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Modeling the Macroeconomic Effects of AIDS, with an Application to Tanzania

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A Solow-style model is developed to study the effects of the AIDS epidemic on the growth path of the economy and GDP per capita. The model uses conjectures about the demographic effects of AIDS in Tanzania to estimate the macroeconomic effects on the economy. The findings suggest that, without decisive policy action, AIDS may reduce Tanzanian GDP in the year 2010 by 15 to 25 percent in relation to a counterfactual no-AIDS scenario. Per capita income levels are expected to fall by 0 to 10 percent by 2010.

The acquired immunodeficiency syndrome (AIDS) epidemic in Africa has received considerable attention by epidemiologists and demographers, as well as health economists concerned with the sectoral impact of the disease. Given the alarming—and still growing—prevalence of the disease within various regions in Côte d'Ivoire, Kenya, Malawi, Tanzania, Uganda, Zaire, and Zimbabwe, several questions are now being raised: Will AIDS have important macroeconomic effects on the stricken societies? If so, what will these effects be, and to what extent can various policies alter them?

This article develops a simple but tractable framework for analyzing the effects of AIDS on the growth paths of potential gross domestic product (GDP) and per capita GDP. The classic Solow (1956) growth model is extended to incorporate the key macroeconomic consequences of AIDS. Using this model, AIDS and no-AIDS scenarios are compared analytically and through simulations based on Tanzanian demographic and macroeconomic data.

Section I discusses various channels through which AIDS might affect the macroeconomy and describes its expected demographic impact in Tanzania. A model incorporating these key channels is developed in section II. The model is used to discuss the likely effect on the ratio of capital to labor and on output per capita as the economy moves from a no-AIDS situation toward a new steady

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state, in which AIDS is assumed to be endemic. Although comparing steady states is useful for developing intuition about the possible consequences of AIDS, the directions of several key effects are shown to be ambiguous. Furthermore, the time horizon needed to reach a new steady state may be very long indeed, given the epidemiological and demographic dynamics of a disease like AIDS. To address these concerns, section III uses a simple simulation model to forecast the time paths of macro aggregates in Tanzania as the prevalence of AIDS rises. These time paths are compared with simulated results for a no-AIDS situation to determine the severity of the impact of the disease on the growth path of the Tanzanian economy. Bulatao's (1990) demographic scenarios for the no-AIDS case and a rather pessimistic AIDS scenario are used as inputs in the simulated version of the model. (A brief appendix relates the growth model approach developed here to the human capital approach, which is commonly used in the health economics literature.) Section IV concludes with a tentative discussion of the policy implications of the analysis.

I. Channels of the Macroeconomic Influence of AIDS

The rising prevalence of AIDS can be expected to affect the macroeconomy through several separate channels. At the most primitive level, the effects of AIDS can be grouped into two categories: those associated with rising morbidity and those associated with rising mortality rates for particular age cohorts, especially sexually active adults and children infected at birth.

Rising Morbidity

The rise in morbidity will have two immediate effects: a negative labor productivity effect and a positive health care expenditure effect. These effects, in turn, may alter savings behavior as well as investment in education. The negative labor productivity effect will arise because sick or worried workers are less productive than happy, healthy workers. Even the productivity of those who do not have AIDS may be negatively altered as infection rates and illness among friends, families, and coworkers rise.

The positive health care expenditure effect refers to increased expenditures by households and the (public or private) health care system to assist AIDS patients and their families in coping with deteriorating health.[1] Pallangyo and Laing (1990) estimate that in Tanzania, for example, the average cost incurred per adult AIDS patient over the duration of the patient's illness is approximately T Sh50,139, assuming that the present centralized health care delivery system (not home-based care) remains in place and that 60 percent of the required drugs for treatment are actually available. For children, the corresponding figure is

1. Care must be taken to consider the difference in health expenditures in the no-AIDS and AIDS scenarios, because health care costs that are not related to AIDS may be reduced if individuals die earlier and more quickly as a result of AIDS. Also, changes in the age structure may affect health care costs per capita.

T Sh34,395. These figures imply annual costs per adult patient of T Sh33,426 and per child patient of T Sh34,395, under the assumption that the typical adult with AIDS lives one and a half years and the typical child with AIDS one year.[2] Comparing these figures with Tanzania's per capita income, which was roughly T Sh12,590 in 1988, it is clear that these AIDS-related health care costs could become a tremendous burden as the epidemic worsens.[3]

As health care costs rise because of AIDS, there will be a negative domestic saving effect, except in the unlikely case where the entire increase in medical spending is paid for by reducing other current expenditures. The AIDS epidemic will affect saving through several mechanisms: The direct effect of higher medical expenditures will presumably reduce saving as well as nonhealth current expenditures to some extent. In addition, AIDS may affect saving through its effect on the growth rate, life expectancy, age structure, and healthiness of the population. Whether the negative saving effect falls primarily on private or public saving will depend to a large extent on the nature of the health care delivery system. The fall in domestic saving will imply a reduction in capital formation, which in turn will lead to a potentially large adverse effect on per capita income over the long term. In addition to the direct dissaving effect, AIDS may increase precautionary demand for saving by households that experience greater income variability in the presence of AIDS.

