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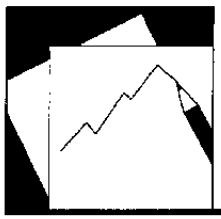

IMF Working Paper

Modeling the Macroeconomic Impact of HIV/AIDS

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Modeling the Macroeconomic Impact of HIV/AIDS

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Abstract

The paper addresses the impact of HIV/AIDS on per capita output and income, with particular emphasis on the role of labor mobility between the formal and informal sectors, and the impact of the epidemic on investment decisions. The study finds that HIV/AIDS affects both the supply of labor and the demand for labor in the formal sector. Only if there is a significant rise in the capital-labor ratio, will there be an increase in formal sector employment. However, this is associated with a decline in the rate of return to capital. To the extent that companies respond to this by reducing investment, conventional models underestimate the adverse impact on employment, per capita output, and income. The analysis of the impact of HIV/AIDS on output is complemented by an assessment of the impact on income.

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I. Introduction

The HIV/AIDS epidemic has a devastating impact on many countries in sub-Saharan Africa, resulting, for example, in a manifold increase in mortality rates for the working-age population,[2] a significant deterioration in the quality of health services,[3] a decline in the quality of public education,[4] an increase in economic risk,[5] and a rise in production costs.[6,7] The focus of the present study is on the impact of HIV/AIDS on per capita income. In particular, it addresses two issues:

- Most of the economies worst affected by HIV/AIDS are characterized by high rates of unemployment or a high share of the working population in the informal sector. Various authors have argued along the lines that "per capita output might actually rise as workers involved in low-productivity activities fill the vacancies created by AIDS in the more productive formal sector".[8] However, this is not obvious, as higher costs or a decline in the supply of skilled workers would also result in a decline in the demand for unskilled workers in the formal sector. Unlike earlier papers, which calibrated the overall effect of HIV/AIDS on per capita income in a dual economy, the present study provides a theoretical analysis of the role of labor mobility between the formal and the informal sector.

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[2] For example, the International Programs Center at the U.S. Bureau of the Census estimates the mortality rate for the adult population in Zimbabwe for the year 2002 at 3.1 percent, 2.9 percent of which is attributed to HIV/AIDS.

[3] There are abundant reports on hospitals overcrowded owing to an increasing number of AIDS patients. The situation differs substantially across countries and regions; for Southern Africa, most reports indicate that 50-70 percent of hospital beds are occupied by patients who are HIV positive.

[4] The epidemic affects both the supply of education (through increased mortality of teachers) and the demand for education (through lower birth rates, increased infant mortality, and falling enrollment rates). For most countries in the region, pupil-teacher ratios are projected to increase, owing to the HIV/AIDS epidemic; see also Haacker (2002).

[5] In the absence of medical or life insurance (as is common in many African countries, especially in the informal sector), the illness and death of a breadwinner have a negative and oftern catastrophic impact on a household's income and wealth.

[6] Most important, through absenteeism, increased training costs, disruptions to the production process, and medical and death-related costs.

[7] Haacker (2002) provides a broader discussion of the economic consequences of HIV/AIDS. A recent report by the International AIDS Economics Network on "State of the Art: AIDS and Economics" (see IAEN (2002)) includes survey articles on a broad range of issues.

[8] See, for instance, Cuddington and Hancock (1994).

- In most studies on the impact of HIV/AIDS on economic growth or per capita income, the negative impact of declines in productivity or the supply of human capital is at least partly offset by an increase in the (physical) capital-labor ratio.[9] Aggregate changes in savings rates appear to be relatively small, and the steady state capital-labor ratio rises as the growth rate of the working population declines. However, a significant increase in the capital-labor ratio is associated with a substantial decline in the rate of return to capital, and the assumption that this would not affect the investment behaviour is questionable. To clarify how this affects estimates of the macroeconomic impact of HIV/AIDS, we use a model in which domestic investment rates do respond to changes in the rate of return to capital.

Section II discusses various approaches to modeling the impact of HIV/AIDS on per capita income, broadly distinguishing among the basic neoclassical growth model, simple dual-economy models, and various multisector models. In particular, this section addresses how the impact of HIV/AIDS differs between a simple dual-economy model and a one-sector neoclassical growth model. Section III focuses on the role of capital mobility in the context of the neoclassical growth model and the dual-economy model. Section IV explores a setting in which there is a pool of unemployed unskilled workers. Section V summarizes the findings and concludes. The Appendix provides a numerical example for the models discussed in this paper.

[9] Compare the studies referred to in the opening section of Section II.

II. HIV/AIDS and Per-Capita Income

By now, a large number of different models have been developed to address the macroeconomic impact of HIV/AIDS. The one-sector neoclassical growth model was first applied in this context in the early 1990s,[10] and several authors extended this approach to capture various features of a dual economy.[11] More recently, there have been attempts to incorporate the impact of HIV/AIDS into more elaborate macroeconomic models.[12] Some studies have attempted an econometric analysis of the impact of HIV/AIDS on economic growth.[13] Below, we focus on the impact of HIV/AIDS in a neoclassical closed economy setting, with particular emphasis on the role of labor mobility between the formal and the informal sector. While the emphasis of the analysis is on qualitative aspects of the model, the Appendix provides a numerical example for the one-sector model and the dual-economy model discussed here.

A. The One-Sector Neoclassical Growth Model

In the context of the one-sector neoclassical growth model, the HIV/AIDS epidemic may affect per capita income through its impact on total factor productivity, capital accumulation, the growth rate of the labor force, and labor productivity. Regarding the impact on the labor force, most authors distinguish between the supply of skilled and unskilled labor. More formally, the aggregate production function may take the form

$$Y = AK^{\alpha}(e_H p_H L)^{\beta}(e_U p_U L)^{\gamma}, \tag{1}$$

where $\alpha+\beta+\gamma=1$; p_H stands for the proportion of highly-skilled agents in the working population L; p_U $(=1-p_H)$ stands for the proportion of unskilled agents; e_H and e_U are efficiency parameters for each group; Y, A, and K represent output, total factor productivity, and capital, respectively. The capital stock evolves according to

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[10] See Cuddington (1993a) for Tanzania, Cuddington and Hancock (1994) for Malawi, or Haacker (2002) for several countries in Southern Africa.

