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Macroeconomic Impact of HIV/AIDS in the Asian and Pacific Region

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Macroeconomic Impact of HIV/AIDS in the Asian and Pacific Region

Ajay Tandon

November 2005

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ERD Working Paper No. 75

MACROECONOMIC IMPACT OF HIV/AIDS IN THE ASIAN AND PACIFIC REGION

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November 2005

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FOREWORD

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ABSTRACT

This paper reports estimates of the economic impact of HIV/AIDS in the Asian and Pacific region using a standard growth model. Following previous research on this issue, an economywide aggregate production function is estimated with health capital as an input. HIV/AIDS is assumed to influence the accumulation of health capital proxied by a life expectancy shortfall measure. The model is estimated empirically using cross-country panel data spanning the period 1960–2000. Using a global sample, results indicate a negative impact of increasing HIV/AIDS prevalence on health capital and on economic growth. Using fairly conservative projections for HIV/AIDS prevalence, the model predicts a particularly large adverse impact on economic growth in Cambodia and Papua New Guinea.

I. INTRODUCTION

Widespread prevalence of diseases such as Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome or HIV/AIDS, malaria, and tuberculosis are a significant constraint to development in low- and middle-income countries. The impact of HIV/AIDS has been especially devastating in sub-Saharan Africa where some countries are now seeing declines in life expectancy of up to 20 years as a result of the disease taking on pandemic proportions in the continent. Globally, HIV/AIDS is now the leading cause of adult mortality (WHO 2004). In 2004, an estimated 4.9 million deaths worldwide were attributable to HIV/AIDS (UNAIDS and WHO 2004). Given an average lag of 10 years between infection and death, the morbidity effects for an estimated 39.4 million people now living with HIV/AIDS are also substantial.

The impact of HIV/AIDS has been felt not only in terms of increasing mortality and morbidity but also in the economic sphere since the disease disproportionately strikes young adults and those in productive age groups. There is empirical evidence that suggests that the disease has had a significant, adverse microeconomic impact on households and firms, as well as on the macroeconomy of affected countries. Concern for the latter has spawned a burgeoning literature attempting to estimate the impact of the HIV/AIDS pandemic focusing specifically on economic growth in the worst-affected countries of sub-Saharan Africa (Bonnel 2000, Over 1992, Dixon et al. 2001, Bloom and Mahal 1997).

In the Asian and Pacific region, HIV/AIDS prevalence has yet to reach the levels observed in sub-Saharan Africa (Table 1).

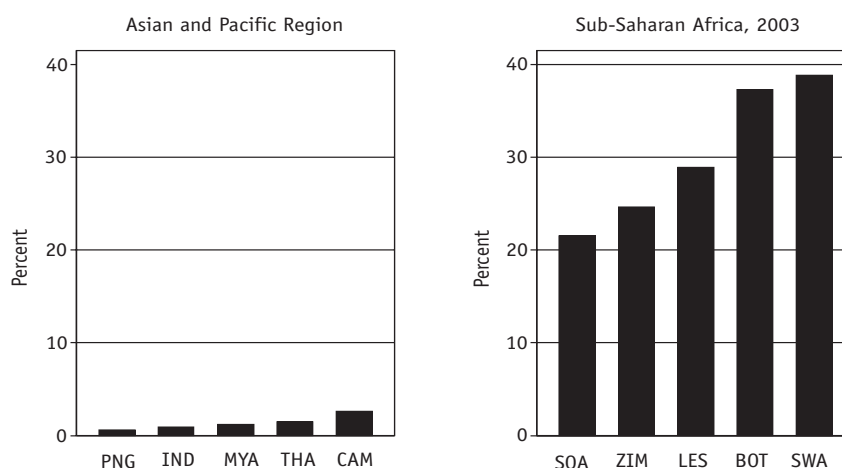
TABLE 1
HIV/AIDS IN THE ASIAN AND PACIFIC REGION AND SUB-SAHARAN AFRICA, 2003
(15-49 AGE GROUP)