In all likelihood, higher medical expenditures—and ultimately higher funeral costs—will reduce other current expenditures, not just saving. Funeral costs can be very large in traditional societies, where workers must stop working and travel great distances to pay their last respects. Families with the AIDS illness may attempt to increase saving in anticipation of having to pay large funeral expenses in the not-too-distant future. And anecdotal evidence suggests that reduced spending on education (reduced supply) may be an important consequence of ballooning health care expenditures. The demand for education may also be reduced as children are forced to leave school earlier to support ill parents. The potential for adverse growth effects from AIDS will be heightened to the extent that investment in human capital is reduced.

The adverse effect of AIDS on the stock of human capital will have several related aspects, which will depend in part on whether the human capital is acquired through experience (learning by doing) or is the result of investments in education or on-the-job training programs. The analytical and simulation models below focus on experience-based human capital; no explicit decision to invest in education is involved. To the extent that AIDS causes experienced

2. The World Bank (1992) estimates that 90 percent of children with AIDS die within one year and 100 percent die within two years. As for adults with AIDS, it is estimated that 80 percent die within one year and 90 percent within two years.

3. It is difficult to obtain detailed information on AIDS-related health costs, days of illness, and other related statistics. Despite these difficulties, Scitovsky and Over (1988) have compiled evidence from various sources showing medical costs per person per year between one and ten times the value of per capita GDP for a selected group of industrial and developing countries in the mid-1980s.

workers in the current work force to die prematurely, it will erode the existing human capital stock and hence national output. Additional losses (in relation to the no-AIDS scenario) will cumulate over time as AIDS shifts the composition of the labor force permanently toward younger, less-experienced workers.

In the case of human capital resulting from investment in education and training, by contrast, the effects of AIDS will be slightly different. Again, there will be the loss (unanticipated at the time of investment) of existing human capital as previously educated workers die prematurely. In addition, as AIDS becomes more prevalent, the perceived costs and benefits from undertaking new investments in human capital will change.[4] Total expenditure will shift toward health care and away from schooling. To the extent that AIDS reduces expected lifetime, the incentives for individual workers or their employers to invest in education and training will also be reduced. Shifts in the relative wages of skilled and unskilled workers caused by differences in the prevalence of AIDS among various skill groups might also affect decisions to invest in human capital.

Rising Mortality Rates

The gradual rise in mortality rates caused by AIDS will have two important demographic aspects, which in turn will have macroeconomic consequences.

First, there will be a *negative population growth rate effect,* which will result in a smaller population at each future date. The presumption from demographic simulations is that the effect of higher death rates will more than offset any change in birth rates, so that the population growth rate will indeed fall. There are at least two reasons why birth rates may be affected by the AIDS epidemic: (a) fertility rates may change if, as the prevalence of AIDS rises, women alter their childbearing behavior because of various economic and noneconomic considerations (which could cut in either direction), and (b) AIDS may change the number of women in the various childbearing-age cohorts, thereby affecting the overall birth rate, even if behavior patterns within each age cohort are unchanged. Bulatao's (1990) model incorporates the latter effect, but (understandably) not the former, as it would require that the model completely endogenize fertility decisions. According to Bulatao's demographic simulations, the size of Tanzania's working-age population by 2010 will be roughly 20 percent smaller because of the AIDS epidemic than it would be without it.

Second, a rising number of deaths from AIDS will shift the age structure of the population toward the younger-age cohorts.[5] Bulatao (1990) estimates that the AIDS epidemic in Tanzania will have opposing effects on the youth and elderly

4. One might view the first effect as a "stock" effect, which results from the unexpected negative shift in health after the investments are made. The second effect is an ongoing "flow" effect, which depends on how AIDS affects both the supply and demand for investments in education and training.

5. For interesting, recent discussions of the macroeconomic effects of the aging of the population in major industrial countries, see Masson and Tryon (1990) and the references listed there. To the extent that AIDS causes the age distribution to shift away from the elderly, one might expect macroeconomic consequences that are roughly the opposite of what Masson and Tryon predict for an aging population.

dependency ratios:[6] between 1985 and 2000 the youth dependency ratio (the number of people ages 0 to 14 as a fraction of the number of people ages 15 to 64) will rise a couple of percentage points more than it would if there were no AIDS; the elderly dependency ratio (the number of people age 65 and older as a fraction of the number of people ages 15 to 64) will be slightly higher with AIDS than without until 2000, after which it will fall during the next 20 years by roughly 2 percent more than it would if there were no AIDS. (The higher elderly dependency ratio up to 2000 is presumably because the first AIDS cases appeared only in the late 1970s and AIDS-related mortality rates are increasing more dramatically in the younger-adult cohorts, at least initially.) In sum, the AIDS epidemic will reduce the overall size of the population and will shift its composition toward the young. The labor force, in turn, will be composed of younger, less-experienced workers. According to Bulatao's estimates, the mean age of the working-age population (15 to 64 years of age) will fall from 32 years in 1985 to 28 years in 2020 with AIDS, compared with 31 to 31.5 years in 2020 without AIDS.