[11] See Over (1992), Cuddington (1993b) for Tanzania, Cuddington and Hancock (1995) for Malawi, and BIDPA (2000) or MacFarlan and Sgherri (2001) for Botswana.

[12] See Kambou, Devarajan and Over (1993), who use an 11-sector CGE model for Cameroon. ING Barings (2000), Arndt and Lewis (2001), and BER (2001) apply different models to study the impact of HIV/AIDS in South Africa.

[13] See Bloom and Mahal (1997), Bonnel (2000), or Dixon, McDonald, and Roberts (2001).

$$\dot{K} = sY - \delta K; \tag{2}$$

the savings rate s may comprise domestic savings, as well as (net) foreign direct investment. The supply of labor grows at rate n.[14] Transforming the model into per capita terms and solving for the steady state capital stock (k^*) and output level (y^*) yields

$$k^* = \left(\frac{sA}{\delta+n}\right)^{\frac{1}{\beta+\gamma}} (e_H p_H)^{\frac{\beta}{\beta+\gamma}} (e_U p_U)^{\frac{\gamma}{\beta+\gamma}} \quad \text{and} \quad y^* = A^{\frac{1}{\beta+\gamma}} \left(\frac{s}{\delta+n}\right)^{\frac{\alpha}{\beta+\gamma}} (e_H p_H)^{\frac{\beta}{\beta+\gamma}} (e_U p_U)^{\frac{\gamma}{\beta+\gamma}}. \tag{3}$$

Haacker (2002) links the level of total factor productivity to AIDS prevalence in the working population, drawing on various case studies; in Arndt and Lewis (2001), AIDS prevalence affects the rate of growth of TFP. If HIV/AIDS disproportionally affects the unskilled population, the share of highly skilled workers in the population (p_H) will rise.[15] Whereas most empirical studies on the link between human capital and economic growth focus on educational attainment, the HIV epidemic primarily affects the per capita level of human capital through increased mortality, which causes the share of more experienced agents in the working population to fall.[16] Many studies on the impact of HIV/AIDS therefore assume a link between labor productivity (e_H and e_U, respectively) and the age structure of the population, based on empirical wage equations.[17] BIDPA (2000), for example, estimates the following relationships for a worker of age i:

$$\begin{aligned} e_{H,i} &= 6.2 + 0.067(i-20) - 0.0012(i-20)^2 \\ e_{U,i} &= 5.6 + 0.027(i-15) - 0.0006(i-15)^2 \end{aligned} \tag{4}$$

[14] Throughout the paper, we assume that skilled and unskilled labor grow at the same rate n.

[15] The picture regarding the socioeconomic gradient of the epidemic (i.e., how it affects different subgroups of the population) is not clear. Women are affected worse (and at a younger age); various professions (most notably sex workers and migrant workers) are at higher risk; at least in the early stages of the epidemic, HIV prevalence rates tend to be higher in urban areas. However, there is no clear pattern across countries regarding the level of skills. One recent study for South Africa (BER, 2001) suggests that, while HIV prevalence rates are similar for the unskilled and skilled, they are somewhat lower for the highly skilled (about 10 percent of the labor force). BIDPA (2000) does not differentiate between skill levels.

[16] The International Programs Center at the U.S. Bureau of the Census, for example, estimates that life expectancy in Zimbabwe has fallen from 65 years to 39 years.

[17] With the exception of Over (1992), all studies listed in footnotes 9 and 10 follow this approach.

Regarding the impact of HIV/AIDS on savings rates, some studies link the decline of savings to required health expenditure, and make assumptions as to how much of this is financed out of savings or by a reduction in current consumption. Others focus on households' savings behavior, e.g. assuming that households affected by AIDS do not save.[18] Most recently ecently, Freire (2002) addresses the impact of increased mortality on savings in a life cycle model.

Finally, the HIV/AIDS epidemic results in a decrease of the growth rate of the working-age population (through higher mortality and lower birth rates), which does have a positive impact on the capital-labor ratio.

B. The Dual Economy

The one-sector neoclassical growth model assumes full employment and the absence of distortions in the labor market. Applied to the study of HIV/AIDS in a low-income country with a large informal sector and/or underemployment, this model may, therefore, yield misleading results. In particular, some analysts have suggested that workers in the formal sector who die from AIDS will be replaced by unemployed workers, thereby reducing unemployment and raising per capita income. Several studies therefore add an informal sector, characterized by low capital intensity and a high share of unskilled workers.[19,20]

Unlike these earlier studies, which use a dual-economy model to calibrate the overall impact of HIV/AIDS on per capita income, the present paper explicitly analyses the role of labor mobility. To this end, we use a two-sector neoclassical growth model. The formal sector uses capital, skilled labor, and unskilled labor. The informal sector draws on capital

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[18] Both these approaches have serious drawbacks; however, given the scarcity of microeconomic data on households affected by HIV/AIDS in sub-Saharan Africa, they serve as useful approximations. One issue that is frequently raised in discussions is the savings behavior of people who are HIV positive (but have not developed any symptoms yet). Finding out about an HIV infection shortens an individuals life expectancy, and an optimizing agent would respond by increasing current consumption. At the same time, the news reduces this household's expected lifetime income; if there are relatives to care for, or in anticipation of treatment costs, the agent may actually increase savings.

[19] See footnote 11 for a list of studies following this approach.