	PREVALENCE (PERCENT)	NUMBER OF PEOPLE LIVING WITH HIV
Asian and Pacific Region		
Cambodia	2.6	170,000
Thailand	1.5	560,000
Myanmar	1.2	320,000
India	0.9	5,000,000
Papua New Guinea	0.6	16,000
Viet Nam	0.4	200,000
People's Republic of China	0.1	830,000
Sub-Saharan Africa		
Swaziland	38.8	200,000
Botswana	37.3	330,000
Lesotho	28.9	300,000
Zimbabwe	24.6	1,600,000
South Africa	21.5	5,100,000
Eritrea	2.7	55,000

Source: UNAIDS (2004).

In 2004, the HIV prevalence rate for Sub-Saharan Africa was 7.4% compared to South and Southeast Asia's 0.6%, or East Asia's 0.1% (UNAIDS 2004). Figure 1 compares the rates in the top five highest-prevalence countries in Asia versus Africa: the highest prevalence country in Asia is Cambodia with a rate of about 2.6% which is still far below the rates seen in Africa.

FIGURE 1
HIV/AIDS PREVALENCE IN THE ASIAN AND PACIFIC REGION
AND SUB-SAHARAN AFRICA, 2003
(15-49 AGE GROUP)



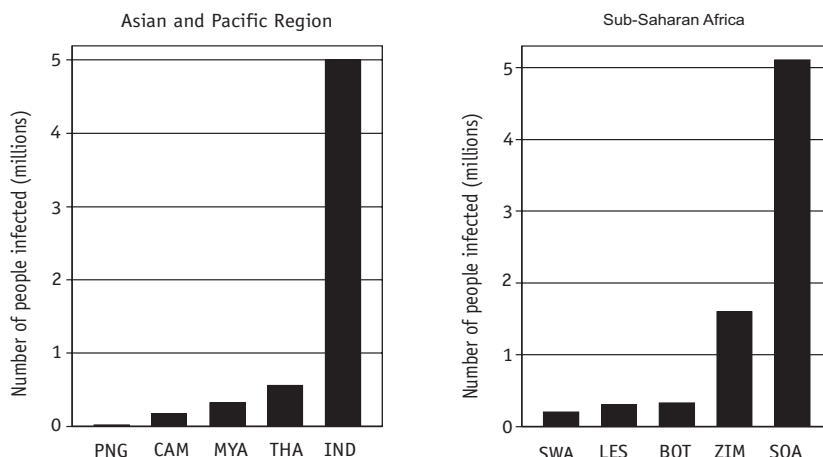
Note: See Table 1 for country codes.
Source: UNAIDS (2004).

Despite low prevalence rates, the *number* of people afflicted with the disease is already enormous in the Asian and Pacific region. This is on account of the large populations in many Asian countries. As illustrated in Figure 2, India—despite having a prevalence rate of “only” 0.9%—is estimated to have 5 million people living with HIV/AIDS: the country with the second-highest number of people living with HIV/AIDS in the world after South Africa. And, even with a relatively low prevalence rate, it is estimated that almost half of all deaths in Cambodia in the 15-49 years age group are HIV/AIDS-related (Haacker 2004).

Furthermore, there are widespread concerns regarding the future spread of the disease in the region, and especially so in the relatively high-prevalence countries such as Cambodia, India, Myanmar, Papua New Guinea, and Thailand. These concerns are, at least in part, fueled by the fact that knowledge and awareness of HIV/AIDS is fairly low in some of the countries in the region (UNAIDS 2004).

