsett (2020) for various tests of the exclusion restriction $cov(\varphi HIV_{i2001} + \psi \overline{ART}_t, \varepsilon_{it} \neq 0)$ with regards to income. I assume that the same exclusion restriction holds in the consumption context as well.

Table 5: The impact of ART on consumption per capita

	Change in log consumption per capita	
	(1)	(2)
	OLS	IV
ART coverage (% of population)	0.96**	1.35**
	(0.38)	(0.59)
First stage F statistic		68.50
Hausman test p value		0.172
N	1,134	1,134

Notes: Data from 1990-2017 for 42 SSA countries. Controls include country and time fixed effects, and country linear time trends. In columns 3 and 4, ART coverage is instrumented for using predicted ART coverage, which is overall coverage in low and middle income countries interacted with HIV prevalence in 2001. Hausman test tests exogeneity of observed ARV coverage. Standard errors are clustered at the country level and show in parentheses. ***p < 0.01, **p <0.05, *p<0.1.

where $\hat{\pi}$ is the coefficient estimated by OLS, which is assumed to be identical across all countries. Figure 9 presents the resulting growth rates in actual and counterfactual over the period 2000-17 for high HIV countries only. Differences between growth rates between the two scenarios in low HIV countries are relatively small since only small proportion of the population are treated with ART. Within high HIV countries, the estimates suggest that growth over the period would have been around 10% lower, on average, in the counterfactual no-ART scenario. There is some variation between countries, with Botswana displaying the largest difference in growth between the two scenarios.

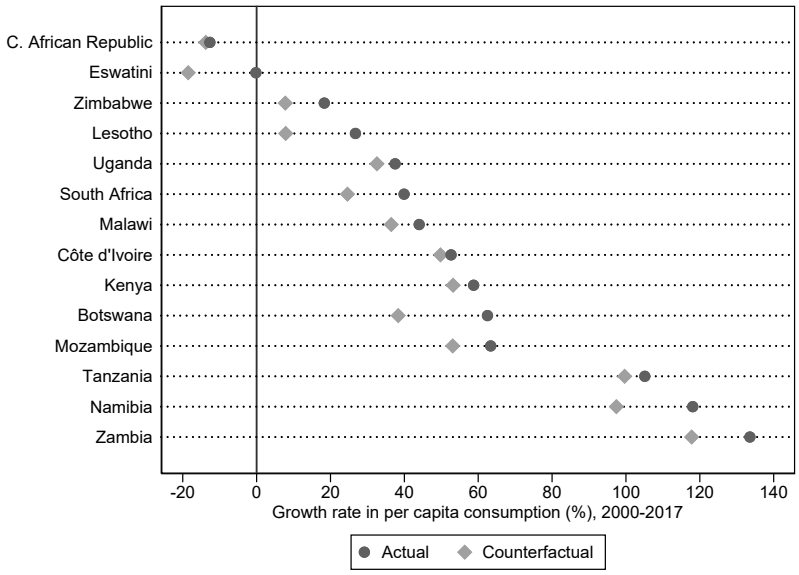


Figure 9: Growth rates of actual and counterfactual consumption (%), high HIV countries, 2000-17

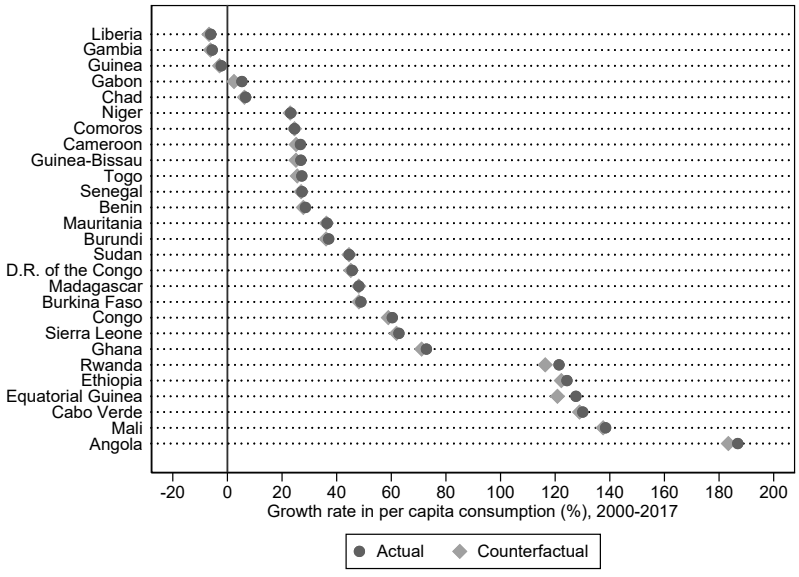


Figure 10: Growth rates of actual and counterfactual consumption (%), low HIV countries, 2000-17