[20] For an alternative setting featuring unemployed unskilled workers who do not contribute to aggregate output, see Section IV.

and unskilled labor only, and is less capital-intensive than the formal sector.[21] We further assume that the parameter describing the efficiency of unskilled labor (parameter e_U, above) is the same for the formal and the informal sector, and that capital accumulation in the informal sector is limited to savings generated within the sector. As unskilled agents may now work in the formal and informal sector, labor market clearing requires that $L_U = L_{U,i} + L_{U,f}$. To allow for labor market imperfections, a parameter λ defines a wedge between wages for unskilled workers in the formal and the informal sectors,[22] which means that

$$w^*_{U,f} = \lambda w^*_{U,i}, \text{ with } \lambda \geq 1. \tag{5}$$

In these circumstances, informal sector output takes the form

$$Y_i = A_i K_i^{\alpha_i} (e_U L_{U,i})^{\gamma_i}, \tag{6}$$

with $\alpha_i + \gamma_i = 1$. The steady state output per capita and the (unskilled) equilibrium wage rate for the informal sector are given by

$$y_i^* = (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U, \tag{7}$$

$$\text{and} \quad w^*_{U,i} = \gamma_i (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U. \tag{8}$$

For the formal sector, aggregate output takes the form

$$Y_f = A_f K_f^{\alpha_f} (e_H L_H)^{\beta_f} (e_U L_{U,f})^{\gamma_f}, \tag{9}$$

with $\alpha_f + \beta_f + \gamma_i = 1$. The formal sector is assumed to be more capital intensive than the informal sector, implying that $\alpha_f > \alpha_i$ or, equivalently, $\gamma_i > \beta_f + \gamma_f$. The amount of

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[21] The assumption that the informal sector does not use skilled labor does not affect our results, provided that the share of skilled worker is higher in the formal sector, but it does simplify the formal analysis significantly.

[22] This could, for instance, reflect efficiency wages and/or asymmetric information. As it is not clear how this wedge would change in response to the HIV/AIDS epidemic using either model, we do not attempt to endogenize λ. Note that, for $\lambda = 1$, the model encompasses the case of perfect mobility of unskilled labor.

unskilled labor used in the formal sector is endogeneous in the dual-economy model and depends on the unskilled wage rate (see eq. (5)). Using Eq. (8) and Eq. (5) (with $\partial Y_f / \partial L_{U,f} = w^*_{U,f} = \lambda w^*_{U,i}$) to substitute for $e_U L_{U,f}$ in eq. (9), we obtain

$$Y_f = A_f^{\frac{1}{\alpha_f+\beta_f}} \left[\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta+n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\alpha_f-\beta_f}} K_f^{\frac{\alpha_f}{\alpha_f+\beta_f}} (e_H L_H)^{\frac{\beta_f}{\alpha_f+\beta_f}} . \qquad (10)$$

In equilibrium, the capital stock grows at the same rate (n) as skilled and unskilled labor. Defining $\bar{y}_f = Y_f / (e_H L_H)$ and $\bar{k}_f = K_f / (e_H L_H)$, and using the fact that in steady state $s_f \bar{y}_f = (\delta+n)\bar{k}_f$, the steady state level of capital per efficiency unit of skilled labor for the formal sector is

$$\bar{k}_f = A_f^{\frac{1}{\beta_f}} \left[\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta+n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\beta_f}} \left(\frac{s_f}{\delta+n} \right)^{\frac{\alpha_f+\beta_f}{\beta_f}} , \qquad (11)$$

and the steady state level of formal sector output is equal to

$$Y_f = A_f^{\frac{1}{\beta_f}} \left[\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta+n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\beta_f}} \left(\frac{s_f}{\delta+n} \right)^{\frac{\alpha_f}{\beta_f}} e_H L_H . \qquad (12)$$

To obtain the steady state level of total output, it is necessary to determine the allocation of unskilled labor between the formal and the informal sectors. The formal sector wage for an unskilled worker with efficiency e_U is equal to $w_{U,f} = \gamma_f Y_f / L_{U,f}$. Using Eqs. (5), (8), and (12), it follows that

$$e_U L_{U,f} = (A_f)^{\frac{1}{\beta_f}} \left(\frac{s_f}{\delta+n} \right)^{\frac{\alpha_f}{\beta_f}} \cdot \left(\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta+n} \right)^{\frac{\alpha_i}{\gamma_i}} \right)^{\frac{-(\beta_f+\gamma_f)}{\beta_f}} e_H L_H . \qquad (13)$$

Eq. (13) can be used to analyze the implications of the HIV/AIDS epidemic on the allocation of unskilled labor between the formal and the informal sectors.

It can easily be shown that changes in sector-specific variables (like A_f, A_i, s_f, and s_i) do have the expected effect on the allocation of unskilled labor: A decline in A_f or s_f results in a reallocation of labor away from the formal sector, a decline in A_i or s_i is associated with a reallocation of labor towards the formal sector. However, this result is little helpful in the present context, as the HIV/AIDS epidemic does affect the two sectors simultaneously. Regarding such simultaneous shocks, we find the following:

(1) A proportional decrease in the supply of skilled and unskilled labor (L_H and L_U) would leave the allocation of unskilled labor (in percent) unchanged. If, however, this is associated with an increase in mortality rates, and, say, the efficiency of skilled labor e_H is more sensitive to this than e_U, the relative size of the formal sector will shrink.[23]

(2) A decline by A_f and A_i by the same proportion results in a shift of unskilled labor to the informal sector, provided that the elasticity of output with respect to capital is higher in the formal sector, that is, $\alpha_f > \alpha_i$.[24]

(3) Similarly, provided that $\alpha_f > \alpha_i$, an equiproportionate decline in the savings rates for the formal and informal sector will result in a reallocation of labor to the informal sector.