Another characteristic of the disease in the Asian and Pacific region is that, unlike in Africa where HIV/AIDS has diffused to the general population, HIV/AIDS prevalence in Asian countries has remained highly concentrated among certain population subgroups such as injecting drug users (IDUs), sex workers, and men who have sex with men. In epidemiological terms, HIV/AIDS

FIGURE 2
HIV/AIDS NUMBER IN THE ASIAN AND PACIFIC REGION
AND SUB-SAHARAN AFRICA, 2003
(15-49 AGE GROUP)



Note: See Table 1 for country codes.
 Source: UNAIDS (2004).

usually starts off with increasing prevalence in such high-risk population subgroups. Left unchecked, high rates in high-risk population subgroups spill over into the general population, leading eventually to an epidemic. Using the typology introduced by the World Bank (World Bank 1998), countries can be categorized using three broad HIV/AIDS prevalence characteristics:

- (i) *nascent epidemic*: HIV/AIDS prevalence in less than 5% in all population subgroups;
- (ii) *concentrated epidemic*: HIV/AIDS has spread in a defined subpopulation but not in the general population, as indicated by prevalence rate greater than 5% in at least one population subgroup and less than 1% among urban women attending antenatal clinics; and
- (iii) *generalized epidemic*: HIV/AIDS is firmly established in the general population as indicated by over 1% prevalence rate among women attending urban antenatal clinics.

Countries in the Asian and Pacific region that are classified as having a generalized epidemic are Cambodia, Myanmar, Papua New Guinea, Thailand, and six states in India. Those with concentrated epidemic include People's Republic of China (PRC), Indonesia, Malaysia, Nepal, and Viet Nam. The remainder have low prevalence and are in the nascent epidemic category (UNAIDS 2004).

In this paper, the impact of HIV/AIDS on economic growth in the Asian and Pacific region is estimated using parameters derived from a global sample of countries. The methodology followed has been used previously in the literature for assessing the impact of HIV/AIDS on economic growth in sub-Saharan Africa. An economywide aggregate production function is estimated with health capital as an input. HIV/AIDS is assumed to influence the accumulation of health capital—proxied by life expectancy shortfall measure—and hence impact the macroeconomy through its effect on the health production function. The model is estimated empirically using cross-country panel data

spanning the period 1960–2000. Using a global sample, results indicate a negative impact of increasing HIV/AIDS prevalence on health capital and economic growth, one that is particularly worrisome in countries such as Cambodia and Papua New Guinea.

The remainder of the paper is organized as follows. The next section reviews the background on the linkages between health and macroeconomics. Subsequently, the model and results are outlined. The paper ends with a brief discussion of the results. The Technical Appendix gives details of the model derivation.

II. MACROECONOMICS AND HEALTH

It is now widely acknowledged that the health status of a country's population is an *intrinsic*, constituent indicator of the level of development of the country. Development indicators such as the UNDP's Human Development Index (HDI)—which is an average of the health, education, and economic status of a country—have been especially influential in helping focus attention on health and other nonincome dimensions of poverty and well-being (UNDP 2004). Similarly, the importance accorded to health is very much evident in the UN Millennium Declaration signed by 189 countries in 2000. The Declaration includes several health-related Millennium Development Goals (MDGs) such as achieving declines in infant mortality and maternal mortality, as well as stopping the spread of HIV/AIDS, malaria, and other diseases.

Several theoretical arguments, however, underscore the fact that improvements in population health are also *instrumental* in helping achieve the more traditional income-related development outcomes such as those relating to macroeconomic growth and reductions in poverty rates. In this view, health—along with education and work experience—is a component of human capital investments that yields “returns” in the form of higher output and productivity both at the macro and the micro level. In this human capital conceptualization, the adverse impact of widespread prevalence of diseases such as HIV/AIDS in a population is measured primarily in terms of the net economic burden they place on individuals as well as on the macroeconomy.

Why might we expect adverse economic consequences from rising HIV/AIDS prevalence rates, especially in developing countries where 90% of those infected reside? Theoretically, one way to assess the economic impact of HIV/AIDS is to look at the effect due to morbidity and the effect due to mortality resulting from the disease. The morbidity effects, as summarized by Cuddington (1993), can be further classified into two broad categories: (i) the negative effects on labor productivity and human capital and (ii) the macroeconomic effect of lower individual savings rates due to the rise in HIV/AIDS-related health expenditure. The mortality effects of HIV/AIDS would tend to lower population growth rates as well as change the demographic composition of the population. Not all the economic impact of HIV/AIDS, though, will be negative, e.g., reductions in population growth may well raise per capita income levels (Young 2005).