The foregoing shifts in age structure can be expected to have important effects on both aggregate supply and aggregate demand. On the supply side, the size of the working-age population (and perhaps the participation rate of the labor force) will be reduced. The smaller working-age population will directly reduce potential output (even if participation rates and the rate of capital investment are unaffected). The loss in output will be exacerbated by a fall in labor force productivity as the average age and experience of the labor force declines.

On the demand side, the shift in the size and composition of the population will affect the level and the composition of public expenditures, as well as the economy's overall (private and public) saving rates. For example, the smaller absolute number of younger people will place lower demands on the educational system. In per capita terms, by contrast, educational expenditures may rise because of the increased proportion of the young in the total population. The resulting effect on the government budget will be exacerbated because more and more of the young will be orphans as the AIDS epidemic worsens, implying higher government costs (if not total social costs) of raising children.

If the elderly dependency ratio falls, per capita expenditures on health and pensions and social security (where present) will fall, other things being equal. A higher youth dependency ratio, however, is often associated with higher medical expenditures in developing countries. Of course, the emergence of AIDS hardly leaves other things equal where health care costs are concerned. Presumably the higher health care costs arising from AIDS will overwhelm any net change in health costs associated with a younger population, although this should be investigated more thoroughly.

6. The shift in the population age structure toward the young is apparent when five-year age cohorts are examined. See Cuddington (1991b) for details.

Finally, overall consumption rates will be higher (and therefore household saving rates will be lower) because of the younger age structure, which should affect saving rates through standard life cycle savings channels. In addition, the severing of generational linkages among dynastic households (as parents die, leaving children either as orphans or in the care of grandparents of other relatives) will also adversely affect saving rates.

II. A Simple Analytical Model

This section describes an initial attempt to model the macroeconomic consequences of the AIDS epidemic. The model is a version of the simple Solow growth model, which has been extended to incorporate many of the considerations highlighted in section I. The Solow growth model is not without shortcomings. To focus squarely on the growth process, the model abstracts from unemployment and short-run macroeconomic stabilization issues. In effect, it makes the optimistic assumption that policymakers are able to implement stabilization and structural adjustment policies that keep the economy near its capacity level. The model obviously has important limitations, especially when studying African economies, most of which have suffered from chronic unemployment or underemployment. To completely capture the macroeconomic effects of AIDS would require addressing the additional (and difficult) question of whether the AIDS epidemic will increase or decrease the extent of unemployment.

Nevertheless, the highly aggregated model continues to be a workhorse model in the economic development literature (see, for example, Lucas 1988). It stresses the linkages between population growth and capital accumulation, on the one hand, and the resulting ratio of capital to labor and per capita income levels on the other. Thus, the model is a logical starting point for a study on the macroeconomic effects of AIDS. One must first determine how AIDS affects capacity output, that is, potential GDP, before considering persistent deviations from full capacity and the effect of AIDS on employment levels.

Cuddington (1991a) considers a slightly more disaggregated model, where production can occur either in the formal or informal sectors of the economy. The formal sector is relatively capital-intensive, has sticky wages, and has access to formal credit markets. The informal sector employs those who are unable to find (more highly paid) work in the formal sector. This perspective seems particularly relevant given the dualistic nature of many of the AIDS-stricken African economies. This article, however, highlights the major conceptual issue involved without the additional complexity that the two-sector framework inevitably entails.

The Solow model is well known; hence, the extension of it used here is sketched only briefly to show how the effects of AIDS are introduced.[7]

7. See Cuddington (1991b) for mathematical details on the material in this section.

Aggregate Output

Aggregate output, Y_t, is assumed to be produced using Cobb-Douglas technology with constant returns to scale:

$$Y_t = \alpha \gamma^t E_t^{\beta} K_t^{1-\beta} \tag{1}$$

where E_t represents labor input measured in efficiency units and K_t is the capital stock. The labor share of national output is denoted by β, and the rate of technological change over time by γ. A constant scale factor denoted by α is adjusted to fit the model to the actual data in 1985, the first year of the simulation.

The extent of the AIDS epidemic is measured by the proportion of the population that has AIDS, denoted by a_t. The negative effect of the prevalence of AIDS on output arises from the adverse effect of AIDS on the health, experience level, and size of the labor force. These considerations are incorporated in the calculation of labor efficiency units E_t:

$$E_t = \sum_{i=15}^{64} (1 - za_{it})\, \rho_i L_{it} \tag{2}$$

where L_{it} is the number of workers of age i at time t, and z indicates the fraction of the work year lost per AIDS-stricken worker as a result of absence or reduced productivity on the job. The loss may be not only in the AIDS victim's labor but also in the labor of others. Thus, z does not necessarily lie between 0 and 1. For example, if a person who gets AIDS stops working immediately and that person's spouse also must stop work to provide full-time care, then $z = 2$.