(4) However, a decline in the rate of population growth, raising the capital-labor ratio in the formal sector relative to the informal sector, would cause the share of unskilled labor in the formal sector to rise.

To obtain the impact of HIV/AIDS on total output $Y (=Y_f+Y_i)$, denote the share of the formal sector in output by σ, and the share of the unskilled workforce working in the formal sector by ρ. The percentage change in total output, as HIV/AIDS affects productivity (A_f, A_i), savings rates (s_f, s_i), the rate of population growth (n), the efficiency of labor (e_H, e_U), and the size of the skilled and unskilled labor supply (L_H, L_U), is equal to:

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[23] See, for example, BIDPA (2000), quoted in Eq. (4).

[24] This result reflects the fact that the impact of a change in total factor productivity (A) on the steady state capital stock is larger when the elasticity of output with respect to capital is higher.

$$\frac{dY}{Y}=\sigma\left[\frac{1}{\beta_f}\left[\frac{dA_f}{A_f}+\alpha_f\frac{ds_f}{s_f}-\frac{\alpha_f dn}{(\delta+n)}\right]-\frac{\gamma_f}{\gamma_i\beta_f}\left[\frac{dA_i}{A_i}+\alpha_i\frac{ds_i}{s_i}-\frac{\alpha_i dn}{(\delta+n)}\right]+\frac{de_H}{e_H}+\frac{dL_H}{L_H}\right]$$
$$+(1-\sigma)\left[\frac{1}{\gamma_i}\left[\frac{dA_i}{A_i}+\alpha_i\frac{ds_i}{s_i}-\frac{\alpha_i dn}{(\delta+n)}\right]\right] \qquad (14)$$
$$+\frac{1}{1-\rho}\left[\frac{de_U}{e_U}+\frac{dL_U}{L_U}\right]-\frac{\rho}{1-\rho}\left[\frac{1}{\beta_f}\left[\frac{dA_f}{A_f}+\alpha_f\frac{ds_f}{s_f}-\frac{\alpha_f dn}{(\delta+n)}\right]-\frac{\beta_f+\gamma_f}{\gamma_i\beta_f}\left[\frac{dA_i}{A_i}+\alpha_i\frac{ds_i}{s_i}-\frac{\alpha_i dn}{(\delta+n)}\right]+\frac{de_H}{e_H}+\frac{dL_H}{L_H}\right]$$

Eq. (14) describes the percentage change in output in terms of the share of the formal sector in output σ, multiplied by the percentage change in formal sector output (row 1, compare Eq. (12)), plus the share of the informal sector in output, multiplied by the percentage change in output per efficiency unit of unskilled labor (row 2, compare Eq. (7)) and the percentage change in efficiency units of unskilled labor in the informal sector (row 3, compare Eq. (13)).

Simplifying Eq. (14) by combining similar terms yields

$$\frac{dY}{Y}=\frac{\sigma-\rho}{\beta_f(1-\rho)}\left[\frac{dA_f}{A_f}+\alpha_f\frac{ds_f}{s_f}-\frac{\alpha_f dn}{(\delta+n)}\right]+\frac{-\sigma\gamma_f+(1-\sigma)\left[\beta_f-\frac{\rho(\beta_f+\gamma_f)}{1-\rho}\right]}{\gamma_i\beta_f}\left[\frac{dA_i}{A_i}+\alpha_i\frac{ds_i}{s_i}-\frac{\alpha_i dn}{(\delta+n)}\right]. \qquad (15)$$
$$+\frac{\sigma-\rho}{1-\rho}\left[\frac{de_H}{e_H}+\frac{dL_H}{L_H}\right]+\frac{1-\sigma}{1-\rho}\left[\frac{de_U}{e_U}+\frac{dL_U}{L_U}\right]$$

To summarize, our analysis indicates that, in the dual economy, the formal sector is generally more responsive to common shocks. Thus, an equiproportionate decline in TFP in the respective sector, or a decline in the savings rate, will reduce the relative size of the formal sector. On the other hand, a decline in the rate of growth of the working population, by increasing the capital-labor ratio in the formal sector relative to the informal sector, will raise the share of the formal sector.[25]

This means that the hypothesis that HIV/AIDS will result in a decline in unemployment, as workers from the formal sector who die are replaced by unemployed workers or workers from the informal sector, is incomplete and potentially misleading: HIV/AIDS affects both the supply of and the demand for labor. In the context of the present model, the share of the formal sector expands only if the capital-labor ratio in the

[25] See the appendix for a numeric example.

formal sector expands sufficiently strongly relative to the informal sector, and that the size of this effect outstrips the adverse effects of a decline in productivity, savings rates, and the efficiency of skilled labor, which affect the formal sector more strongly than the informal sector

C. Multisector Models and Econometric Studies

While the focus of this paper is on modeling the impact of HIV/AIDS in the context of the neoclassical one- or two-sector models described above, a brief outline of alternative modeling strategies provides some useful context.

Three studies have recently analyzed the impact of HIV/AIDS in South Africa, using more complex macroeconomic models. A study commissioned by ING Barings South African Research emphasizes the impact of HIV/AIDS on the labor force (distinguishing among four skill levels) on productivity (through absenteeism and illness), on production costs, and on the demand for health services. They predict that, while the labor supply (weighted by skill level) will decline by 12.8 percent by 2010, real GDP will decline by 3.1 percent compared to a scenario without AIDS.[26] Arndt and Lewis (2001), using a 15-sector CGE model, draw on the same demographic projections as used in the ING Barings study. They project that GDP per capita will decline by 8 percent by 2010, relative to a no-AIDS scenario, and that domestic absorption excluding food, medical services, and HIV/AIDS-related government expenditure will fall by 13 percent. BER (2001) focuses on the epidemic's effects on the overall population and the labor force, direct and indirect costs to private businesses, and government and household expenditure. It finds that potential GDP growth will decline by between 1.4 percent and 1.8 percent between 2002 and 2015, and that per capita GDP growth will increase by 0.7 – 1.0 percent over the same period.