More recently, an IMF publication comprehensively classifies the impact of HIV/AIDS into three broad categories: (i) demographic impact of the disease, (ii) macroeconomic impact, and (iii) impact on government finance and public services (Haacker 2004). By disproportionately affecting young adults and those in the productive age groups, the primary demographic impact of HIV/AIDS is estimated to lead to an increase in the dependency ratio (i.e., an increase in the number of younger and older dependents as a proportion of the productive age group). The effects are also reflected

in the significant rise in orphan rates and the greater number of women-headed families (UNAIDS, UNICEF, and USAID 2004). There are several pathways through which HIV/AIDS has a macroeconomic impact other than those related to demography. In addition to rising health expenditure and lower income-generating potential and savings among households, private firms and businesses may also suffer from lower productivity on account of higher personnel costs due to health-related expenses on absenteeism, sickness, death, and recruitment, as well as organizational disruptions. These constitute an additional burden and a deterrent both to expanding domestic investment and fostering foreign direct investment (World Economic Forum 2004). Similar effects can be seen in the public sector, where significant pressure on the budget is created by a decline in the revenue side given the reduction in working-age labor force, and increases in the expenditure side resulting from higher health and welfare costs. Possible broader effects of higher HIV incidence include repercussions for future political stability caused by dissatisfaction with the government and with widening inequality.

More generally, HIV/AIDS is likely to increase the prevalence of economic risk in the economy—at the individual, firm, and government level—eroding the fundamental basis for optimal intertemporal decision-making (Haacker 2004). It is important to reiterate at the outset that the devastating morbidity and mortality effects of HIV/AIDS ought to provide more than enough justification for investing additional resources to control the spread of the disease. An assessment of the economic impact of the disease is simply an “over and above” second-order effect that merits research if only to provide additional impetus and to raise awareness regarding the likely economic benefits of efforts aimed at reducing the spread of the disease.

III. ECONOMETRIC FRAMEWORK

There are several different modes for studying the interactions between health and macroeconomic growth. These include computer simulation models as well as econometric methods using cross-sectional data or panel data. This paper focuses on the latter approach.

One seminal attempt to examine the impact of human capital on economic growth using an econometric framework can be found in Mankiw, Romer, and Weil (1992).¹ Their framework augments the standard Solow growth model by explicitly incorporating human capital as an additional factor of production. They assume that aggregate output in country i and time t , Y_{it} , is a function of physical inputs K_{it} , labor L_{it} , labor-augmenting productivity A_{it} , as well as human capital E_{it} :

$$Y_{it} = (K_{it})^\alpha (E_{it})^\beta (A_{it} L_{it})^{1-\alpha-\beta},$$

where α and β are the elasticities. Mankiw et al. (1992) conceptualize human capital solely as educational attainment and do not incorporate health in their empirical estimation. A subsequent paper by Knowles and Owen (1995) extends their framework by incorporating both education E_{it} and health H_{it} as components of human capital:

$$Y_{it} = (K_{it})^\alpha (E_{it})^\beta (H_{it})^\psi (A_{it} L_{it})^{1-\alpha-\beta-\psi}.$$

¹ Some have criticized the empirical implications of Mankiw et al.'s growth regression. See Felipe and McCombie (2002).

As mentioned in the previous section, there are several reasons to include health as an input of the macroeconomic production process. Health is directly correlated with labor productivity. In addition, healthier populations—due to lower health-related expenditure and higher probabilities of future survival—are more likely to save and invest for the future. Health, in addition to providing utility in itself, also influences the ability of individuals to gain utility from consumption of other products. Interestingly, in their empirical estimates Knowles and Owen (1995) find a strong, more robust relationship between health capital and income per capita than between education capital and income per capita.