D Additional figures and tables

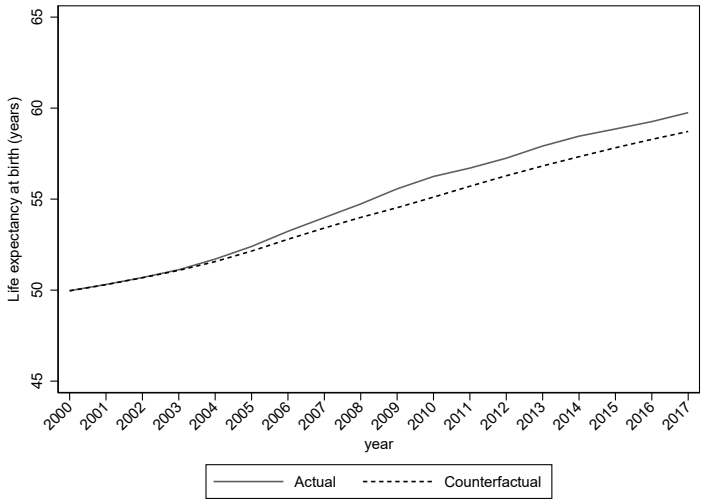


Figure 11: Actual and counterfactual life expectancy at birth (low HIV countries), 2000-2017.

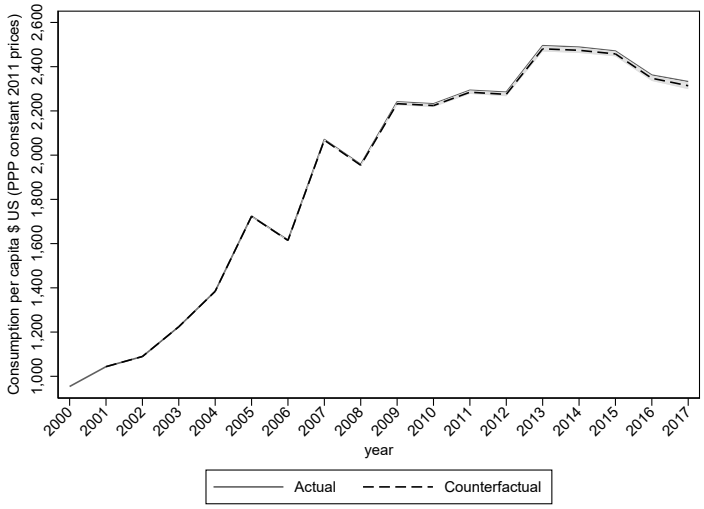


Figure 12: Actual and counterfactual consumption per capita (low HIV countries only), 2000-2017. Notes: 95% confidence interval shaded.

Table 6: Welfare growth statistics with a lower VSL-consumption threshold, 2000-2017

	Average annual growth rates				Decomposition of welfare growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Region	Cons.	Welfare	Welfare (c.f.)	Diff.	Life exp. ART	Cons. ART	Life exp. other	Cons. other
SSA	4.09	6.47	5.40	1.07	0.78	0.29	1.60	3.80
SSA (w)	10.94	14.97	13.76	1.22	0.92	0.29	3.11	10.65
Std. dev.	6.53	8.26	7.95	1.33	0.97	0.38	1.83	6.49
High HIV	3.14	6.00	3.54	2.46	1.78	0.68	1.08	2.46
Low HIV	4.57	6.70	6.32	0.37	0.28	0.10	1.85	4.47

Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Cons. stands for consumption per capita. All figures are reported in percentages. Welfare defined as equivalent consumption. Column (3) gives the growth rate of equivalent consumption in the no-ART scenario. Column (4) reports the difference between columns (2) and (3). Columns (5) and (6) may not always sum to the difference in (4) due to rounding. Second row figures for SSA are weighted by country population size. High HIV countries defined as those with prevalence rates (% aged 15-49 years) greater than 5% in 2000. Parameters are calibrated using 2017 values to yield a $VSL = 100 * c$

Table 7: Value of ART-related gains with a lower VSL-consumption threshold, summary statistics, 2000-2017

			Value of ART in terms of annual cons.		
	(1)	(2)	(3)	(4)	(5)
	Gain in life exp. due to ART	Gain in cons. due to ART	Value of ART life exp. gains	Total value of ART gains	% of mean cons. 2017
SSA	3.7	165	370	535	11
SSA (w)	3.0	102	228	329	8.3
Std. dev.	4.5	359	787	1,142	15
High HIV	8.7	433	969	1,402	28
Low HIV	1.2	32	70	102	3

Notes: regional averages for 42 countries based author's calculations using equations (6), (8) and (9). Parameters are calibrated using 2017 values to yield a $VSL = 100 * c$. Cons. stands for consumption per capita. Second row SSA values are weighted by country population size. Columns (3) and (4) measured in $US (PPP constant 2010 prices). High HIV countries defined as those with prevalence rates (% aged 15-49 years) greater than 5% in 2000.

Table 8: Value of ART gains over time, high HIV countries, 2000-17

	(1)	(2)	(3)	(4)
	$VSL = 170 * c$		$VSL = 100 * c$	
Country	Total value of ART gains (annual cons.)	% of mean cons. 2017	Total value of ART gains (annual cons.)	% of mean cons. 2017
Botswana	8,179	81.7	4,586	45.8
C. A. R	120	15.5	59	7.6
Côte d'Ivoire	269	9.3	160	67.4
Eswatini	7,836	109.4	4,826	5.5
Kenya	589	20.1	316	10.8
Lesotho	1,986	56.6	1,571	44.7
Malawi	634	54.2	286	24.5
Mozambique	534	49.4	297	27.5
Namibia	4,025	41.5	2,588	26.7
South Africa	4,237	43.7	3,027	31.2
Tanzania	379	20.6	186	10.1
Uganda	586	40.7	250	17.3
Zambia	1,758	69.2	791	31.2
Zimbabwe	1,279	64.6	688	34.8

Notes: Columns (1) and (3) are reported in annual consumption $US (PPP constant 2011 prices). Columns (2) and (3) report the value of ART as a percentage of the absolute change in welfare.

Table 9: Value of ART gains over time, low HIV countries, 2000-17

	(1)	(2)	(3)	(4)
	$VSL = 170 * c$		$VSL = 100 * c$	
Country	Value of ART gains (annual cons.)	% of mean cons. 2017	Total value of ART gains (annual cons.)	% of mean cons. 2017
Angola	188	7.1	106	3.3
Benin	52	3.1	33	1.9
Burkina Faso	40	3.0	23	1.6
Burundi	37	4.7	21	2.5
Cabo Verde	93	1.6	66	1.1
Cameroon	236	9.2	139	5.2
Chad	50	4.1	29	2.3
Comoros	2	0.1	1	0.0
Congo	114	5.7	67	3.1
D.R.C	21	3.2	11	1.7
Eq. Guinea	1,669	15.5	1,061	9.6
Ethiopia	42	4.3	26	2.3
Gabon	574	10.7	382	6.8
Gambia	107	4.5	66	2.7
Ghana	164	4.3	106	2.6
Guinea	94	4.5	55	2.5
Guinea-Bissau	176	10.3	105	5.9
Liberia	38	5.1	21	2.6
Madagascar	3	0.2	2	0.1
Mali	85	3.6	46	1.8
Mauritania	23	0.9	15	0.6
Niger	10	1.4	6	0.7
Nigeria	343	9.7	191	5.1
Rwanda	227	15.1	122	6.8
Senegal	28	1.1	18	0.7
Sierra Leone	151	10.9	61	4.0
Sudan	10	0.4	6	0.2
Togo	101	7.0	63	4.2

Notes: Columns (1) and (3) are reported in annual consumption $US (PPP constant 2011 prices). Columns (2) and (3) report the value of ART as a percentage of the absolute change in welfare.