The econometric evidence on the impact of HIV/AIDS on economic growth is weak. An early study finds an insignificant link between real GDP growth and cumulative AIDS cases for a cross section of 51 countries until 1992.[27] Bonnel (2000) finds a negative relationship between HIV prevalence and growth of GDP per capita, postulating a direct effect of HIV/AIDS on GDP, as well as an indirect effect through the erosion of policy

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[26] This substantial increase in per capita income appears to be accounted for by a decline in unemployment and an increase in aggregate demand (in per capita terms).

[27] See Bloom and Mahal (1997).

institutions. Using panel data from 41 African countries between 1960 and 1998, Dixon, McDonald and Roberts (2001) find a significant effect of HIV/AIDS on health capital (as measured by life expectancy), but not a significant impact of health capital on growth. In interpreting these studies, however, it is important to bear in mind that HIV prevalence and AIDS deaths did not increase substantially in many African countries until the 1990s, and that the quality of the data, e.g. on output and HIV prevalence,[28] is relatively poor.

III. The Role of Capital Mobility

In the one-sector and the dual-economy models discussed above, the adverse impact of HIV/AIDS on per capita income through declines in total factor productivity and labor productivity is largely offset by an increase in the capital-labor ratio, associated with a decline in the rate of growth in the workforce. However, an increase in the capital-labor ratio is associated with a decline in the rate of return to capital, and it is unlikely that enterprises will continue to invest in the absence of adequate returns, or that banks will lend to domestic enterprises if they can get higher yields elsewhere.

In this section, we analyze the impact of HIV/AIDS with investment rates responding to changes in the rates of return to capital. As the focus of the paper is on the longer run, that is, on changes in the steady state level of output, we assume for the one-sector model that capital is perfectly mobile, and that the returns to capital are tied to the yields of some alternative foreign asset; this means that

$$\frac{\partial Y}{\partial K} = r^*. \tag{16}$$

For the dual-economy model, we maintain the assumption of segmented capital markets. While savings generated in the informal sector are invested in the informal sector, capital is perfectly mobile for the formal sector. Allowing for capital mobility, it is important to capture changes in net interest income from abroad, the analysis below therefore distinguishes between changes in output and changes in income (which includes interest income).

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[28] Aggregate HIV prevalence rates are generally estimated by fitting a demographic and epidemiological model to relatively few observations, mainly data on HIV prevalence among pregant women from from antenatal clinics. An alternative method focuses on trends in the pattern of mortality rates by age.

A. The One-Sector Neoclassical Growth Model

The steady state levels of the capital-labor ratio and of output per capita (using Eqs. (1) and (16)) are given by

$$k^* = \left(\frac{\alpha A}{r^*}\right)^{\frac{1}{\beta+\gamma}} (e_H p_H)^{\frac{\beta}{\beta+\gamma}} (e_U p_U)^{\frac{\gamma}{\beta+\gamma}} \tag{17}$$

$$\text{and} \quad y^* = \left(\frac{\alpha}{r^*}\right)^{\frac{\alpha}{\beta+\gamma}} A^{\frac{1}{\beta+\gamma}} (e_H p_H)^{\frac{\beta}{\beta+\gamma}} (e_U p_U)^{\frac{\gamma}{\beta+\gamma}}. \tag{18}$$

Comparing Eq. (18) with Eq. (3), we see that the impact of HIV/AIDS in the model with capital mobility is worse than for the closed-economy model. While the elasticity of steady state output with respect to a a decline in productivity A or the (average) efficiency of labor, $(e_H p_H)^{\frac{\beta}{\beta+\gamma}} (e_U p_U)^{\frac{\gamma}{\beta+\gamma}}$, is the same in both models, changes in the savings rate and, crucial in the present context, changes in the population growth rate do not have an impact on per-capita income in the model with capital mobility. If, for example, a decline in the rate of growth of the working population results in an (incipient) increase in the capital-labor ratio (and thus an increase in per-capita output), this means that the rate of return on capital would decline, and investors will reduce investment in the affected economy in order to keep the rate of return to capital in line with alternative assets. Thus, while much of the adverse impact of HIV/AIDS on per-capita income is offset or even reversed in the closed-economy model,[29] there is no such effect if investment decisions respond to changes in the rate of return to capital. This means that at least for the longer run, conventional closed-economy models are likely to understate the adverse impact of HIV/AIDS.

However, as domestic investors move funds abroad, this generates interest income and, unlike in the closed-economy model, the impact of HIV/AIDS on per-capita output and per-capita income may differ. Per capita income, denoted z, equals the share of skilled (β)and unskilled (γ) labor in output, plus the income from savings invested at interest rate r^* (either in the domestic economy, or abroad), which in steady state is equal to $\frac{r^* s}{\delta + n}$ (in percent of steady-state output.

[29] See the introduction to Section II.

$$z^* = \left[\beta+\gamma+\frac{r^* s}{\delta+n}\right]\left(\frac{\alpha}{r^*}\right)^{\frac{\alpha}{\beta+\gamma}} A^{\frac{1}{\beta+\gamma}}(e_H p_H)^{\frac{\beta}{\beta+\gamma}}(e_U p_U)^{\frac{\gamma}{\beta+\gamma}}. \tag{19}$$

While per capita output y^* does not respond to changes in s or n, per capita income z^* does.[30] However, provided that the economy's net foreign assets are not too large, it can be shown that the impact of HIV/AIDS on per-capita income, allowing for capital mobility, is worse than in the closed-economy model. Using Eq. (3) and (19), the impact of HIV/AIDS is worse in the model with capital mobility if

$$\frac{\alpha}{\beta+\gamma} > \frac{\frac{r^* s}{\delta+n}}{\beta+\gamma+\frac{r^* s}{\delta+n}}. \tag{20}$$

$$\text{or, equivalently,} \quad \alpha\frac{\beta+\gamma}{\beta+\gamma-\alpha} > \frac{r^* s}{\delta+n}. \tag{21}$$

Eq. (21) is satisfied provided that $r^* s/(\delta+n)$, which stands for steady-state interest income from capital invested at home and abroad, is not too large relative to α, the share of capital in domestic output, i.e. provided that the economy's net foreign assets are not too large. (Correspondingly, the impact will be worse the larger the economy's foreign debt.) Intuitively, this result obtains because, in the closed economy, the domestic capital stock and, thus, wages rise with per capita savings; in the economy with perfect capital mobility, they do not.