Theoretically, the most appealing and apparent way to incorporate HIV/AIDS into the augmented Solow model is following the approach taken in Dixon, McDonald, and Roberts (2001) and in McDonald and Roberts (2004). This approach assumes that HIV/AIDS prevalence has an effect on the *accumulation* of health capital. In addition to an aggregate production function, it specifies a second equation characterizing a health production function, whereby health outcomes in a country are assumed to be a function of several inputs. These inputs z_{it} could be taken to include factors such as health expenditure, infrastructure, governance, education, etc. Health outcomes are also assumed to be functions of a country's epidemiological environment d_{it} (such as disease prevalence rates):

$$H_{it} = f(z_{it}, d_{it}).$$

By taking the HIV prevalence rate to be a proxy measure for d_{it} , we can estimate its impact on macroeconomic growth through its effect on health capital accumulation.²

Based on the above formulation, output per capita in a country can be derived to be a function of the share of resources devoted to physical, education, and human capital (see Technical Appendix for details). As is standard in the literature, we use the share of gross domestic product (GDP) invested on average over each 5-year period (I) as a proxy for the share of resources devoted to physical capital. Education capital accumulation E is proxied by the secondary school enrollment ratio. For health capital H , the methodology of Anand and Ravallion (1993) and others is followed, using the shortfall of life expectancy (LE) from 80 years, defined as $-\ln(80-LE)$.

The equation estimated is:

$$\ln(YC) = f[\ln(I), \ln(n+g+\delta), \ln(E), \ln(YC_{-1}), \ln(H)].$$

The model incorporates endogeneity of health capital by instrumenting for it in a two-stage estimation procedure. From the following health production function:

$$\ln(H) = f[\ln(YC), HIV, \ln(MAL), \ln(CAL)],$$

the predicted value is used as an independent variable in the levels equation.³ For the health production function, health system determinants is proxied by income per capita. Other determinants included are caloric intake per capita (CAL). The disease environment is proxied by the proportion of the population at risk of malaria (MAL) as well as by the HIV prevalence rate. Table 2 lists all variable acronyms along with the data sources.

² The effects of HIV/AIDS on education capital accumulation have not been considered in the estimation framework.

³ This follows from McDonald and Roberts (2004).

TABLE 2
VARIABLE DEFINITIONS AND SOURCES

VARIABLE	DEFINITION	SOURCE
YC	Real GDP per capita	Penn World Tables (2004) ⁴
I	Share of GDP invested	<i>World Development Indicators</i> (World Bank 2004)
$n+g+\delta$	n =Population growth rate g =Technological growth rate δ =Depreciation rate of capital	<i>World Development Indicators</i> (World Bank 2004)
E	Secondary school enrollment	<i>World Development Indicators</i> (World Bank 2004)
H	Life expectancy shortfall	<i>World Development Indicators</i> (World Bank 2004)
HIV	Prevalence of HIV	UNAIDS (2004)
MAL	Population at risk of malaria	Gallup, Sachs, and Mellinger (1999) ⁵
CAL	Calorie intake per capita	FAO (2004)

The model is estimated using a two-way error component model, i.e., including both a country-specific fixed effect and a time-period specific effect (Dixon et al. 2001). Panel data are used for the analysis. Data are in eight 5-year intervals in the period 1960–2000, i.e., $t=1, \dots, 8$, where $t=1$ refers to 1960–1964, $t=2$ is 1965–1969, and so on. A uniform combined technology growth and depreciation rate of 5% are assumed.

IV. RESULTS

Table 3 reports the results of the estimation using instrumental variables. The first (top) part of the table reports the levels equation, which includes the instrumented value of the life expectancy shortfall variable (predicted $\ln H$). The second (bottom) part of the table reports the coefficients for the instrumental variables regression. The effect of HIV on economic growth is estimated via its effects on life expectancy: this is calculated from the coefficients in the two equations and reported in the row titled “HIV Impact.” The first column reports the results from a global sample of 94 countries. The positive sign on the lagged income term indicates presence of a convergence effect (with countries having a lower per capita income growing faster). Investment has the expected positive sign as well. Education capital has a negative effect on per capita income, but the coefficient is insignificant. This is a common finding among empirical growth models: when both health capital and education capital are included, the latter’s effect often becomes insignificant. This may, in part, have to do with the choice of secondary schooling as a proxy. This merits further investigation. Health capital (predicted) has a strong positive effect on per capita income.