The parameter ρ_i captures the experience, and hence productivity level, of laborers of age i without AIDS. Average experience is adversely affected as the worsening AIDS epidemic shifts the age structure in favor of younger, less-experienced workers. That is, aggregate human capital accumulated through experience is lost because workers, on average, die at a younger age.

A direct measure of work experience is unavailable. Thus, it is assumed that a worker's experience can be roughly proxied by taking the worker's age and subtracting 15 years. Studies of the relation between earnings (and presumably productivity) and experience suggest a positive but nonlinear relation between the two variables. Consequently, the simulation model assumes that labor efficiency (without AIDS) for a worker of age i is:

$$\rho_i = 0.8 + 0.02\,(i-15) - 0.0002\,(i-15)^2. \tag{3}$$

The parameters were chosen to produce productivity differentials that are in the range of values suggested by de Beyer's (1990) estimated earnings functions for workers in the manufacturing sector. No cohort-specific information exists on the prevalence of AIDS or the associated productivity loss (a_{it} or z) for Tanzania. Hence, population averages are used for each cohort.

In addition to its negative impact on labor productivity, AIDS reduces the size of the labor force (in relation to the no-AIDS scenario) as mortality rates rise.

This effect is captured by specifying that AIDS has a negative effect on the population growth rate at time t, denoted n_t:

$$n_t = n_t(a_t) \quad \text{where} \quad \partial n / \partial a < 0. \tag{4}$$

In the simulation model, mortality rates are specified for each age cohort. This information is used to generate population growth and the number of persons with and without AIDS as the epidemic worsens.

Saving Behavior

The model developed here focuses on the direct effect of increased health care expenditures on saving. Assume that annual health care expenditures on AIDS patients equals a given per-patient cost, m, multiplied by the number of patients, $a_t L_t$.[8] A fraction, x, of the annual AIDS-related medical costs is financed out of saving, and the remaining portion $(1 - x)$ is reflected in a reduction of other current expenditures.[9] The value of x presumably lies between 0 and 1 if only the direct health care costs of AIDS are considered. If other channels through which AIDS may affect saving are considered, however, x may be greater than 1. With these assumptions, total domestic saving is:

$$S_t = s_0 Y_t - x\, m\, a_t L_t \tag{5}$$

where s_0 is the domestic saving rate out of GDP without AIDS. By assuming that s_0 remains unchanged as the prevalence of AIDS rises, all but the direct dissaving effect of AIDS is ignored. This specification of total domestic saving implies that the saving rate (the ratio of domestic saving to GDP) falls as the prevalence of AIDS or the health care cost per patient, or both, rises. For notational simplicity in the analytical model, the saving rate is written as a negative function of the prevalence of AIDS:

$$s = s(a_t) \quad \text{where} \quad \partial s / \partial a < 0. \tag{6}$$

In addition to domestic saving, capital accumulation may be financed by foreign capital inflows. The ratio of capital inflows to GDP is assumed to equal s^* in both the no-AIDS and the AIDS scenarios. Assuming that foreign capital inflows are in the form of foreign aid, the model can ignore any capital outflows representing returns to foreign-owned capital.

Capital Accumulation

As in the Solow (1956) growth model, the change from period to period in the ratio of capital to labor ($k = K/L$) can be written as:

$$\Delta k = [s(a) + s^*] f(k, a) - n(a)\, k - \theta k \tag{7}$$

8. The constant per-patient medical cost implies that there are no scale economies in caring for AIDS patients. This implication seems indisputable when considering decentralized care systems (home care) for AIDS patients, but it may or may not be realistic for centralized provision of AIDS care.

9. In part, reductions in other current expenditures may reflect reductions in health costs that are not related to AIDS as AIDS-related expenses rise.

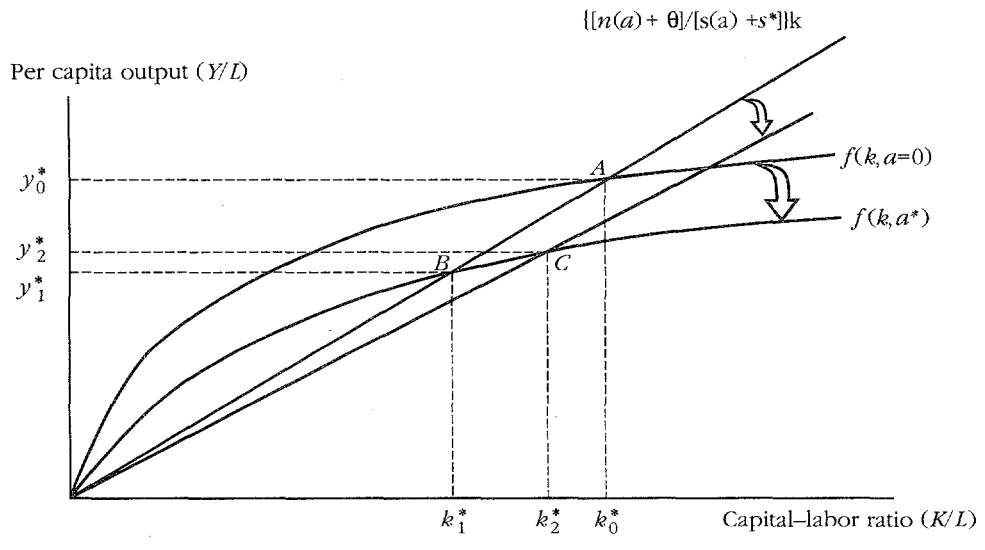
where $f(k, a)$ is production per worker. The total saving rate is denoted by $s(a) + s^*$ and the capital depreciation rate by θ. The first term in equation 7 shows that, as the prevalence of AIDS increases, its negative impact on labor productivity and national saving will tend to reduce the rate of capital formation. These effects tend to reduce the ratio of capital to labor over time. Working in the other direction (as reflected in the second term in equation 7), however, is the negative longer-term effect of AIDS on the labor force growth rate, which tends to raise k over time. The ultimate effect of these offsetting influences on the steady-state ratio of capital to labor, k^*, is found by setting capital accumulation per capita to 0 in equation 7:

$$y^* \equiv f(k^*, a^*) = \frac{n(a^*) + \theta}{s(a^*) + s^*} k^*. \tag{8}$$

The equilibrium ratio of capital to labor, k^*, and the corresponding output per worker, y^*, are shown in figure 1, which plots the left- and right-hand sides of equation 8. The point where the two loci intersect represents the steady-state values of y^* and k^*.

Using the model as summarized by figure 1, it is possible to analyze the effect of an exogenous rise in the prevalence of AIDS, a_t, on GDP per capita and the ratio of capital to labor. First, the increase in the prevalence of AIDS shifts the aggregate production function downward (as shown) because of the negative effect of deteriorating health on labor productivity. Later, the rising share of younger, less-experienced workers exacerbates this downward shift of the production function. The negative productivity effect, taken in isolation, reduces both out

Figure 1. *The Effect of AIDS on Per Captia Output and the Capital–Labor Ratio*



put per capita and the ratio of capital to labor in the new steady state (and along the transition path). Second, the AIDS epidemic ultimately reduces the labor force growth rate, which tends to flatten the $[(n + \theta)/(s + s^*)]k$ locus in figure 1. Working in the other direction is the negative effect of AIDS on the saving rate and hence the rate of capital accumulation, which tends to steepen the $[(n + \theta)/(s + s^*)]k$ locus. In principle, either the population growth rate effect or saving rate effect could dominate, so the $[(n + \theta)/(s + s^*)]k$ could become steeper or flatter. The new y^* and k^* are found where the new production function $f(k, a^*)$ intersects the new $[(n + \theta)/(s + s^*)]k$ locus. Clearly, per capita income and the ratio of capital to labor may be higher or lower with the spread of AIDS.

The simulation exercises in the following section trace out the time paths of the y and k (as well as other macro) variables between 1985 and 2010. Detailed demographic output from Bulatao's (1990) epidemiological-demographic simulation model for Tanzania is used in macroeconomic projections for the no-AIDS and AIDS cases. The simulations shed some additional light on the direction and range of plausible magnitudes of the macroeconomic effects of AIDS. Furthermore, they describe the transition path of the economy between 1985 and 2010 as the AIDS epidemic worsens, rather than just compare the steady states with and without AIDS. (Of course, the Tanzanian economy will not yet have reached a with-AIDS steady state by 2010.)

III. Simulation Exercises

The basic demographic input for the macro simulation model includes Bulatao's (1990) projections for the number of persons in each five-year age cohort in each year from 1985 through 2010 in both his no-AIDS scenario and his modified standard AIDS scenario. The latter scenario should be interpreted as a worst-case scenario because it is based on the assumption that only 15 percent of the adult population is monogamous. Although the simple analytical model in section II assumes that the entire population is in the labor force, the simulation exercises divide the population into five-year age cohorts. The labor force is assumed to be comprised of working-age adults, defined as people who are ages 15 to 64.[10] Bulatao's projections on total AIDS cases in the adult population are used to calculate variable a_t, the proportion of the working-age population with AIDS.[11]

10. This assumption is necessitated by the lack of detailed information about the labor force in Tanzania. Available evidence, however, suggests that the labor force participation rate is greater than 90 percent, so the assumption should be reasonable.

11. The demographic simulations of Bulatao specify the number of HIV-positive individuals in the population. The number of AIDS cases is determined by using assumptions about the rate of progression to the AIDS illness. In the simulation exercises below, a_t reflects only actual AIDS cases. It excludes people who are HIV-positive but asymptomatic on the presumption that productivity does not deteriorate and medical bills do not mount until the onset of AIDS-related illness.

The AIDS simulations differ from those of the no-AIDS scenario in several ways. First, the prevalence of AIDS in adults, a_t, rises from 0.09 percent in 1985 to 3.15 percent in 2010, whereas a_t is (by definition) always 0 in the no-AIDS case. Second, the size of the population is smaller in the AIDS scenario because of higher mortality rates. Third, the age structure shifts in favor of the younger age cohorts, resulting in a lower average age of the work force in the AIDS scenario.[12]

Assumptions Used in the Simulations

Both child and adult cases of AIDS are considered in the calculation of the annual medical costs of treating AIDS patients. In light of the figures discussed in section I, the annual cost of treating an adult AIDS patient, m_a, is assumed to be (constant 1980) T Sh3,230. The corresponding figure for children with AIDS, m_c, is T Sh2,467.