B. The Dual Economy

As in the discussion of the open economy, we maintain the assumption that the capital market is segmented within the economy, and that capital accumulation in the informal sector is limited to savings generated within the sector. The formal sector, however, is fully integrated in the international capital market.

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[30] This result points to some implications of the HIV/AIDS epidemic with respect to the distribution of wealth. While income for those who do not save (presumably, agents with lower income) goes down, the accumulation of wealth per capita for those who do save may increase. However, given the simplistic structure of the model used here, these conclusions are largely speculative.

For the informal sector, the analysis made above for the closed economy still applies, and the steady-state levels of output and the wage are are given by Eq. (7) and (8), reprinted for convenience:

$$Y_i^* = (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U L_{U,i}, \quad \text{and} \quad w_{U,i}^* = \gamma_i (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U .$$

Using the fact that $\partial Y_f / \partial K = r^*$, $\partial Y_f / \partial L_{U,f} = w_{U,f}^* = \lambda w_{U,i}^*$, and Eq. (7) for the steady state level of $w_{U,i}^*$, the steady state level of output for the formal sector can be written as

$$Y_f = (A_f)^{\frac{1}{\beta_f}} \left[\frac{r^*}{\alpha_f} \right]^{\frac{\alpha_f}{\beta_f}} \left[\frac{\lambda \gamma_i A_i}{\gamma_f} \left(\frac{s_i A_i}{\delta + n} \right)^{\frac{\alpha_i}{1-\alpha_i}} \right]^{\frac{-1}{\beta_f}} e_H L_H . \tag{22}$$

The allocation of unskilled labor to the formal sector is then determined by

$$e_U L_{U,f} = (A_f)^{\frac{1}{\beta_f}} \left[\frac{r^*}{\alpha_f} \right]^{\frac{\alpha_f}{\beta_f}} \cdot \left(\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right)^{\frac{-(\beta_f + \gamma_f)}{\beta_f}} e_H L_H . \tag{23}$$

The results from the above discussion still carry through, except that changes in the savings rate do not have an impact on the allocation of unskilled labor here. Similar to Eq. (14), the change in total output, as HIV/AIDS affects various economic and demographic variables, is summarized by Eq. (24).

$$\begin{aligned} \frac{dY}{Y} = \sigma & \left[\frac{1}{\beta_f} \frac{dA_f}{A_f} - \frac{\gamma_f}{\gamma_i \beta_f} \left[\frac{dA_i}{A_i} + \alpha_i \frac{ds_i}{s_i} - \frac{\alpha_i dn}{(\delta + n)} \right] + \frac{de_H}{e_H} + \frac{dL_H}{L_H} \right] \\ & + (1 - \sigma) \left[\frac{1}{\gamma_i} \left[\frac{dA_i}{A_i} + \alpha_i \frac{ds_i}{s_i} - \frac{\alpha_i dn}{(\delta + n)} \right] \right] \\ & + \frac{1}{1-\rho} \left[\frac{de_U}{e_U} + \frac{dL_U}{L_U} \right] - \frac{\rho}{1-\rho} \left[\frac{1}{\beta_f} \frac{dA_f}{A_f} - \frac{\beta_f + \gamma_f}{\gamma_i \beta_f} \left[\frac{dA_i}{A_i} + \alpha_i \frac{ds_i}{s_i} - \frac{\alpha_i dn}{(\delta + n)} \right] + \frac{de_H}{e_H} + \frac{dL_H}{L_H} \right] \end{aligned} \tag{24}$$

To obtain the impact of HIV/AIDS on income, rather than output, define

$$Z = r^* \cdot W + (\beta_f + \gamma_f) Y_f + Y_i , \tag{25}$$

that is, income Z is equal to the sum of the returns to accumulated (formal sector) savings W, which may be invested at home or abroad, wage income from the formal sector,

and informal sector output. With $W = s_f Y_f /(\delta+n)$ in steady state, the percentage change of total income, as various economic and demographic variables change, is determined by the following:

$$\frac{dZ}{Z} = \left[1+\sigma\left[\frac{r^* s_f}{\delta+n}-\alpha_f\right]\right]^{-1}\left[\frac{dY}{Y}+\sigma\frac{\frac{r^* s_f}{\delta+n}\left[d\frac{ds_f}{s_f}-\frac{dn}{(\delta+n)}\right]}{\beta_f+\gamma_f+\frac{r^* s_f}{\delta+n}}\right] \tag{26}$$

As for the one-sector model, it can be shown that the impact of HIV/AIDS on per-capita income is worse than in the closed economy, as long as

$$\frac{\sigma+\sigma\left[\frac{r^* s_f}{\delta+n}-\alpha_f\right]}{1+\sigma\left[\frac{r^* s_f}{\delta+n}-\alpha_f\right]}\frac{\frac{r^* s_f}{\delta+n}}{\beta_f+\gamma_f+\frac{r^* s_f}{\delta+n}} < \sigma\frac{\alpha_f}{\beta_f}. \tag{27}$$

Eq. (27) is satisfied for zero net foreign assets (i.e., $r^* s_f /(\delta+n) = \alpha_f$), as $\alpha_f < \alpha_f /\beta_f$ is always true in this model. As the left-hand side of Eq. (27) is increasing in $r^* s_f /(\delta+n)$, Eq. (27) may not be satisfied for high values of $r^* s_f /(\delta+n)$. This confirms the intuition from the one-sector model that the impact of HIV/AIDS on per-capita income will be worse than in the closed economy, provided that the economy's net foreign assets are not too large.