⁴ See Heston et al. (2002).

⁵ See Gallup et al. (1999).

TABLE 3
ESTIMATION RESULTS

	FULL SAMPLE <i>i</i> = 94; <i>n</i> = 592	ASIAN DEVELOPING COUNTRIES <i>i</i> = 15; <i>n</i> = 92
Dependent variable: ln(<i>YC</i>)		
ln <i>I</i>	0.176 (0.026)*	0.104 (0.041)*
ln (<i>n+g+δ</i>)	0.191 (0.060)*	-0.257 (0.153)
ln <i>E</i>	-0.011 (0.025)	-0.015 (0.044)
ln (<i>YC</i> ₋₁)	0.778 (0.032)*	-0.227 (0.103)*
Predicted ln <i>H</i>	0.328 (0.089)*	4.504 (0.428)*
Constant	1.723 (0.461)*	22.676 (2.026)*
HIV Impact	-0.052	
Dependent variable: ln <i>H</i>		
ln (<i>YC</i>)	0.145 (0.020)*	0.236 (0.059)*
<i>HIV</i>	-0.028 (0.002)*	-0.010 (0.039)
ln <i>MAL</i>	-0.027 (0.006)*	-0.016 (0.020)
ln <i>CAL</i>	0.217 (0.064)*	-0.011 (0.165)
Constant	-5.980 (0.447)*	-4.68 (1.112)

* means significant at the 0.05 level.
 Note: Standard errors in parentheses.

The bottom part of Table 3 reports the coefficients of the instrumental variables regression. Malaria has a negative sign indicating the adverse health effects of widespread prevalence of the disease. Caloric consumption has a significant positive effect on life expectancy. HIV/AIDS prevalence has a strong negative effect on life expectancy. The overall impact of HIV/AIDS prevalence on income per capita can be derived from the coefficients, and this is estimated to be -0.052.

The third column in Table 3 reports results using a sample of Asian developing countries for which data were available (*n*=15). Using this subsample of the global sample of countries also yields estimates of a negative effect of HIV/AIDS prevalence on growth. However, the effect is not statistically significant. There are a couple of reasons why the estimates using just the Asian developing country subsample can be somewhat discounted. First is the issue of low sample size and hence of low power in the ability to detect marginal effects. Second, Asian developing countries have yet to see the kinds of widespread prevalence rates that are evident in sub-Saharan Africa, hence it is not surprising that the macroeconomic effects of HIV/AIDS prevalence in Asia so far have not been significant. However, to infer what might happen in the future—i.e., in the absence of a concerted effort to stem the rise in prevalence of the disease in the Asian and Pacific region—one has to infer the estimates from data that includes African countries in the sample.

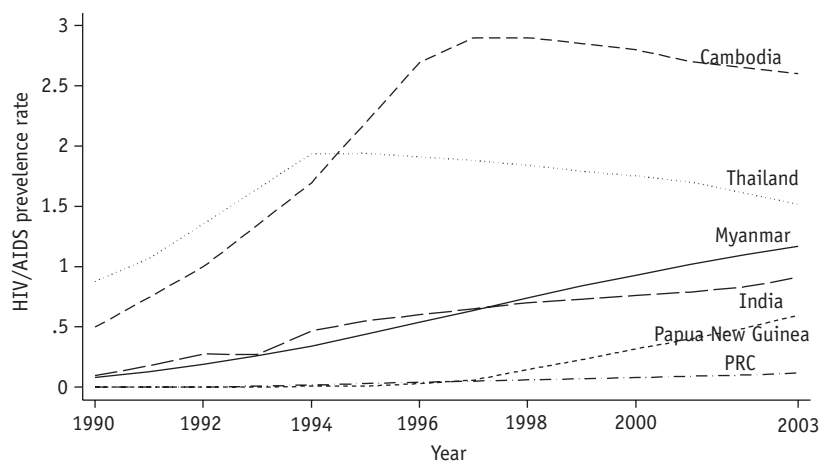
As mentioned earlier, the results of the econometric estimation using a global sample of countries indicate a negative effect of HIV/AIDS prevalence on GDP per capita with a -0.052 magnitude. What this implies is that a one percentage point increase in the HIV/AIDS prevalence—keeping other factors such as investment and education constant—will decrease income per capita on average by 5.2%. We can use this parameter to calculate the macroeconomic effects on Asian developing countries that currently have high prevalence rates: the estimates imply, for instance,

