The London School of Economics and Political Science

Economic Growth in Development – Health, Demographics, and Access to Technologies

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Declaration

I certify that the thesis I have presented for examination for the MPhil/PhD degree of the London School of Economics and Political Science is solely my own work.

I warrant that this authorization does not, to the best of my belief, infringe the rights of any third party.

Abstract

The first substantive chapter (II) addresses the macroeconomic impact of HIV/AIDS, with reference to sub-Saharan Africa. The framework is designed to capture some interactions between the formal and the informal sector, and – reflecting open capital markets of many economies affected by HIV/AIDS – to address the implications of capital mobility. Additionally, our study is the first academic study of the growth impact of scaling up antiretroviral treatment. Allowing for capital mobility, our analysis returns a stronger impact of HIV/AIDS on output and income per capita than the corresponding closed-economy models. The estimated impact on the informal sector is more pronounced than for the formal sector, reflecting a stronger impact of HIV/AIDS on savings rates. GDP per capita is lower in the scenario with comprehensive scaling-up of antiretroviral treatment, as rising costs of care and treatment affect savings rates.

Chapter III adapts a microeconomic framework with forward-looking agents to study the contributions of health, as well as income, to living standards, drawing on empirical work on the value of statistical life. For leading industrialized countries, the contribution of health over long periods of time has been of similar magnitude as rising incomes, but the contribution of health has slowed down since about 1950. For developing countries, the slowdown occurred somewhat later. HIV/AIDS has resulted in steep declines in living standards in a number of countries in sub-Saharan Africa.

Chapter IV focuses on the impact of capital-deepening arising from falling relative prices of ICT equipment. The estimated impact of ICT-related capital deepening on growth in developing countries is substantial (about 0.3 percentage points), although lower than comparable estimates for leading industrialized countries. Unlike in some industrialized countries, the impact of ICT-related capital deepening has not slowed down after 2000, owing to growing absorption of communications equipment.

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I. INTRODUCTION

The studies included in this thesis contribute to the literature on economic growth in the context of economic development. Specifically, they address three areas.

Chapter II focuses on *the impact of HIV/AIDS on economic growth*. It provides a comprehensive survey of the academic literature on health and growth (Chapter II.1), with particular emphasis on studies focusing on the impacts of HIV/AIDS, and an analysis of the macroeconomic impacts of HIV/AIDS (Chapter II.2) that – among other issues – provides the first available analysis of the growth impacts of increased access to treatment. The chapter also discusses the role of assumptions regarding the extent of capital mobility, and – within the constraints of a 2-sector growth model – points at some of the distributional implications of HIV/AIDS.

Chapter III deals with *the roles of health and economic growth in economic development* more generally. Unlike Chapter II (especially II.1), which focuses on the impact of health on growth, Chapter III reviews the contributions of both to living standards. Chapter III.1 lays the ground, with a review of the available academic literature. Chapter III.2 presents an analytical framework, and compares the properties of this framework with some of the approaches adopted in the literature. In addition to updating some earlier work on the contributions of rising income and growth to living standards over long periods of time in advanced industrialized countries, it addresses the contributions of improved health standards, as well as rising incomes, to living standards globally since 1950. It considers the adverse impacts of HIV/AIDS in a number of country (as the epidemic represents a health development that stands out in the post-1950 period as a reversal in otherwise positive developments in key health indicators over time and across countries).

Chapter IV addresses the growth impact of information and communication technologies (ICTs), with particular emphasis on developing countries. Most of the available literature, summarized in Chapter IV.1, focuses on the United States and other OECD countries. An important constraint for the analysis of the economic impact of ICTs in developing countries is the lack of relevant national accounts data. Chapter IV.2 therefore discusses the availability of data, and describes the dataset constructed to analyse the impact of ICT.

Chapter IV.3 presents a model designed to analyse the growth impacts of ICT-related capital deepening in developing countries (i.e., it draws on a relatively small set of macroeconomic variables), and presents estimates of the impacts of ICT-related capital deepening for these countries, as well as comparisons with middle- and high-income countries.

Chapter V concludes.

A. Health, HIV/AIDS, and Economic Growth

The body of work this chapter draws from and contributes to (see, for example, Haacker (2004, 2008a)) was motivated by the economic impacts of HIV/AIDS in sub-Saharan Africa, and – in particular – in Southern Africa. The ongoing epidemic represents the most severe reversal in health standards recorded for a major region since 1950 (when the data we use start). In order to assess the macroeconomic and development prospects of countries significantly affected by HIV/AIDS, it is therefore necessary to understand the implications of HIV/AIDS in these countries.[1]

Chapter II.1 sets the stage for our discussion, summarizing key indicators for the demographic impact of HIV/AIDS, and discussing the relevant literature. As the economic impacts of HIV/AIDS derive from its impacts on health, the broader literature on the impacts of health on economic growth is also relevant. Our survey therefore sets out by reviewing the academic literature on health and growth. However, the health impact of HIV/AIDS does not simply represent a reversal of health gains achieved in the course of development, as the epidemic does have health impacts which, in important respects, differ from other health conditions.[2] For this reason, and in light of the strong impact of HIV/AIDS on key health indicators in sub-Saharan Africa, many studies focus on the impact of HIV/AIDS on growth, and Chapter II.2 closes with a discussion of this literature.

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[1] An Appendix to Chapter II.1, reprinted from Haacker (2008b), provides an introduction to the epidemiology and impact of HIV/AIDS, and provides a brief discussion of the international response to the epidemic.

[2] For example, HIV/AIDS does have a strong impact on mortality among young adults, whereas many other health conditions affect primarily infants, young children and old people.

Chapter II.2 provides an analysis of the impact of HIV/AIDS on output and income per capita. The first part develops an analytical framework, designed to address two aspects of the impact of HIV/AIDS. First, the countries with the highest rates of HIV prevalence can arguably be characterized as dual economies, in which a formal sector coexists with an informal, largely agricultural, sector that provides the livelihood of a large share of the population, but generates an income per capita that is much lower than incomes in the formal sector. Second, in many studies of the impact of HIV/AIDS, an increase in the capital-labor ratio (tied to a slowdown in the rate of population growth) plays a major role in the economic assessment. However, most of the highly affected countries are characterized by a large degree of capital mobility, which means that the postulated increase in the capital-labor ratio may not materialize. Our analysis therefore contrasts the impacts of HIV/AIDS in an open-economy setting (with perfect capital mobility, at least for the formal sector) with a more conventional closed-economy setting. The second part of Chapter II.2 provides an assessment of the economic impact of HIV/AIDS, calibrating the model in line with the latest available evidence. One notable feature of our analysis is a discussion of the implications of increasing access to antiretroviral treatment, which has so far not been addressed in the academic literature.

B. Contribution of Health (and Income) to Living Standards

While the interactions between health and income are complex,[3] improvements in both incomes and health have arguably played important roles in improving living standards. In Chapter III, we assess the contributions of improved health and incomes to rising living standards, treating both as outcomes of the development process, without attempting to identify fundamental causes of the improvements in either dimension.

Chapter III.1 describes the heritage that our analysis draws from. The central concept is that of an agent with an intertemporal utility function, valuing income (because it enables

[3] See Chapter II.1 for a survey of the literature on the impacts of health on income. Deaton (2003, 2006) provides more comprehensive discussions of the interactions between health and income, also covering the role of inequality.

higher utility from consumption) and health (in the form of reduced mortality, as it increases the likelihood of experiencing anticipated utility streams in the future). The microeconomic branch of the literature we draw from expands on this concept, refining it – for example – by exploring the age-dependence of trade-offs between income and mortality risks or the interactions between the trade-offs between income and mortality risks on one hand and the shape of the utility function on the other hand. The empirical branch of this literature primarily links observed differences in wage rates to employment-specific mortality risks, in order to derive valuations of incremental mortality risks, which can be extrapolated to yield estimates of the "value of statistical life."[4] The macroeconomic branch of the literature draws on the microeconomic and empirical literature, applying estimates of the "value of statistical life" to assessing the contributions of rising life expectancy (or reduced mortality) and incomes to living standards.

Within this context, our own analysis (Chapter III.2) largely belongs to the macroeconomic branch of the literature. The first part of the paper develops the analytical framework and, based on a review of the available literature, motivates the functional form and the parameters adopted in our analysis. One area in which our analysis contributes to the literature on the methodological side concerns the analysis of discrete changes in life expectancy. The latter part of the paper investigates the contribution of increased life expectancy to living standards in different contexts. We first discuss this in the context of the economic development of major industrialized countries, updating earlier work by Crafts (1997). Second, we discuss the contributions of increasing life expectancy and economic growth to improvements in living standards globally since 1950. Third, noting the apparent declines in living standards in a number of countries since about 1990 which can be attributed to the impact of the evolving HIV epidemic, a section of Chapter III.2 provides a more substantial discussion of the impacts of HIV/AIDS on living standards.