IV. A Model with Unemployed Unskilled Workers

In this section, we adapt the models used above to a setting in which there is a large pool of unemployed unskilled workers, which do not contribute to aggregate output. It is frequently suggested that, in this situation, increased mortality associated with an HIV/AIDS epidemic would result in an increase in per-capita output. Unlike in the dual economy model discussed above, unemployed workers who replace those who have died in the formal sector did not contribute to aggregate output previously. However, as in the models discussed above, HIV/AIDS does have an impact on the demand for labor.

In this setting, total output is equal to

$$Y = AK^{\alpha}(e_H L_H)^{\beta}(e_U L_{U,e})^{\gamma}, \tag{28}$$

where $L_{U,e}$ stands for employed unskilled workers. Unskilled workers have a reservation wage, which is equal to $\overline{w}$. As we assume that there are unemployed unskilled workers, the marginal product of labor is equal to the reservation wage in (this) equilibrium, and $\partial Y / \partial(e_U L_{U,e}) = \overline{w}$. Substituting for the demand for unskilled labor gives

$$Y = A^{\frac{1}{\alpha+\beta}} \left[\frac{\overline{w}}{\gamma}\right]^{\frac{-\gamma}{\alpha+\beta}} K^{\frac{\alpha}{\alpha+\beta}} (e_H L_H)^{\frac{\beta}{\alpha+\beta}}, \tag{29}$$

and the steady-state level of output is equal to

$$Y = A^{\frac{1}{\beta}} \left[\frac{\overline{w}}{\gamma}\right]^{\frac{-\gamma}{\beta}} \left(\frac{s}{\delta+n}\right)^{\frac{\alpha}{\beta}} e_H L_H . \tag{30}$$

In per capita terms,

$$y = A^{\frac{1}{\beta}} \left[\frac{\overline{w}}{\gamma}\right]^{\frac{-\gamma}{\beta}} \left(\frac{s}{\delta+n}\right)^{\frac{\alpha}{\beta}} e_H p_H , \tag{31}$$

where p_H stands for the proportion of skilled workers in the supply of labor. Thus, assuming that $\overline{w}$ does not change, the change in per-capita output owing to HIV/AIDS is equal to

$$\frac{dy}{y} = \frac{1}{\beta}\frac{dA}{A} + \frac{\alpha}{\beta}\left(\frac{ds}{s} - \frac{dn}{\delta+n}\right) + \frac{de_H}{e_H} + \frac{dp_H}{p_H}. \tag{32}$$

From Eq. (14), the change in formal sector output in the dual economy setting is equal to

$$\frac{dY_f}{Y_f} = \sigma\left[\frac{1}{\beta_f}\left[\frac{dA_f}{A_f} + \alpha_f \frac{ds_f}{s_f} - \frac{\alpha_f dn}{(\delta+n)}\right] - \frac{\gamma_f}{\gamma_i \beta_f}\left[\frac{dA_i}{A_i} + \alpha_i \frac{ds_i}{s_i} - \frac{\alpha_i dn}{(\delta+n)}\right] + \frac{de_H}{e_H} + \frac{dL_H}{L_H}\right]. \tag{33}$$

It appears that the impact of HIV/AIDS in the setting with unemployed unskilled workers is very similar to the impact on the formal sector in the dual economy. In particular, the assertion that per-capita output would rise as previously unemployed workers replace those who have died rests on the precarious assumption that an increase in the capital-labor ratio outweighs the adverse productivity effects. Moreover, in the dual economy, the demand for labor in the formal and the informal sector tend to shift in the

same direction. This means that, in the dual economy model, the reservation wage of workers in the formal sector declines if both sectors are subject to an adverse shock, thus mitigating the impact on formal sector output. Thus, in the economy with unemployed workers (and constant reservation wage), the formal sector tends to be more responsive to shocks.

For the open economy, it can similarly be shown that the change in per-capita output is equal to

$$\frac{dy}{y} = \frac{1}{\beta}\frac{dA}{A} + \frac{de_H}{e_H} + \frac{dp_H}{p_H}. \tag{35}$$

Comparing this to Eq. (25), we note again that the impact of HIV/AIDS on per-capita output for the open economy is very similar to the impact in the dual-economy model, and unambiguously negative.

V. Summary and Conclusions

Drawing on the literature on the macroeconomic effects of the HIV/AIDS epidemic and, in particular, the effect on per capita income, we focus on two questions. First, how do the conclusions regarding the impact of HIV/AIDS on per capita income differ between a dual economy model and a one-sector neoclassical growth model? And second, what are the consequences if, in the long run, investors respond to changes in the rate of return to capital?

We find that the dual economy model, as far as the impact of HIV/AIDS is concerned, has features similar to the one-sector model. We cannot confirm the hypothesis that HIV/AIDS does result in a decline in unemployment rates, and through this on per-capita output, as formal sector workers who die are replaced by underemployed workers from the informal sector. HIV/AIDS affects both the supply and the demand for workers in the formal sector, and the net effect is ambiguous. Also, a positive net effect would hinge on a significant increase of the capital-labor ratio in the formal sector, which – in light of our analysis of the open economy – is doubtful. Using a somewhat different model, which features a pool of unemployed unskilled workers, we obtain very similar results.