Historical data on GDP, gross fixed investment, foreign capital inflows, and gross domestic saving were used to get rough orders of magnitude for the key parameters and starting values for the macro variables in the model.[13] Gross investment was roughly 21 percent of GDP during 1966–80, of which 11 percent was financed by domestic saving. The remaining 10 percent, therefore, was financed by foreign saving.[14] The simulations assumed that foreign capital inflows would continue at their historical rate of 10 percent of GDP and that, in the no-AIDS scenario, domestic saving would remain at its historical norm. Because of the lack of empirical information about the effect of AIDS on domestic saving, a range of values for the x parameter in equation 5 was considered.

Given the estimates of the initial capital stock,[15] the labor force, and the shares of labor and capital, the scaling constant in the production function was chosen to ensure that the value of 1985 GDP implied by the production function matched the actual value. The assumed rate of technological change was then adjusted to achieve a rate of growth in per capita output under the no-AIDS scenario equal to roughly 0.5 percent between 1990 and 2000 (the rate forecast in World Bank 1990a for Sub-Saharan Africa). This adjustment was made to generate a no-AIDS case that seemed plausible. The analysis then compared the

12. Bulatao's projected time series of the working-age population in the two cases are reproduced in Cuddington (1991b, tables 1 and 2).

13. Macroeconomic data were obtained from Tanzania (1979, 1981) except for the 1985 GDP, which is from World Bank (1990b).

14. World Bank (1990b) reports a higher fraction of total investment that is foreign-financed. During 1968–88, foreign capital inflows (measured by the resource balance) represented roughly 17 percent of GDP. This figure implies a domestic saving rate of 5 percent. In the simulation model, only the total (domestic plus foreign) saving ratio matters, not its breakdown.

15. Estimates of the capital stock are typically unavailable in developing countries. Therefore, several different methods were used to estimate the economy's overall ratio of capital to output (K/Y) in 1985. (See Cuddington 1991b for details.) Using a value of 3 (chosen after some experimentation) and the actual value of the 1985 GDP, an estimate of the capital stock in 1985 was obtained. The capital stock in subsequent years was calculated by adding new investment and subtracting depreciation at an assumed rate of 5 percent.

Table 1. *Macroeconomic Indicators in the AIDS Scenario in Tanzania*

AIDS costs met from reduced saving, x (fraction of annual AIDS-related medical costs)	*Indicator*	*Labor productivity lost per AIDS case, z (fraction of work year lost)* 0.0	0.5	1.0	1.5	2.0
0.0	GDP in 2010 (millions of 1980 Tanzanian shillings)	89,859	88,708	87,555	86,399	85,241
	Average growth rate of GDP, 1985–2010 (percent)	3.3	3.3	3.2	3.2	3.1
	Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.20	2.17	2.14	2.11	2.08
	Average per capita growth rate of GDP, 1985–2010 (percent)	0.7	0.6	0.6	0.5	0.5
	Savings rate in 2010 (percentage of GDP)	0.11	0.11	0.11	0.11	0.11
0.5	GDP in 2010 (millions of 1980 Tanzanian shillings)	88,415	87,275	86,131	84,985	83,836
	Average growth rate of GDP, 1985–2010 (percent)	3.3	3.2	3.2	3.1	3.0
	Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.16	2.13	2.11	2.08	2.05
	Average per capita growth rate of GDP, 1985–2010 (percent)	0.6	0.6	0.5	0.5	0.4
	Savings rate in 2010 (percentage of GDP)	0.09	0.09	0.09	0.09	0.09
1.0	GDP in 2010 (millions of 1980 Tanzanian shillings)	86,909	85,778	84,644	83,508	82,369
	Average growth rate of GDP, 1985–2010 (percent)	3.2	3.1	3.1	3.0	3.0
	Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.13	2.10	2.07	2.04	2.01
	Average per capita growth rate of GDP, 1985–2010 (percent)	0.6	0.5	0.5	0.4	0.3
	Savings rate in 2010 (percentage of GDP)	0.08	0.08	0.08	0.08	0.08

results under the no-AIDS scenario with those under the AIDS scenario to determine the net effect of AIDS on the economy.