that a 10% increase in the prevalence of HIV/AIDS in Cambodia would lead to a decline in GDP per capita of almost 1.4%. In India, a 10% increase in prevalence (from a current rate of about 0.91% to 1%) would shave off 0.5% in growth of GDP per capita. Similar magnitude of effects can be inferred for Myanmar, Papua New Guinea, and Thailand.

Given the complex epidemiology of the disease, projecting HIV/AIDS prevalence rates in the future can be difficult. Cambodia and Thailand have been seeing declines in prevalence rates in recent years (Figure 3). The remaining high-prevalence countries such as India, Myanmar, and Papua New Guinea have been seeing steady increases over time. Rather than projecting from current trends, however, medium-term prevalence forecast scenarios are used for the Asian and Pacific region as reported in Chin (2003). His projections are relatively conservative as he argues that the pattern and prevalence of heterosexual risk behavior is fairly low in most countries of the Asian and Pacific region compared to sub-Saharan Africa. Hence, he argues that—given the different patterns of socioeconomic interactions among population subgroups—HIV/AIDS prevalence is unlikely to follow the path taken by sub-Saharan African countries (Chin 2003).

Nevertheless, even using the conservative projections in Chin (2003), the economic impact of any increase in HIV/AIDS prevalence will still be significant. Table 4 reports the current and projected prevalence rates for selected Asian developing countries as well as the associated economic impact, the latter being calculated from the parameter estimates reported in this paper.⁶ Papua New Guinea is projected to have the highest increase in HIV/AIDS prevalence, and hence the highest adverse economic effect: a decline in annual GDP per capita of about 4%. The effects on the other

FIGURE 3
TRENDS IN HIV/AIDS PREVALENCE FOR SELECTED ASIAN DEVELOPING COUNTRIES, 1990-2003



Source: UNAIDS (2004).

⁶ Chin (2003) reports a range for the projected maximum HIV prevalence. This paper takes the upper bound of his estimates and assumes that these numbers will be reached by 2010.

TABLE 4
PROJECTED ECONOMIC IMPACT OF HIV/AIDS (PERCENT)

COUNTRY	HIV PREVALENCE, 2003	PROJECTED PREVALENCE, 2010	AVERAGE ANNUAL IMPACT ON GDP PER CAPITA, 2004–2010
Cambodia	2.6	4	-2.0
Thailand	1.5	3	-1.1
Myanmar	1.2	2	-0.6
India	0.9	1	-0.1
Papua New Guinea	0.6	6	-4.0
PRC	0.1	0.5	-0.3

Sources: UNAIDS (2004) and Chin (2003).

Asian developing countries are also substantial: Cambodia can see declines of 2% in GDP per capita per year and Thailand of 1.1% per year. It must be reiterated that these projected increases in HIV/AIDS prevalence rates are to be viewed as lower bounds and are far from certain: historical experience shows that projections have tended to always underestimate the future spread of the disease (ADB 2004).

V. DISCUSSION

This paper has estimated the impact of HIV/AIDS on economic growth using a global sample of countries over the period 1960–2000, as well as using a subsample of Asian developing countries. The model extends the augmented Solow growth framework by assuming that: (i) health capital is one component of human capital influencing economic growth, and (ii) HIV/AIDS has an impact on the accumulation of human capital and, via this channel, influences economic growth.