In the closed-economy model, much of the adverse impact of HIV/AIDS on per capita income is offset by an increase in the capital-labor ratio, associated with a decline in the population growth rate. However, this implies a decline in the rate of return to capital, and,

with significant changes in the population growth rate, this decline can be substantial. If, in the longer run, investors do respond to changes in the rate of return, and the domestic rate of return to capital moves in line with the rate of return of some alternative foreign asset, then the capital-labor ratio would not rise. This means that longer-run projections of the impact of HIV/AIDS on per capita income, based on a closed-economy neoclassical growth model (or a more refined closed-economy model with similar features regarding the determinants of savings and investment), are likely to understate the adverse impact of HIV/AIDS.

While for an analysis of the impact of HIV/AIDS on wages (and, presumably, the income of the poorer segments of the population) it is sufficient to look at per capita output, the impact of HIV/AIDS on (average) per capita income, that is, per capita output plus or minus income from net foreign assets, may differ. However, as long as the economy under consideration does not have substantial net foreign assets, the impact of HIV/AIDS on per capita income will still be worse than in the closed economy. Correspondingly, the lower the level of net foreign assets, or the higher the external debt, the larger will be the adverse impact of HIV/AIDS on per capita income. In the context of sub-Saharan Africa, this is particularly relevant for highly-indebted low-income countries. Thus, a macroeconomic assessment of the impact of HIV/AIDS should include an analysis of the implications for the sustainability of external debt.

A NUMERICAL EXAMPLE

This appendix gives numeric examples for the four types of models discussed in Sections II and III. The parameters are chosen primarily for illustrative purposes, and are not calibrated to fit any particular country.

Demographic assumptions: Consider an economy with an HIV prevalence rate of 10 percent. The growth rate of the working population falls by 1 percent, from 3 percent to 2 percent. Skilled workers account for 20 percent of the working population. In the dual-economy model, 25 percent of unskilled workers (20 percent of the working population) are employed in the formal sector, and the rest in the informal sector.

Twenty percent of the (working) population are skilled workers employed in the formal sector, 20 percent are unskilled workers employed in the formal sector, and 60 percent are are unskilled workers employed in the informal sector.

Economic (structural) assumptions: In the one-sector model, the factor shares are 37 percent for capital, 28 percent for skilled labor, and 35 percent for unskilled labor. In the dual-economy modcel, the formal sector accounts for 70 percent of the economy's output. In the formal sector, respective factor shares are 40 percent for capital, 40 percent for skilled labor, and 20 percent for unskilled labor. In the unskilled labor, the share of capital is 30 percent, and the share of unskilled labor is 70 percent. The parameter λ, representing the wage differential for unskilled labor between the formal and the informal sector, is equal to 2. The rate of depreciation (δ) is equal to 10 percent.

Assumptions on the economic impact of HIV/AIDS: As a result of increasing mortality rates, the average labor productivity falls by 2 percent for skilled agents, and by 1 percent for unskilled agents. The aggregate savings rate (both for the formal and the informal sector) falls from 15 percent to 14.7 percent, i.e., by 2 percent or 0.3 percentage points, and total factor productivity declines by 1.5 percent.

Table A1 summarizes the impact of HIV/AIDS for the one-sector model, both for the closed and the open economy. For the open economy, the table differentiates between the impact on output and on income, respectively, and two scenarios are shown: The first scenario shows an economy with zero net investment income from abroad (or zero debt service), the second scenario shows an economy with net investment income from abroad of minus 5 percent of GDP (or external debt service of 5 percent of GDP).

Table A1. The Impact of HIV/AIDS in the One-Sector Model
(in percent)

	Total impact	Owing to decline in ... A	s	n	e_H	e_U
Closed Economy						
Per capita Output	-0.5	-2.4	-1.2	4.5	-0.9	-0.6
Per capita Income	(same)					
Open Economy, Perfect Capital Mobility						
Per capita Output	-3.8	-2.4	0.0	0.0	-0.9	-0.6
Per capita Income	-1.7	-2.4	-0.7	2.8	-0.9	-0.6
Open Economy, Perfect Capital Mobility, with net debt service of 5 percent of GDP						
Per capita Income	-2.0	-2.4	-0.6	2.5	-0.9	-0.6

Sources: Author's calculations.
Notes: For per capita output and income, the table shows the total impact (percentage change), which then is attributed to changes in TFP (A), the savings rate (s), the population growth rate (n), and the efficiency of labor (e_H and e_U).

Table A2. The Impact of HIV/AIDS in the Dual-Economy Model
(in percent)

	Total impact	Owing to decline in ... A	s	n	e_H	e_U
Closed Economy						
Per capita Output	-0.4	-2.5	-1.3	4.9	-1.2	-0.4
Formal Sector	-0.2	-2.7	-1.6	6.0	-2.0	0.0
Informal Sector	-0.9	-2.0	-0.6	2.4	0.7	-1.3
Per capita Income	(same)					
Labor allocation	0.5	-0.5	-0.7	2.7	-2.0	1.0
Open Economy, Perfect Capital Mobility						
Per capita Output	-3.8	-2.5	-0.1	0.3	-1.2	-0.4
Formal Sector	-5.9	-2.7	0.4	-1.6	-2.0	0.0
Informal Sector	1.0	-2.0	-1.3	4.9	0.7	-1.3
Per capita Income	-2.2	-2.5	-0.6	2.5	-1.2	-0.4
Labor allocation	-5.2	-0.5	1.3	-4.9	-2.0	1.0
Open Economy, Perfect Capital Mobility, with net debt service of 5 percent of GDP						
Per capita Income	-2.4	-2.5	-0.6	2.3	-1.2	-0.4

Sources: Author's calculations.
Notes: For per capita output and income, the table shows the total impact (percentage change), which is attributed to changes in TFP (both A_f and A_i), the savings rate (s_f and s_i), the population growth rate (n), and the efficiency of labor (e_H and e_U). The rows on labor allocation shows the change in unskilled workers working in the formal sector (in percent of the total number of unskilled workers).

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