[4] For a comprehensive survey of the available literature, see Viscusi and Aldy (2003), which also covers studies of the value of statistical life not based on labor market data. The principle that data on valuations of (quasi) incremental mortality risks convey information on valuations of life was introduced by Schelling (1968).

C. ICT Equipment Investment and Growth in Development

Our discussion sets out with an analysis of the academic literature on the growth impacts of advances in ICTs, most notably of ICT-related capital deepening associated with falling prices of ICT equipment (Chapter IV.1). As limited availability of sufficiently disaggregated national accounts data acts as a constraint to comprehensive economic assessments of the economic impacts of advances in ICTs in developing countries, Chapter IV.1 is devoted to a discussion of the data used in our analysis. Chapter IV.3 provides an assessment of the role of advances in ICTs in developing countries. One section focusing on the "steady-state" impact, that also provides comparisons with middle- and high-income countries, is complemented by an analysis of the growth impacts of ICTs through ICT-related capital deepening over time.

Most of the literature on the economic impacts of information technologies, and on the growth impacts of ICT-related capital-deepening which are the focus of our analysis, originates in the United States. Our survey of the literature (Chapter IV.1) therefore sets out with a review of the literature relating to the United States, before discussing cross-country studies (largely relating to OECD and EU countries), including issues that are specific to country comparisons, such as the consistency of data across countries. While our primary interest is the impact of ICTs in developing countries, the discussion of the literature addressing this directly is brief, reflecting the small number of such studies. Chapter IV.3 closes with a discussion of studies on the productivity effects of ICT-related capital-deepening on the sectoral level, which have refined the understanding of the impacts of ICTs in advanced economies, but – owing to limited availability of data – do not offer a template for our analysis geared towards the impacts of ICTs in developing countries.

One considerable constraint to the analysis of the economic impacts of ICTs, and – in particular – the impacts of ICT-related capital deepening is the lack of sufficiently detailed national accounts data in most developing countries. Chapter IV.2 is therefore devoted to a discussion of the available data, and to a documentation of the dataset constructed to support the subsequent analysis. The most important source of data for our purposes are trade data, exploiting that missing data on trade flows can frequently be proxied by the corresponding data from partner countries (see, for example, Feenstra and others, 2005). However, our approach goes beyond the existing approaches, by accounting for bias that occurs when partner country data are substituted for missing countries. Another important type of data required for our analysis are data on prices of ICT equipment. In this regard, our price series are based on official price indices from the United States, as the national accounts data for the United States are arguably the most advanced in terms of measuring advances in ICTs, and as ICT equipment can be regarded as highly tradable (see Schreyer, 2002). However, regarding communications equipment, our analysis reflects recent advances not fully captured in the official price data for the United States (see, for example, Doms (2005)).

Chapter IV.3 provides an assessment of the macroeconomic impact of advances in ICTs through capital deepening in developing countries, drawing on two building blocks. The first is the existing body of work on accounting for the sources of economic growth (particularly several studies by or associated with Dale Jorgenson). Regarding the economic impacts of advances in ICTs, two key features of this approach are (1) the recognition that falling prices of ICT equipment translate into high rates of growth of the stock of ICT equipment (at constant prices), and thus disproportionate contributions to economic growth, and (2) that the rates of return to different types of assets should be equal.[5] This means, in the present context, that the gross rate of return of ICT-related assets, in equilibrium, is higher than for other assets, reflecting the rapid decline of relative prices of ICT equipment (similar to effects of high rates of physical depreciation, rather than economic obsolescence). The second building block is the dataset on ICT-related spending presented in Chapter IV.2.

Chapter IV.3 sets out with a presentation of the analytical framework, building on the work by Jorgenson and others but adapting it in light of the limited availability of data (notably for the labor market) for our countries of interest. This is followed by an analysis of the steady-state properties of the model, and of the impacts of productivity shocks (i.e., shocks to the relative prices of ICT equipment) over time, using perturbation techniques. The framework is used for an analysis of the impacts of falling prices of ICTs in steady state (including comparisons with high-income countries), and an assessment of the evolution of

[5] See, for example, Jorgenson and Stiroh (2000) for an exposition. Jorgenson, Ho, and Stiroh (2005) includes an updated discussion.

the impacts of ICT-related capital deepening over time (1991–2006). We also provide a brief discussion of the growth implications of productivity gains in the production of ICT equipment, though this is not the focus of the chapter (as few developing countries feature an economically significant ICT-producing sector).

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II.1. HEALTH, HIV/AIDS AND GROWTH: LITERATURE SURVEY

A. Introduction

The ongoing HIV/AIDS epidemic, owing to its severe impact in terms of health and increasing mortality, the social and demographic consequences, and the complexities of the response, is regarded as a threat to development in many low-income countries, most notably in sub-Saharan Africa where most countries with high HIV prevalence are located.[6] The present chapter discusses the available economic literature regarding the impacts of HIV/AIDS on economic growth.

Below, we will proceed in three broad steps. First, we present some data describing the state of the epidemic and its demographic impacts. For sub-Saharan Africa, the region where HIV prevalence has been highest, we also review recent trends in economic growth and discuss whether or to what extent the impact of HIV/AIDS can explain those trends.

Second, the economic impacts of HIV/AIDS occur – directly or indirectly – through its impacts on health, i.e. increasing morbidity (i.e., decreasing state of health) among the population or increased mortality. For this reason, it makes sense to begin our discussion of the broader literature on the impacts of HIV/AIDS on economic growth with a summary of the literature on the effects of health on economic growth. However, the lessons from this literature do not necessarily translate directly into our more specific context, as the profile of morbidity and mortality associated with HIV/AIDS differs from that of many other diseases, and HIV/AIDS cannot simply be interpreted as reversal of previous health gains.[7]

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[6] The Appendix, from Haacker (2008), provides an overview of the epidemiology and impact of and the international response to HIV/AIDS. Haacker (2004a) is the most comprehensive discussion of macroeconomic effects of HIV/AIDS so far.

[7] A point also made by Acemoglu and Johnson (2006), who observe that "most of the diseases [their study focuses on] had the greatest impact on children (with the notable exception of tuberculosis), while HIV/AIDS affects individuals at the peak of their labor productivity ..."

Finally, we turn to the literature focusing directly on the economic impacts of HIV/AIDS. We first review the small set of empirical studies reviewing the impacts of HIV/AIDS on growth directly. Our discussion of applied studies based on macroeconomic models designed to capture the impacts of HIV/AIDS distinguishes three types of models: (1) studies adopting a growth-accounting framework inspired by the neoclassical growth model, (2) studies with a more elaborate sectoral structure (CGE models, also large-scale macroeconomic models developed for a different purpose but adapted to study the impacts of HIV/AIDS), and studies in which key variables reflect forward-looking behavior of economic agents.

A concluding section summarizes our findings and provides some pointers for future work.

B. HIV/AIDS and Growth – Basic Data

To provide some context for our discussion, we summarize the most important data and estimates regarding the state of the global HIV/AIDS epidemic, and discuss the recent growth experience in some of the most affected countries. (The Appendix, taken from Haacker (2008), provides further background material.) Table 1 shows the latest available estimates of HIV prevalence for a number of countries with high HIV prevalence for the population of ages 15–49,[8] as well as for selected countries with a high absolute number of people living with HIV/AIDS.

[8] For a more extensive discussion of how to interpret these population averages, see Haacker (2004b) or Epstein (2004).