Simulation Results

There is obviously considerable uncertainty regarding the choices of two key parameters: the fraction of the annual AIDS-related medical costs financed out of saving, x, and the annual proportion of labor lost per AIDS-stricken worker as a result of absence or reduced productivity on the job, z. To date no estimate of the effect of AIDS on private or public saving is available. A rough order of magnitude for z can be obtained using Pallangyo and Laing's (1990) estimate that the average adult AIDS patient in Tanzania experiences 286 days of illness. If

Table 1. *(continued)*

AIDS costs met from reduced saving, x (fraction of annual AIDS-related medical costs)	*Indicator*	*Labor productivity lost per AIDS case, z (fraction of work year lost)* 0.0	0.5	1.0	1.5	2.0
1.5	GDP in 2010 (millions of 1980 Tanzanian shillings)	85,332	84,210	83,086	81,960	80,831
	Average growth rate of GDP, 1985–2010 (percent)	3.1	3.1	3.0	3.0	2.9
	Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.09	2.06	2.03	2.00	1.98
	Average per capita growth rate of GDP, 1985–2010 (percent)	0.5	0.4	0.4	0.3	0.3
	Savings rate in 2010 (percentage of GDP)	0.06	0.06	0.06	0.06	0.06
2.0	GDP in 2010 (millions of 1980 Tanzanian shillings)	83,677	82,564	81,450	80,334	79,215
	Average growth rate of GDP, 1985–2010 (percent)	3.0	3.0	2.9	2.9	2.8
	Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.05	2.02	1.99	1.96	1.94
	Average per capita growth rate of GDP, 1985–2010 (percent)	0.4	0.4	0.3	0.2	0.2
	Saving rate in 2010 (percentage of GDP)	0.04	0.04	0.04	0.04	0.04

Note: The following assumptions underlie the calculations in the AIDS scenario:

Value	*Parameter*
39,131	GDP in 1985 (millions of 1980 Tanzanian shillings)
3	Capital-output ratio in 1985 (K/Y)
0.7	Labor's share of output (β)
0.008	Productivity growth rate ($\gamma - 1$)
0.05	Depreciation rate (θ)
0.11	Initial savings rate (s)
0.10	Rate of capital inflow (s^*)
3.23	Medical cost of treating an adult AIDS patient for one year, m_a (thousands of 1980 Tanzanian shillings)
2.47	Medical cost of treating a child AIDS patient for one year, m_c (thousands of 1980 Tanzanian shillings)

Source: Author's calculations.

Table 2. *Macroeconomic Indicators in the No-AIDS Scenario in Tanzania*

Indicator	*Value*
GDP in 2010 (millions of 1980 Tanzanian shillings)	104,448
Average growth rate of GDP, 1985–2010 (percent)	3.9
Per capita GDP in 2010 (thousands of 1980 Tanzanian shillings)	2.19
Average per capita growth rate of GDP, 1985–2010 (percent)	0.7
Savings rate in 2010 (percentage of GDP)	0.11

Note: The parameter values in table 1 also apply here, except that $m_c = m_a = 0$.
Source: Tanzania (1979, 1981) and World Bank (1990b).

adult AIDS patients live approximately one and a half years but are absent from work for 286 days, the productivity loss can easily reach 50 percent (x would equal 0.5) even if the patients and their family members are fully productive on all other days.

Sensitivity analysis was used to identify the range of plausible estimates for the macroeconomic consequences of the AIDS epidemic. Simulations of the AIDS scenario were run using alternative values (ranging from 0 to 2) for the two key AIDS-related parameters in the model, namely, the annual labor productivity lost per AIDS patient, z, and the proportion of AIDS-related medical expenditures that comes out of reduced saving, x, rather than current consumption. Table 1 projects what GDP and its average growth rate, per capita GDP and its average growth rate, and the saving ratio will be in 2010 under alternative (x, z) assumptions.[16] To assess the macroeconomic consequences of AIDS, these figures should be compared with the projections for the no-AIDS case, shown in table 2. For example, consider the plausible AIDS scenario in which the productivity of those with the disease is cut in half ($z = 0.5$) and half of the medical expenditure for aids patients is financed by reducing domestic saving ($x = 0.5$). In this case real GDP grows at an average rate of roughly 3.2 percent a year (compared with 3.9 percent without AIDS), so that the level of real GDP by 2010 is (constant 1980) T Sh87 billion (compared with T Sh104 billion). That is, under the AIDS scenario in which both x and z are 0.5, the economy is approximately 16 percent smaller by 2010 than it would be if there were no AIDS epidemic. The effect of AIDS on per capita income is much smaller. Per capita income grows 0.6 percent a year in the AIDS scenario, compared with 0.7 percent in the no-AIDS scenario. By 2010 in the AIDS scenario, growth in per capita GDP is roughly 2.7 percent smaller than in the no-AIDS scenario (2.13 compared with 2.19).

The parameter values in tables 1 and 2 give a range of plausible estimates for the economic effects of the epidemic. The presence of AIDS reduces the average real GDP growth rate in 1985–2010 from 3.9 percent to a range of 2.8 to 3.3 percent, depending on the chosen (x, z) parameters. Not surprisingly, real GDP is lower in each future period in the AIDS scenario because of the smaller, less-experienced work force. The size of the economy by 2010 is reduced by 15 to 25 percent, from a real GDP of (constant 1980) T Sh104 billion without AIDS to a range of T Sh79 billion to T Sh89 billion in the various AIDS scenarios.