Results indicate a negative effect of HIV/AIDS on economic growth using the global sample. The effect remains negative but insignificant using the sample of Asian economies. The latter is not surprising given problems relating to sample size and the fact that the prevalence rates in Asia are still relatively low in comparison with those seen in Africa. Nevertheless, the World Bank projects that the number of HIV/AIDS-infected people would double globally if prevalence rates in PRC, India, and Indonesia would replicate those seen in Cambodia and Thailand (World Bank 2005). The results of the analysis show that the effects on economic growth of increasing HIV/AIDS prevalence—although not catastrophic—are likely to be fairly large. Using relatively conservative projections, the paper finds the negative impact on GDP per capita growth to be especially large in high-prevalence countries such as Cambodia and Papua New Guinea.

The analysis presented underscores the need for a concerted strategy to stem the rise of the disease in the Asian and Pacific region, not simply from a health point of view but also from an economic perspective. As mentioned previously, the mortality and morbidity effects of the disease are in of themselves extremely serious enough to merit interventions aimed at preventing and alleviating the effects of the disease. In 2004, less than 6% of the estimated 170,000 people in Asia who need retroviral drugs were getting them (UNAIDS 2004). However, given resource constraints, focusing attention on the economic benefits of such interventions can hopefully help raise awareness and rally much-needed political support for the cause.

VI. TECHNICAL APPENDIX

This Technical Appendix details the derivation of the econometric model, data used, estimation strategy, as well as detailed results. The production function is specified as:

$$Y_I = (K_{it})^\alpha (E_{it})^\beta (H_{it})^\psi (A_{it} L_{it})^{1-\alpha-\beta-\psi}.$$

Rewriting this in terms of quantities per effective unit of labor:

$$y_{it} = (k_{it})^\alpha (e_{it})^\beta (h_{it})^\psi,$$

where $y=Y/AL$, $e=E/AL$, and $h=H/AL$. Assuming a constant function of output is saved and invested, labor grows at a country-specific rate n_i ; technology grows at a period-specific rate g_t ; and all forms of human capital depreciate at the same date δ for all countries yields the equation for the steady-state output per capita y_{it}^* :

$$\ln y_{it}^* = \ln A_{i0} + g_t t - C_1 \ln (n_i + g_t + \delta) + C_2 \ln s_i^K + C_3 \ln s_i^E + C_4 \ln s_i^H,$$

where $C_1=(\alpha+\beta+\psi)/(1-\alpha-\beta-\psi)$, $C_2=\alpha/(1-\alpha-\beta-\psi)$, $C_3=\beta/(1-\alpha-\beta-\psi)$, and $C_4=\psi/(1-\alpha-\beta-\psi)$. s_i^K , s_i^E , and s_i^H are the shares devoted to physical, education, and health capital, respectively. A_{i0} is the initial level of technology in country i .⁷ Linearizing around the steady-state level of output per capita, we get the following two equations. The first is in terms of *growth* in output per capita, and the second in terms of *levels* of output per capita:

$$\ln y_{it}^* - \ln y_{i0}^* = -\varphi \ln y_{i0}^* + \sum_j \theta_j x_{it}^j + \eta_t + \mu_i + v_{it},$$

where $\varphi = 1 - e^{-\lambda t}$, $\theta_1 = -\theta_2 = \varphi\alpha/(1-\alpha)$, $\theta_3 = \varphi\beta/(1-\alpha)$, $\theta_4 = \varphi\psi/(1-\alpha)$, $x_{it}^1 = \ln (n_i + g_t + \delta)$, $x_{it}^2 = \ln s_i^K$, $x_{it}^3 = \ln e_{it}^*$, $x_{it}^4 = \ln h_{it}^*$, and $\eta_t = g_t t$. λ is the convergence rate. The same equation can be written in terms of levels as well:

$$\ln y_{it}^* = (1 - \varphi) \ln y_{i0}^* + \sum_j \theta_j x_{it}^j + \eta_t + \mu_i + v_{it}.$$

This is the equation that forms the basis for estimating the effects of human capital on economic growth.

⁷ The model followed is the version found in Dixon et al. (2001) and McDonald and Roberts (2004).

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