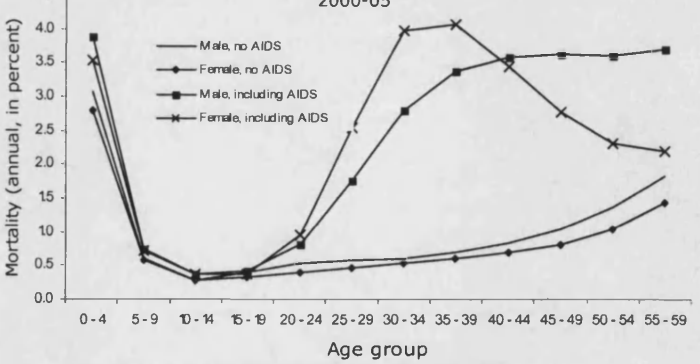
Table 1. The Demographic Impact of HIV/AIDS in Selected Countries

	HIV prevalence, ages 15–49 (Percent)	Crude death rate (Per 1,000)	Crude death rate: Impact of HIV/AIDS	Population growth (Percent)	Population Growth: Impact of HIV/AIDS	Life Expectancy at Birth (Years)	Life Expectancy: Impact of HIV/AIDS (Years)
	2007	2000–05	2000–05	2000–05	2000–05	2000–05	2000–05
Botswana	23.9	16.3	10.6	1.2	-1.1	46.6	-20.4
Central African Republic	6.3	19.4	5.8	1.6	-0.6	43.3	-10.1
Democratic Republic of Congo	1.2-1.5	19.3	1.8	2.9	-0.2	45.0	-3.0
Lesotho	23.2	17.7	9.4	1.0	-1.0	44.6	-19.3
Malawi	11.9	17.5	8.0	2.6	-0.8	45.0	-16.5
Mozambique	12.5	19.2	5.3	2.4	-0.5	44.0	-8.9
Namibia	15.3	12.9	7.5	1.4	-0.8	51.5	-16.8
Nigeria	3.1	17.5	1.4	2.5	-0.1	46.6	-2.4
South Africa	18.1	13.5	6.5	1.1	-0.7	53.4	-12.7
Swaziland	26.1	17.2	10.0	1.2	-1.1	43.9	-19.8
Tanzania	6.2	14.6	4.1	2.6	-0.4	49.7	-8.6
Zambia	15.2	21.7	9.3	1.9	-0.9	39.2	-15.6
Zimbabwe	15.3	20.5	14.0	0.7	-1.4	40.0	-25.8
Memorandum items:							
Global Average	0.8	8.8	n.a.	1.24	n.a.	66.0	n.a.
Sub-Saharan Africa	5.0	15.7	n.a.	2.47	n.a.	48.8	n.a.

Source: UNAIDS (2008) for HIV prevalence, UN Population Division (2007a) for demographic indicators and estimates of demographic impact of HIV/AIDS. The estimates by UN Population Division (2007a) are based on earlier estimates of HIV prevalence (UNAIDS/WHO (2006)), which have subsequently been revised substantially in some cases (e.g., Central African Republic, Swaziland, Zimbabwe). The estimates of the impact of HIV/AIDS are based on the difference between the estimates of actual demographic variables and a counterfactual "no AIDS" scenario included in UN Population Division (2007). The changes in demographic indicators shown are somewhat lower than the gross impact of HIV/AIDS, as some people whose deaths are attributed to HIV/AIDS would die for other reasons in the no-AIDS scenario. For a detailed discussion of the assumptions underlying the estimates of the impacts of HIV/AIDS, see UN Population Division (2007b).

There are several lessons that can be drawn from Table 1. First, the impact of HIV/AIDS is extremely severe in the high-prevalence countries, where HIV/AIDS-related mortality accounts for the majority of all deaths in 6 of 10 countries. As illustrated in Figure 1, this increase in mortality appears even more pronounced when data disaggregated by age (or sex) are considered (Figure 1), with HIV/AIDS resulting in a manifold increase in mortality among the working-age population, most notably between ages 30 and 39.

Figure 1. Zambia: HIV/AIDS and Mortality by Age and Sex 2000-05



Source: Author's calculations, based on UN Population Division (2007a).

Additionally, Table 1 summarizes estimates of the impact of HIV/AIDS on demographic variables which are frequently considered among determinants of economic growth, namely population growth and life expectancy.[9] We see that estimated population growth declines substantially for the high-prevalence countries, by between 0.5 and 1.4 percentage points, dropping by about one-half for the 4 countries featuring the highest HIV prevalence rates. One of the most striking aspects of the demographic impact of HIV/AIDS is the steep drop in life expectancy experienced in many countries, averaging 17 years for the 10 countries with the highest HIV prevalence rates, and in some cases wiping out health gains made over half a century.

Compared with the steep declines in life expectancy and other health indicators, GDP growth has held up fairly well. Figure 2 illustrates trends in GDP growth from 1990 for the 10 countries with the highest HIV prevalence rates at end-2005 (all in sub-Saharan Africa), as well as average GDP growth for sub-Saharan Africa. We do not see a dramatic decline in GDP growth in countries with high HIV prevalence, although the data suggest that growth in these 10 countries has decelerated somewhat relative to the average for sub-Saharan Africa.[10]

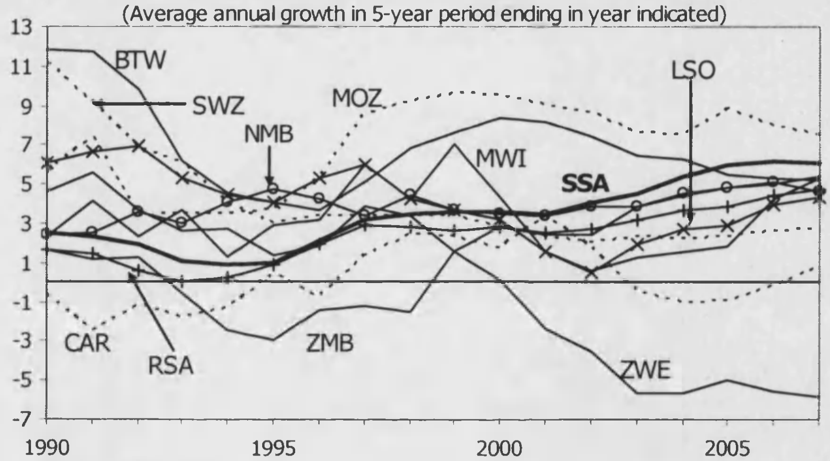
Regarding changes in GDP per capita, the picture is similar (Figure 3). This seems surprising at first sight, as one would expect that increasing mortality associated with HIV/AIDS would result in lower population growth, so that the slowdown in the growth of GDP per capita (if any) is less pronounced than the decline in GDP growth. However, many of the countries with high HIV prevalence are further advanced in the demographic

[9] It is important to stress that the estimates of the demographic impact of HIV/AIDS shown in Table 1 are generated by demographic and epidemiological models using a range of assumptions regarding the underlying demographics, and epidemiological and medical aspects of HIV/AIDS. Any inferences regarding relationships between the data shown would primarily reflect features of the underlying model. See Deaton (2006, p. 15 and Fig. 2) for a similar point regarding the pitfalls associated with the use of generated demographic variables.

[10] It is worth pointing out some special factors that resulted in various "outliers" in Figure 2. Growth in Swaziland is high in the early years shown because it benefited from foreign direct investment serving the South African market until the end of apartheid, developments in Botswana are dominated by the diamond sector, and the collapse in economic growth in Zimbabwe in the later years shown is attributed by most observers to the adverse impact of economic policies.

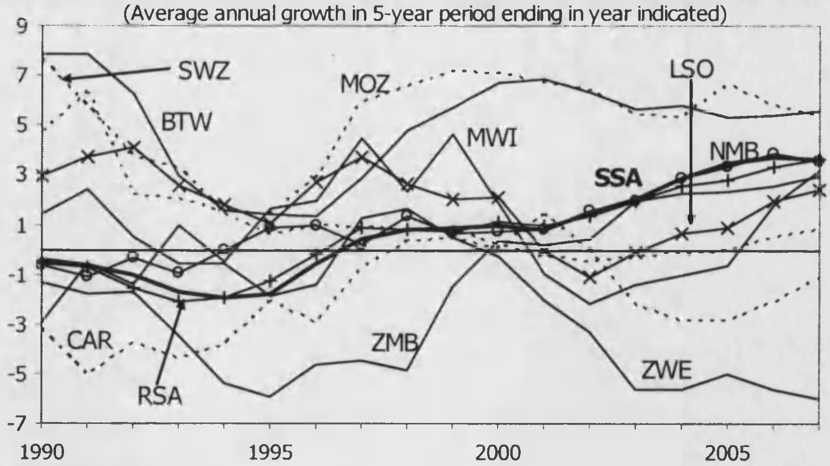
transition, with higher life expectancies (before the arrival of HIV/AIDS) and lower fertility rates than the average for sub-Saharan Africa. For this reason, the slowdown in population growth in the countries with high HIV prevalence is actually lower than the average for sub-Saharan Africa, and the decline in the growth rate of real GDP per capita relative to the average for sub-Saharan Africa less pronounced, compared to the slowdown in real GDP growth.