The effect of AIDS on per capita GDP is more moderate: per capita GDP in 2010 ranges from 0.5 percent larger to 11 percent smaller than it would be without AIDS. Per capita GDP is forecast to grow at an average annual rate of 0.7 percent in the no-AIDS scenario, compared with 0.2 to 0.7 percent in the various AIDS cases. The more plausible outcomes, near the upper left of the matrix, exhibit the lowest declines in per capita GDP.

16. See Cuddington (1991b) for tables and graphs showing the time profiles of selected variables with and without AIDS.

The estimated effects of AIDS on future GDP are large, but there are several reasons why the estimates may be too conservative. Output losses related to AIDS will be larger under any of the following circumstances: (a) if there are significant scale economies in production (rather than constant returns to scale, as assumed here); (b) if there is a large positive production externality generated by human capital, as discussed in Lucas (1988), among others; (c) if account is taken of the lost educational investment when young workers die shortly after completing their schooling; (d) if AIDS infection rates are higher among the highly educated or urban members of society who have higher than average productivity; and (e) if AIDS treatment diverts health resources from the treatment of other diseases or general prophylactic efforts, causing the death toll from non-AIDS causes to rise. These points will presumably be addressed in future research on AIDS.

IV. Concluding Remarks

This article has developed a framework for analyzing the macroeconomic consequences of the AIDS epidemic by comparing no-AIDS and AIDS scenarios to isolate the effects of the disease on the growth path of the economy. The macroeconomic consequences of various policy options for the health sector could, in principle, be compared by using the same approach. A policy's impact on the size and composition of the labor force would first have to be simulated by using epidemiological and demographic models. The output from these models plus information on the effects of alternative programs on budgets and savings could then be used as inputs in macroeconomic models, such as the one presented here. When considering policies to control and cope with a devastating disease such as AIDS, it is imperative to account for the direct effects of the disease on individuals' well-being through increased morbidity and mortality rates as well as the indirect effects of the disease on worker productivity and hence the potential to earn income. If linked to an epidemiological and demographic simulation model, a macroeconomic model such as the one described here should be able to analyze the effect of various interventions in the health sector on the productive capacity of the economy. To the extent that such interventions reduce the rate at which the disease spreads, one would expect macroeconomic outcomes that lie between the extremes of the no-AIDS and AIDS scenarios.

Finally, the sensitivity of the findings presented here to the assumptions regarding saving points to the urgency of careful reconsideration of government budget priorities. In economies in which the public sector bears a large proportion of medical costs, the government must make difficult decisions about how to finance medical expenditures as AIDS-related spending rises. To what extent should other current or capital expenditures, or both, be cut? The demographic shifts caused by AIDS will, of course, factor into these decisions. In light of the negative consequences of AIDS on the labor force, policy initiatives to restore productivity and maintain the stock of human capital will be critical for achieving economic growth with high levels of employment.

Appendix. Comparing the Growth Model and Human Capital Approaches to Measuring the Economic Impact of Disease

A common methodology used by health economists to assess the total indirect costs of premature death is the human capital approach. King and Smith (1988) provide a thorough review of the literature using this approach. For an application to the AIDS epidemic, see Over, Bertozzi, and Chin (1989). The human capital approach typically estimates the value of productivity lost (because of AIDS-related illness or death, for example) by computing the present value of the stricken individual's future earnings under certain assumptions about his or her life-cycle wage profile and future participation in the labor force. The earnings stream is typically discounted to the time of death or initial illness.

It is useful to compare the human capital approach to the growth model approach developed here. Both approaches allow for the reduced productivity of sick workers (represented by $z > 0$ in the model in the text). Furthermore, this productivity loss may depend on the age of the worker (indicated by equation 3 in the present context). Using these inputs, the human capital approach focuses on estimating the cost of individual cases of the disease in terms of present value. Furthermore, the human capital approach does not recognize that part of the income lost as a result of AIDS-related deaths would have been saved, thereby contributing to domestic capital formation. Thus, the negative impact on the economy's productive capacity is ignored in assessing the cost of AIDS. Similar assumptions can be introduced into my model by setting the labor share, β, at 1, so that differential saving effects play no role in determining the workers' ratio of output to income. With $\beta = 1$, the production function becomes linear in labor input, which is in effect the assumption implicit in the marginal analysis of the human capital methodology. When β is not equal to 0, by contrast, the production function exhibits diminishing marginal productivity of labor—which would make assumptions of constant income losses per worker invalid. Yet this assumption is implicit in the use of the human capital approach when valuing the total economic loss caused by a multitude of AIDS-related deaths.

Finally, the growth model approach highlights the total effect of the AIDS epidemic on various macroeconomic aggregates (including income lost) over time as the epidemic worsens. Steady-state effects can also be calculated, as shown above. Although it would be straightforward to calculate the present value of the total income lost because of the epidemic—as of some rather arbitrary point in time—this is not the main purpose of the growth model methodology.

One might argue that the human capital approach is better suited to estimating the marginal benefit of preventing a single case of HIV infection (as in, for example, Over, Bertozzi, and Chin 1989). The growth model approach, by contrast, is ideal for assessing the reductions in saving and worker productivity that would result in a lower per capita income despite the lower population growth rate brought on by AIDS.

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