Figure 2. Real GDP Growth in 10 Countries With High HIV Prevalence
(Average annual growth in 5-year period ending in year indicated)



Source: IMF, 2008.

Figure 3. Real GDP Growth per Capita in 10 Countries With High HIV Prevalence
(Average annual growth in 5-year period ending in year indicated)



Source: IMF, 2008.

as the fact that HIV/AIDS accounts for the most significant swings in life expectancy in sub-Saharan Africa in recent years allows us to complement our informal discussion about the growth experience of countries with HIV high prevalence with a closer look at the data. To this end, we create a dataset for 41 countries,[11] including estimates of the growth of GDP per capita from IMF (2008) and estimates of life expectancy from UN Population Division (2007a) for the five-year periods ending in 1985, 1990, 1995, 2000. Overall, the apparent impact of HIV/AIDS on growth of GDP per capita is weak. For the set of 41 countries, we obtain a significant link between the change in life expectancy and growth – a drop in life expectancy of 6 years is associated with a decline in GDP growth by one percentage point. However, this correlation is largely accounted for by the 3 outliers identified in our discussion of Figs. (2) and (3), i.e., Botswana, Swaziland, and Zimbabwe, which feature large swings in GDP growth arguably not related to the impact of HIV/AIDS. If these countries are excluded, the coefficients turn insignificant and – once country dummies are included – negative.

Table 2. GDP Growth and Life Expectancy

	Dependent variable: Growth of Real GDP per Capita			
Change in Life Expectancy	0.17*** (3.25)	0.17** (2.49)		
Change in Log Life Expectancy			0.06* (1.77)	0.06 (1.60)
Time dummies included	Yes	Yes	Yes	Yes
Country Dummies included	No	Yes	No	Yes
Number of observations	205	205	205	205
R^2	0.11	0.41	0.11	0.41
Change in Life Expectancy	0.08 (0.59)	-0.05 (-0.27)		
Change in Log Life Expectancy			0.03 (0.44)	-0.03 (-0.34)
Time dummies included	Yes	Yes	Yes	Yes
Country Dummies included	No	Yes	No	Yes
Number of observations	190	190	190	190
R^2	0.34	0.46	0.34	0.46

Source: Author's estimates. One, 2, and 3 stars indicate estimated coefficients significant on a 10-, 5-, and 1-percent level of confidence. The second set of regressions, based on 190 observations, excludes data for Botswana, Swaziland, and Zimbabwe.

[11] The dataset consists of the 44 countries subsumed under sub-Saharan Africa by the IMF, excluding Eritrea and Liberia (GDP data unavailable for at least part of the period under consideration), and Seychelles (estimates of life expectancy unavailable).

C. Health and Growth

As the economic impacts of HIV/AIDS occur, directly or indirectly, through its impacts on health, the literature on health and growth provides a useful background for our discussion of the macroeconomic effects of HIV/AIDS. However, it is important to bear in mind that the health impact of HIV/AIDS, affecting primarily working-age adults, with a long asymptomatic period followed by a relatively short period with high mortality (at least in the absence of treatment), is quite different from the health developments that motivated much of the literature on health and growth, and that lessons regarding the economic impact from general "health and growth" studies do not necessarily or directly translate into predictions regarding the impact of HIV/AIDS on growth.

Our exposition of the literature on the impacts of health and growth proceeds in three steps. First, we discuss the impact of health or related demographic changes in a simple theoretical growth framework, identifying different channels through which health may affect growth. Second, we review some broad discussions of the theory and determinants of economic growth and consider the role of health in these frameworks. Third, we discuss a number of studies focusing on the impact of health on growth.

Health in the neoclassical growth framework

A useful workhorse for conceptualizing the impact of health on growth (and one frequently referred to in the relevant literature) is the framework developed by Mankiw, Romer, and Weil (1992), in short MRW, which augments the classical Solow growth model by allowing for accumulation of *human* as well as physical capital, with an aggregate production function of the form

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t E L_t)^{1-\alpha-\beta}, \qquad (1)$$

where Y, K, H, and L stand for aggregate output, the stock of physical capital, the stock of human capital, and the size of the labor force.[12] One addition to the MRW framework we introduce is the introduction of an efficiency parameter E, which stands for the effectiveness

[12] Sala-i-Martin (2005) also provides a discussion of different impacts of health on income or growth.

of labor inputs, in addition to a productivity parameter A capturing technological progress (assumed to grow at rate g). Dividing through by effective units of labor AEL, the production function becomes

$$y_t = k_t^{\alpha} h_t^{\beta}, \quad (2)$$

where $y_t \equiv \frac{Y}{AEL}$, $k_t \equiv \frac{K}{AEL}$, and $h_t \equiv \frac{H}{AEL}$. The accumulation of k and h is described by

$$\dot{k}_t = s_k y - (n + g + \delta_k)k, \text{ and} \quad (3)$$

$$\dot{h}_t = s_h y - (n + g + \delta_h)h. \quad (4)$$

This means that the accumulation of physical capital (relative to effective units of labor) depends on investments (= savings, s_k) in physical capital and a term that captures the depreciation of physical capital δ_k and the dilution that occurs through growth n in the size of the labor force L and technological progress (with A growing at rate g). The terms in the equation describing the accumulation of human capital are defined correspondingly.

One further extension to the MRW framework is embodied in Eqs. (3) and (4), as we allow the depreciation rates of physical capital (δ_k) and human capital (δ_h) to differ. Specifically, we think of δ_h as the mortality rate among the population, with the following reasoning (abstracting, for a moment, from technological progress g). To maintain some capital-labor ratio, it is necessary to make investments to increase the capital stock by the same rate as the population growth rate n. However, *human* capital is embodied in people. To retain a constant level in h, it is therefore necessary to make investments $s_h y$ to bring new entrants to the labor force "up to speed" with their peers. The rate at which new workers enter the labor force is equal to the (net) growth rate of the labor force n, plus the rate at which new entrants replace workers who died, δ_h, which motivates our interpretation of the depreciation rate for human capital.

To link key parameters of the growth model to health indicators, it makes sense to operate in terms of birth rates and mortality rates, rather than the rate of population growth (affected by births and deaths) and mortality. We therefore define the birth rate μ and the mortality rate ω. The parameters of the growth model are linked to these demographic/health variables as $n = \mu - \omega$, and $\delta_h = \omega$. Substituting for n and δ_h, in Eqs. (3) and (4) yields

$$\dot{k}_t = s_k y - (\mu - \omega + g + \delta_k)k, \quad \text{and} \tag{5}$$

$$\dot{h}_t = s_h y - (\mu + g)h. \tag{6}$$

Solving Eqs. (2), (3), and (4) for the steady state level of output per efficiency unit yields

$$y_t^* = \left(\frac{s_k}{\mu - \omega + g + \delta_k}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{s_h}{\mu + g}\right)^{\frac{\beta}{1-\alpha-\beta}}. \tag{7}$$

Additionally, one could be interested in output per capita (Y/L), which – along the steady-state growth path – follows

$$\left(\frac{Y}{L}\right)^* = AEy_t^* = AE\left(\frac{s_k}{\mu - \omega + g + \delta_k}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{s_h}{\mu + g}\right)^{\frac{\beta}{1-\alpha-\beta}}. \tag{8}$$

In the framework described by Eqs. (1) – (6), changes in health can affect the steady-state level of output along numerous channels.

- An increase in mortality rates would increase GDP per capita through its impact on the accumulation of physical capital (Eq. (5)). As more people depart from the labor force, the capital/labor ratio increases.
- A decline in birth rates would raise GDP per capita through its impact on physical capital accumulation, as the existing capital stock is less diluted by new arrivals (Eq. (5)). At the same time, it would become less expensive to sustain a given level of human capital; alternatively, for given investment rates in human capital, the steady state level of h would rise ((Eq. (6)).[13]

[13] It is important not to equate birth rates with fertility rates (i.e., the average number of children a women bears). As birth rates are defined as the ratio of births to population size, an increase in mortality can result in an

- An increase in the (average) efficiency of labor E, as a result of a deteriorating health state among the population, would decrease Y/L.
- A decline in the investment rate in physical capital, to accommodate higher health expenditures or reflecting a deteriorating economic outlook, would result in a decline in the steady-state capital stock and output per capita.[14]
- A decline in the investment rate in human capital would result in a decline in h. In addition to the factors noted for physical capital, the decline in human capital could also reflect a more pessimistic outlook regarding the expected returns to human capital (which decline as expected mortality increases).
- Additionally, a decline in the health outlook may reduce the steady-state growth rate g, for example, if there is a feedback effect from human capital to the rate of technological progress.

Additionally, transitional effects may arise. In particular, a sudden increase in mortality rates or a one-off mortality shock associated with an epidemic may result in a temporary increase in $\frac{Y}{L}$, as the denominator slows down or declines whereas Y only gradually adjusts towards the new equilibrium path.

Health in some general studies of economic growth

To gain a perspective on the role of health in the state of research on economic growth, it is useful to sample some broader studies of determinants of economic growth. Complementing our preceding discussion of different channels through which health may affect growth, this overview of the non-specific literature also provides pointers as to which aspects of health identified above are normally considered the most relevant ones.

Temple (1999), in a review of "the new growth evidence," discusses health in the context of human capital, also making reference to the MRW framework. However, much of the discussion focuses on the role of education. While noting that "variables like life expectancy

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increase in the birth rate if it primarily affects people after child-bearing age. On the other hand, an epidemic would reduce birth rates if behavioral changes, increased mortality, or lower health states among women of child-bearing age results in a drop in the number of pregnancies, or if increased morbidity results in fewer successful pregnancies.

[14] For simplicity, we focus on the direct effects do not discuss cross-effects between h and k.

are often used in growth regressions," he points out that "their role is never justified by a well-articulated theory." A more recent discussion of the state of growth empirics, Bosworth and Collins (2003), largely equate human capital with educational attainment, but include life expectancy "as a measure of health." Another health-related variable they capture is the rate of population growth.

Barro and Sala-i-Martin (1997) do not discuss health explicitly in their discussion of the state of growth *theory*, but capture it in their empirical analysis of a cross section of countries, using "an empirical framework that relates the real per capita growth rate to [...] the stock of human capital in the forms of educational attainment and health," proxied by life expectancy at birth (p. 421). They point out, however, that "it is likely that life expectancy has such a strong, positive relation with growth because it proxies for features other than health [...] [such as] better work habits and a higher level of skills. In addition to life expectancy, Barro and Sala-i-Martin include fertility rates in some regressions (see our discussion of the MRW framework, above), but do not motivate it explicitly. Another monograph from the same period, Aghion and Howitt's *Endogenous Growth Theory* (1997), does not discuss the role of health explicitly. However, as they discuss a range of models in which agents optimize over their planning horizons, the discussion could be extended in a fairly straightforward manner to account for changes in mortality or life expectancy.

Among the more recent monographs, Weil (2004) discusses health as one of the forms of human capital (the other being education), in a similar way as Temple (1999) or Barro and Sala-i-Martin (1997). Similar to Weil's more specific work (e.g., Weil (2007)), he discusses the impact of health on productivity. Additionally, he provides some discussion of the interactions of health and income (with higher income also "buying" better health, and of the links between climate, disease, and productivity. For Helpman (2004), health does not feature directly as a ingredient to the "mystery of economic growth," as it is largely focusing on the determinants of growth among the most developed countries.

The edited volume by Aghion and Durlauf (2005) includes some thorough discussions of numerous aspects and strands of the theory of economic growth, although none of them focuses on the role of health.[15] Durlauf, Johnson, and Temple (2005) focus on methodological aspects of growth empirics, and health does not feature in that discussion. However, they summarize the variables used in a large number of empirical studies. Life expectancy appears as the most common "health indicator" used in the literature, others include the prevalence of malaria and survival rates (i.e., the probability of reaching some age y, starting at age x). In addition, demographic (and health-related) variables such as dependency rates and fertility play a role in some studies. Caselli (2005), in his discussion of "accounting for cross-country income differences," discusses the "health status of the labor force" as a component of human capital. He finds that "while the results with the adult mortality rate strongly imply that a correction for differences in health status is a first-order requirement in the measurement of human capital, those using birth weight are much less supportive." In light of the shortcomings of the studies surveyed, he calls for further work "with more accurate indicators of health and more precisely calibrated parameters." Another health-related variable discussed by Caselli (2005) is "experience," i.e. the average level of work experience among the population, a variable that is influenced by demographic and health variables. Banerjee and Duflo (2005) focus on the direct impacts of health on productivity, quoting a number of micro-econometric studies linking the productivity of individuals to certain health characteristics.

Studies specifically addressing the impact of health on economic growth

The study of the impact of health on growth is complicated by an apparent interdependency between health and income. Notably, there is a broad literature focusing on the role of income in attaining good health.[16] Additionally, the correlation between health and growth (or income) may reflect underlying factors that affect both health and growth (Deaton, 2006). With these caveats, we first turn to the empirical literature that aims to identify the links between health and economic outcomes, largely by focusing on microeconomic evidence. We then discuss a number of studies on the links between health and growth that use an

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[15] One relevant chapter, Galor (2005), is discussed in the section on health and growth, below.

[16] See Preston (1975) and Pritchett and Summers (1996) for important contributions, or Deaton (2003) for a recent review of the literature.

approach that can be broadly captured along the lines of our discussion of the neoclassical framework, above. A number of studies, summarized next, use a somewhat more sophisticated approach, with forward-looking agents whose behavior is affected by the (anticipated) state of health. Finally, we discuss some studies allowing for more complex interactions, between health, demographics, and development.

Many of the key issues regarding the link between health and economic outcomes are discussed in a comprehensive (now somewhat outdated) survey by Strauss and Thomas (1998). They stress the complex linkage between health inputs and outputs, as "health varies over the life course and is the outcome of behavioral choices both during childhood and in later life." Also, they stress that health is "fundamentally multidimensional," and point at the challenges of measuring health, including the fact that the "measurement error is likely to be correlated with outcomes of interest like income" (a point also made by Deaton, 2006). One of the lessons from the empirical literature they survey is that health appears to have a larger return at low levels of health.

A more recent review (Thomas and Frankenberg, 2002) find that "carefully designed random assignment studies in the laboratory and field provide compelling evidence that nutritional deficiency – particularly iron deficiency – reduces work capacity and, in some cases, work output." Further, they note that "observational studies suggest that general markers of nutritional status, such as height and body mass index (BMI), are significant predictors of economic success although their interpretation is confounded by the fact that they reflect influences from early childhood and family background."

T. Paul Schultz (2005) points at similar issues to those discussed earlier by Strauss and Thomas, including the lack of "consensus among health specialists on how to conceptualize and measure health status at the individual level," the problem of measurement error, and interdependencies between productivity or income and health which make it difficult to identify causal relationships,[17] and the fact that health outcomes may depend on factors throughout an individual's lifetime, and not just on contemporaneous ones.

[17] Much of the article discusses the use of instrumental-variable techniques to address this issue.

Regarding quantitative studies on the links between health and growth, Bloom, Canning, and Sevilla (2004) is a good starting point, as their approach can be interpreted well in terms of our exposition of health in the neoclassical growth model, above. The core equation they estimate is

$$Y = AK^{\alpha}L^{\beta}e^{\phi_1 s+\phi_2 \exp+\phi_3 \exp^2+\phi_3 h}, \qquad (9)$$

where the $e^{\phi_1 s+\phi_2 \exp+\phi_3 \exp^2+\phi_3 h}$ is an efficiency parameter or a measure of human capital that includes measures of educational attainment (years of schooling, s), health (life expectancy, h), and "experience" of the workforce, which is motivated as a measure of skill but depends directly on the health state of the population (one reason to include it is to control for a potential indirect effect of health on productivity). They suggest that "a one-year improvement in a population's life expectancy contributes to an increase of 4 percent in output."[18] Cole and Neumayer (2006) also focus on productivity rather than growth. Rather than using summary measures of health, they focus on specific aspects of health (malaria incidence, prevalence of malnutrition, and the share of the population with access to safe water).

Bhargava and others (2001) focus on the link between growth and the adult survival rate (i.e., the probability of surviving to age 60 after reaching age 15), which arguably is a better measure of health as it relates to productivity as it excludes child mortality. They find a positive effect of adult survival rates on GDP growth in low-income countries, while the impact appeared to be negligible for higher-income countries.[19]

One recent study of the links between health and growth (or development) is Lorentzen McMillan, and Wacziarg (2005), who look in some more detail at channels through which health may affect growth, especially investment, human capital accumulation, and fertility.

[18] Additionally, Bloom, Canning, and Sevilla (2004) provide a survey of 13 earlier growth accounting exercises. In that literature, an increase in life expectancy of 5 years was associated with a growth rate that is between 0.0 and 0.6 percentage points higher.

[19] Similarly, Gyimah-Brempong and Wilson (2004) find that "the growth impact of health human capital decreases at relatively large endowments of health stock."

They suggest that mortality is an important determinant in explaining growth (the coefficients cannot easily be interpreted, as three different measures of mortality are included in the regressions). Additionally, the authors suggest that adult mortality may affect fertility rates, physical capital investment rates, and school enrolment.[20]

Shastry and Weil (2003) and Weil (2007) follow a different approach to identify links between aggregate health measures and GDP per capita. The approach in Weil (2007), the more comprehensive of the two papers, involves transforming available estimates from microeconomic and historical studies on the link between height and labor productivity into estimates of more commonly used health indicators like adult survival rates.[21] Weil finds that health differences account for about 10 percent of the cross-country variation in income.

Acemoglu and Johnson (2006) address the issue of interdependency of health outcomes and income by focusing on declines in mortality that can be attributed to the international epidemiological transition that began in the 1940s (i.e., changes in mortality that can be arguably attributed to medical innovations rather than economic factors). They find no evidence suggesting that the large exogenous increase in life expectancy led to a significant increase in per capita economic growth in the longer run. In the shorter run, the impact of reduced mortality appeared to be negative, as the population size expanded faster than GDP.

We have already made reference to some studies suggesting a link from health states to educational attainment (e.g., Miguel, 2005). A number of papers have developed a growth-theoretic framework focusing on the impact of changes in mortality on human capital accumulation and growth. The key channel from higher mortality to productivity in these models is the decline in the rate of return on investments in human capital associated with higher mortality (this point is discussed in more detail in Haacker (2004b). Kalemli-Ozcan, Ryder, and Weil (2000) develop a model in which agent's decisions to invest in human

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[20] Additionally, Lorentzen and others (2005) suggest that there may be a effect of mortality on risk behavior, as measured by smoking rates or HIV prevalence.

[21] A second set of studies Weil (2007) considers regards the link between age at menarche (first menstrual period) and labor productivity.

capital depend on the anticipated mortality. They suggest that the negative impact of increased mortality on schooling would double the elasticity of steady-state output with respect to changes in the mortality rate. Kalemli-Ozcan (2002) extends this approach in two directions, introducing endogenous fertility into the model and also allowing for endogenous mortality. She proposes that a decline in mortality results in a decline in demand for children and increases in investment in each child. Another study linking mortality, educational attainment, and fertility, along similar lines, is Soares (2005), although his paper is not primarily geared toward the growth implications. Blackburn and Cipriani (1998) also discuss the link between underlying mortality and growth in a model with endogenous fertility and mortality, featuring physical capital only. Van Zon and Muysken (2001, 2005) adopt an endogenous growth framework motivated by Lucas (1988); the key point from their analysis is that a shift in the health state of the population that necessitates higher health expenditures results in a shift of labor time to health care and a reduced consumption and growth.

Finally, we turn to a set of studies that feature more complex interactions between health, growth, and development. Many of these studies feature externalities and other economic interactions that can give rise to growth "take-offs," but also development traps. Sala-i-Martin (2005) conveys much of the logic of this approach, arguing that (1) citizens of poor countries have little resources and incentives to improve the state of their health, and that poor health has "adverse effect on the growth potential of a country, [...] through the process of education and training, through the effects on other diseases, through the accumulation of physical capital, and through the efficiency of the economy."

In several papers by Galor and Weil (1999, 2000) and Galor (2005), developing a "unified growth theory" describing the transition to the modern growth regime, an increase in returns to human capital, which results in increased investment in human capital (and, eventually, a decline in fertility) is one of the key factors enabling sustained growth. The state of health of the population, as it affects the returns to and the rate of investment in human capital, thus can affect the timing or the occurrence of a growth take-off, or the rate of growth. For example, Galor (2005) argues that "in light of the technologically-based rise in the demand for human capital in the second phase of the Industrial Revolution, however, the rise in the expected length of productive life has increased the potential rate of return to investments in children's human capital, and thus re-enforced and complemented the inducement for investment in education and the associated reduction in fertility rates."

One specific line of thinking about the interactions between health and growth is Acemoglu, Johnson, and Robinson (2003), who postulate a link between disease environments during the period of European colonial expansion and economic and social institutions set up by the Europeans in the respective colonies, shaping the future course of economic development.

D. HIV/AIDS and Growth

The adverse health impacts of HIV/AIDS have motivated a body of literature dealing specifically with the growth impacts of HIV/AIDS. The discussion of the links between health and growth already provides many pointers regarding the economic impacts of HIV/AIDS, and indeed motivates much of the applied literature in this area. However, many of the findings of that literature do not necessarily translate directly to the study of the impacts of HIV/AIDS, as the health consequences of HIV/AIDS are different from those of many other health conditions which dominate the literature on health and growth.

One important difference between HIV/AIDS and other diseases regards the profile of HIV/AIDS-related mortality, which is concentrated among working-age adults, whereas the most significant other diseases affect primarily either children (especially of ages 0–5) and old people (also see Fig. 1). Many observers have expressed concerns that HIV/AIDS therefore could have an impact on production processes, as HIV/AIDS-related deaths disproportionally result in the loss of economically active people. More generally, the profile of mortality raises issues regarding the returns to human capital, as early mortality owing to HIV/AIDS means that the returns to investments in education decline.

The other key difference between HIV/AIDS and many other health conditions arises from the fact that HIV/AIDS is largely asymptomatic for many years, and that the progression to mortality, once the symptoms become apparent, is relatively fast.[22] This distinguishes HIV/AIDS from many health conditions which are debilitating, but are not normally lethal. HIV/AIDS may therefore have a less pronounced impact on the efficiency of labor than is suggested by empirical studies linking productivity to summary health indicators.

Nevertheless, many of the issues addressed by the literature on health and growth are also relevant for the study of the impacts of HIV/AIDS. While there is a considerable number of studies focusing specifically on the impact of HIV/AIDS – reflecting the perception of the

[22] Owing to the increasing availability of ART in low-income countries, the character of HIV/AIDS may shift more towards a chronic disease.

catastrophic health impact of the epidemic in many countries, as well as the noted specifics of the impact of HIV/AIDS compared to general health conditions – the approaches taken in this studies are therefore frequently drawing on the literature on health and growth.

To organize our discussion of the specific literature on HIV/AIDS and growth, we will distinguish four different aspects of that literature. First, we will discuss empirical studies of the impact of HIV/AIDS. Second, we will review studies adopting a growth-accounting framework inspired by the neoclassical growth model, similar to the one used to structure our discussion of the impact of health on growth and per-capita income, above. Third, we discuss a number of studies featuring a richer set of microeconomic underpinnings with forward looking agents, in which expectations regarding he economic and health impacts of HIV/AIDS may affect decisions on the accumulation of human capital or educational choices, or demographic variables like fertility rates. Finally, much of the literature on the economics of HIV/AIDS has been policy-oriented, and we take note of some studies which do not meet academic standards but nevertheless represent significant additions to the literature, as evident – for example – by quotations in later studies.

The empirical evidence regarding the effects of HIV/AIDS on economic growth is weak. One early study, Bloom and Mahal (1997), do not find any impact of HIV/AIDS on growth. However, from today's perspective, the study suffers from serious shortcomings regarding the measurement of the key explanatory variable, the number of AIDS cases, which had been constructed by the authors from very preliminary data.[23] Dixon and others (2001, 2002) provide some mixed evidence regarding the impact of HIV/AIDS on growth, largely though

[23] As Bloom and Mahal explain, "direct measures of the number of AIDS cases are not available for any country in our sample, with the exception of the United States." Instead, they use estimates generated by an epidemiological model, and available data on HIV prevalence, largely from survey data at antenatal clinics. From today's perspective, the latter would be regarded as a very unreliable indicator of national HIV prevalence, and the uncertainties are compounded by the use of an epidemiological model to generate estimates of the number of AIDS cases. Also, their sample – extending through 1992 – precedes the period in which HIV/AIDS-related mortality took off in many countries.

the impact of HIV/AIDS on life expectancy,[24] while the evidence regarding the link from life expectancy to growth is weaker. In a recent paper, Papageorgiou and Stoytcheva (2007) find a statistically significant but very small impact of the observed number of AIDS cases on GDP per worker (using numbers of reported AIDS cases from WHO/UNAIDS epidemiological fact sheets,[25] not generated data as in Bloom and Mahal (1997)). One issue that is not addressed by the studies summarized is the potential role of outliers in the sample, which could be an important issue in light of the large shifts in economic growth rates in three of the countries with very high (possibly the highest) HIV prevalence rates arguably not related to HIV/AIDS, as discussed above.

While the evidence regarding the impacts of HIV/AIDS on GDP per capita is very weak, some studies point at impacts of HIV/AIDS on workers' productivity (see, e.g., Fox and others, 2005, or Morris, Burdge, and Cheevers (2001)). However, there is not sufficient evidence regarding the direct productivity effects across sectors at this time that would allow for drawing inferences regarding aggregate productivity effects.

The increasing recognition of HIV/AIDS as a serious development issue in the early 1990s has motivated a "first wave" of studies analyzing the macroeconomic effects of HIV/AIDS. Two early studies apply a one-sector neoclassical growth model to assess the potential growth impacts of HIV/AIDS in Tanzania (Cuddington, 1993) and Malawi (Cuddington and Hancock, 1994). In addition to direct productivity effects (which could be interpreted as working time lost), labor productivity is assumed to depend on the age structure of the population, through an equation linking productivity of an individual worker to "experience." Reflecting the uncertainty regarding the economic effects to HIV/AIDS, the two studies map a range of assumed changes in productivity and savings (to accommodate

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[24] This finding is not surprising, as the estimates of life expectancy used by Dixon and others, from the World Bank's World Development indicators, are based on estimates of HIV prevalence

[25] One drawback of this approach is the possibility that the extent to which AIDS cases are reported may differ across countries or over time, and that this error is correlated with economic variables, e.g. when the coverage of surveillance is limited in poorer countries, or if countries with higher prevalence rates collect more extensive data.

higher medical and related expenditures) into estimates of the impact of HIV/AIDS on growth. Cuddington, Hancock, and Rogers (1994) point at the possibility of multiple equilibria, as HIV/AIDS-related expenditures are proportionally larger (relative to GDP per capita) at lower levels of income, but note that multiple steady states do not occur for plausible parameter values.

Cuddington (1993b) and Cuddington and Hancock (1995) extend the analysis to a dual economy model with some labor market imperfection. While Cuddington (1993b) observes that labor market reforms may offset the adverse impacts of HIV/AIDS, Cuddington and Hancock (1995) point at the positive partial impact of HIV/AIDS on GDP per capita that arises if workers are drawn from the informal to the formal sector (to replace workers lost to HIV/AIDS), which in their model offset other adverse partial impacts, so that the overall impact is relatively small. Over (1992) extends the "dual economy" model by also allowing for different types of labor inputs, and uses this framework to discuss implications of the "socio-economic gradient" of the epidemic (here, the distribution of HIV/AIDS across classes of skills) for the macroeconomic impact.

Among the more recent study also adopting models similar to the neo-classical frameworks just described are Macfarlan and Squerri (2001), Haacker (2002a, 2002b). Macfarlan and Squerri, using a model building on Cuddington and Hancock (1995), project a slowdown in non-mining GDP growth in Botswana of up to 4 percentage points by 2010, about the same magnitude a their projected slowdown in the size of the working-age population. One factor that they point at (though not model explicitly) is the role of natural resource endowments (a large proportion of GDP in Botswana is accounted for by mining). If this is included in the analysis, GDP per capita (in Botswana or countries with a similar economic structure) could accelerate substantially as population growth slows down.[26]

Haacker (2002a) discusses two features of the models discussed above (and of some studies using a more complex macroeconomic model (e.g., Arndt and Lewis (2000), Bureau

[26] The situation in Botswana is discussed in more detail, though using a less elaborate economic model, in BIDPA (2000).

of Economic Research (2001), or ING Barings (2000), which are discussed further below). First, an important feature of these models is that the adverse direct impact of HIV/AIDS is mitigated by an increase in the capital-labor ratio. Haacker (2002a) suggests that this implies changes in the rate of return to capital which are implausible, given that many of the economies in question feature highly open capital markets and depend on foreign direct investment. The second aspect of many of the studies referred to that Haacker (2002a) investigates are effects on average GDP per capita which occur if a higher share of the population is absorbed by the formal sector, and he discusses the assumptions implicit in such scenarios.

A somewhat different strand of modeling originates with Kambou, Devarajan, and Over (1992), who apply a CGE model to studying the macroeconomic impacts of HIV/AIDS. Models in this tradition apply a more sophisticated sectoral structure, allowing for differential effects of HIV/AIDS across sectors or regions. However, owing to the envelope theorem, the features of CGE models tend to be similar to models based on aggregate macroeconomic variables.

The model employed by Kambou, Devarajan, and Over (1992) distinguishes 11 sectors which differ with respect to the intensity of inputs of rural labor, urban unskilled labor, and skilled labor, with a share of skilled labor that ranges from zero percent (food crops) to 28 percent (public services). In the absence of a clear pattern of HIV prevalence across skill categories, Kambou, Devarajan, and Over analyze equiproportionate shocks to the labor force, as well as shocks to the respective skill categories. The economy appears most vulnerable to shocks to the supply of skilled labor, as this factor is disproportionally used in sectors accounting for a relatively large share of GDP.

Arndt and Lewis (2001) and Arndt (2006) follow similar approaches, with slightly differentiated economic structures and adding various modeling components. Notably, Arndt and Lewis (2001) include more detailed assumptions regarding the impact of HIV/AIDS on spending patterns, whereas Arndt (2006) is designed in order to allow for policy interventions to offset an adverse impact of HIV/AIDS on access to education. Both studies find a large impact of HIV/AIDS on GDP growth. This finding, however, is largely based on the fact that both studies assume a strong impact of AIDS incidence on TFP growth.[27]

The CGE models also provide a backdrop for a group of policy-oriented studies, adapting larger macroeconom(etr)ic models developed for a different purpose to account for the economic effects of HIV/AIDS. The notable representatives of this class of models are ING Barings South African Research (2000), Laubscher and others (2001), and Ellis and others (2006),[28] all focusing on the South African economy. Regarding the sectoral composition of the economy, the structure of the models (and, consequently, the findings) are similar to the CGE models discussed above. There are three (at least comparative) advantages arising from the fact that these studies embed the analysis of the impact of HIV/AIDS in a model designed to conduct comprehensive policy analyses and projections for the South African economy. (1) Frequently, assumptions regarding the impact of HIV/AIDS can usually be easily mapped into model parameters, and (2) as the model generates projections around a fairly comprehensive macroeconomic baseline scenario, it is possible to derive inferences regarding impact of HIV/AIDS on key macroeconomic variables that the more analytical studies do not capture. The obvious disadvantage of using large-scale macromodels is that frequently it is difficult to interpret the findings in terms of the role that various dimensions of the impact of HIV/AIDS are playing, as details of the model have not been published or feature complex macroeconomic interdependencies.

Notable features of ING Barings South African Research (2000) include discussions of the impacts of HIV/AIDS on various segments of the labor market, on domestic savings, and on inflation. The impact on GDP growth is moderate (a decline of 0.3–0.4 percent), as the slowdown in population growth is more pronounced, this implies a notable increase in GDP per capita. Regarding the impacts of HIV/AIDS on productivity, the study assumes that an

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[27] Arndt (2006) assumes that an AIDS incidence rate of 1 percent translates into a slowdown in productivity growth of 1 percentage point. Arndt and Lewis (2001) apply a non-linear specification, whereby an AIDS death rate of 1 percent slows down productivity growth by 23 percent (not percentage points).

[28] Ellis and others (2006), by the same authors as Laubscher and others (2001), largely represents and update of the earlier study.

AIDS incidence rate of 1 percent translates into a decline in the level of productivity of 1 percent. In Laubscher and others (2001) and Ellis and others (2006), the projected impact of HIV/AIDS on GDP growth is somewhat more pronounced (0.3–0.6 percent), although GDP per capita still comes out higher than in a "no-AIDS" counterfactual scenario; the more negative outcome likely reflects the fact that BER (2001, 2006) assume a link between AIDS incidence and TFP growth (similar to Arndt and Lewis, 2000). One unique aspect of Ellis and others (2006) is the discussion of the potential macroeconomic impacts of improved access to antiretroviral treatment,[29] suggesting that an ART program with a coverage rate of 50 percent could reduce the impact of HIV/AIDS on GDP by 17 percent (not percentage points) be 2020, with a projected change in the GDP growth rate of minus 0.38 percentage points with ART rather than minus 0.46 percentage points without.

The models discussed so far have focused on the macroeconomic consequences of HIV/AIDS which arise through the immediate impacts of HIV/AIDS on key macroeconomic variables (or microeconomic variables, such as health status of people living with HIV/AIDS, interpreted from a macro perspective), such as declines in endowments of human capital, disruptions to production processes, or a shift in spending from consumption and investment to health expenditure to cover the costs of care and treatment.

From about 2002, a group of studies have explored more complex and indirect effects of HIV/AIDS which arise when economic agents adjust their behavior in response to the macroeconomic and disease context. This shift in the literature has been motivated by the theoretical literature on economic growth, which emphasizes the role of agents basing their decisions on expectations regarding their economic outlook, and frequently by some discomfort regarding the small impacts of HIV/AIDS suggested by the earlier studies, which contrasts with a more general perception of HIV/AIDS as a serious challenge for economic development, arising from the severe health consequences of the epidemic.

[29] An earlier study discussing the macroeconomic repercussions of ART is Masha (2004), adopting a less elaborate macroeconomic model.

Among these studies, Robalino, Voetberg, and Picazo (2002) argue that increased mortality will result in a decline in the savings rate and investment that exceeds any direct effects arising from higher health expenditures. In Corrigan, Glomm, and Mendez (2005), HIV/AIDS also reduces investments in education, as higher mortality risk means that parents are less likely to benefit in old age from investments in their children.[30]

The studies by Bell, Devarajan, and Gersbach (2004, 2006) and Bell, Bruhns, and Gersbach (2006) cover similar ground, but are built around a more elaborate model of generation of human capital which focuses on the transmission of knowledge from parents to children. While the present authors also allow for an effect of expected mortality (reducing the expected return to human capital) on education decisions as in the more aggregate models, the most significant impacts of HIV/AIDS in these models arise as early mortality disrupts the transmission of knowledge between generations. As orphans tend to receive relatively low education (and as the authors allow for little upward mobility), the impacts of HIV/AIDS accumulate from generation to generation and can become very large.

A related group of studies focuses on the potential impact of HIV/AIDS on fertility. Young (2005, 2007) focuses on two effects of HIV/AIDS, namely the adverse impact on the human capital accumulation of children, and the reduction in fertility that arises through a reduction in unprotected sex and as HIV/AIDS results in an increase in the of scarcity of labor (as the capital/labor ratio rises) and thus in the value of women's time. Young (2005) argues that the fertility effect, primarily through reduced population growth, translates into increased GDP per capita. Young (2007) complements this line of reasoning with a study that focuses more on an cross-country econometric analysis of the impact of HIV/AIDS on fertility and other variables, with findings largely in line with his earlier study. However, the findings of both papers have been put into question by Kalemli-Ozcan (2008).[31,32] Unlike

[30] Another study, frequently quoted but yet unpublished, that highlights the impacts of HIV/AIDS on investments in physical capital and education is Ferreira and Pessoa (2003).

[31] Kalemli-Ozcan suggests that the findings of Young (2005) largely arise from the large weight in his sample of periods before 1990 in which HIV/AIDS was insignificant (and is assumed zero), whereas his findings are reversed if only post-1990 data are included. On Young (2007), she points out that the coefficients of

Young, she finds a positive relationship between fertility and HIV prevalence, which she interprets along the lines of Kalemli-Ozcan (2002) or Soares (2005), which are discussed above.

E. Conclusions and Outlook

There are (at least) three broad lessons we can take from our discussion of the literature on health and growth more generally and the more specific literature of HIV/AIDS and growth. First, the impacts of HIV/AIDS on economic growth at present appear much smaller than what would be suggested by some of the empirical literature on health and growth. This could point at shortcomings in the literature on health and growth more generally, or reflect that health and mortality impacts of HIV/aUDS differ from those associated with many other diseases. Second, there is very wide uncertainty regarding the economic impacts of HIV/AIDS over the next decades, notably because the full impact of HIV/AIDS on education or the accumulation of human capital will only become apparent over time. Third, the findings regarding the (small) macroeconomic effects of HIV/AIDS contrast some microeconomic studies which show a significant impact on affected households; to understand the economic impact of HIV/AIDS, it is necessary to reconcile these findings.

Many empirical studies on determinants of economic growth use life expectancy as a proxy for the state of population health, which is considered as one of the constituents of human capital. However, for HIV/AIDS, with a very specific health impact, the association between life expectancy and an underlying state of health relevant with regard to economic growth presumably is different from the pattern observed in the historical data, a point that is also made by some of the studies discussed above (e.g., Acemoglu and Johnson, 2006).

HIV/AIDS in the fertility regressions become insignificant once the clustering of individual observations is taken into account.

[32] One issue that both Young and Kalemli-Ozcan are not addressing explicitly, but that may affect their findings, is the fact that some of the countries highly affected by HIV/AIDS already were in a more advanced stage of demographic transition than most countries in sub-Saharan Africa.

Notably, it is frequently assumed, implicitly or explicitly, that the impact of HIV/AIDS would be particularly severe because it primarily affects young adults.

Against this background, the apparent absence of a steep decline in GDP growth in countries with high HIV prevalence rates, and declines in life expectancy exceeding 10 years in many cases, is puzzling. For the literature on health and growth, it underlines that life expectancy – even though it fairly robustly "explains" some of the historical variation in growth in empirical studies – may not be a good proxy for underlying health conditions relevant for economic growth, and that the findings of the empirical literature have little predictive power regarding the economic effects of new types of diseases (if this is indeed what it measures, rather than reflecting unobserved variables affecting both health and growth).[33]

While few observers would contest that the impacts of HIV/AIDS on economic growth (at least growth of GDP per capita) are modest, there is strong disagreement regarding the longer-term impacts of the epidemic, with some observers proposing that "economic collapse is a very real danger" in a high-prevalence country (Bell, Devarajan, and Gersbach, 2006), at least in the absence of policy interventions, while Young (2005) suggests that "the AIDS epidemic [...] enhances the future per capita consumption possibilities [...]." In light of the very serious health and demographic disruptions caused by HIV/AIDS, gaining an improved understanding of the potential impacts in the longer term is important. To this end, it would be necessary to develop or refine models in line with the evidence on the impacts of HIV/AIDS (and, if applicable, health conditions and mortality not related to HIV/AIDS) on the microeconomic level, for example, regarding the impact on orphans or education decisions.

The evidence regarding the (modest) impacts of HIV/AIDS on macroeconomic aggregates contrast with microeconomic evidence that shows a serious impact of HIV/AIDS on affected individuals, households, or communities. Consequently, indicators of the average

[33] More generally, the disease environment, both in developed and in developing countries, has changed dramatically over the 20th century. See, for example, Acemoglu and Johnson (2006) or Deaton (2006) for elaborations on this point.

impact of HIV/AIDS (such as GDP per capita) are incomplete and potentially misleading indicators of the economic impacts of HIV/AIDS. Notably, HIV/AIDS can affect development indicators such as poverty rates, access to education, or gender imbalances. Further, to the extent that vulnerability to HIV/AIDS and the ability to cope with the impact is correlated with the socio-economic status or other characteristics (e.g., location) of an individual or household, HIV/AIDS can exacerbate existing inequities. These factors, in turn, can have repercussions for the impacts of HIV/AIDS on aggregate variables like GDP per capita (e.g., through changes in access to education). To capture the economic impacts of HIV/AIDS more fully, it is therefore necessary to improve the understanding of such microeconomic effects, their relevance from a broad development perspective, and the macroeconomic repercussions.[34]

Finally, one shortcoming of the literature that is worth noting is a scarcity of studies that acknowledge that the health impact of HIV/AIDS in endogenous, especially in the context of increased availability of ART in developing countries. To some extent, this reflects the fact that most of the body of existing literature was written or at least conceived before scaling-up of ART took off.[35] Improving the understanding of the determinants and impacts of scaling up is also a necessity for assessing the distributional impacts, as inequities in access to treatment potentially add a dimension to the differential impacts of HIV/AIDS across the population.

[34] See, for example, Haacker (2004b) or Nattrass (2003), for discussions of these and related points.

[35] Among more recent studies, BER (2006), Masha (2004), and Young (2007) discuss economic aspects of scaling up of ART.

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G. List of Acronyms

ART	Antiretroviral treatment
BTW	Botswana
CAR	Central African Republic
CGE	computable general equilibrium
GFATM	Global Fund to Fight HIV/AIDS, Tuberculosis, and Malaria
HIV/AIDS	refers to the *human immunodeficiency virus* and the associated *acquired immunodeficiency syndrome*
LSO	Lesotho
MOZ	Mozambique
MWI	Malawi
NMB	Namibia
RSA	South Africa
SSA	Sub-Saharan Africa
SWZ	Swaziland
TFP	total factor productivity
UNAIDS	Joint United Nations Programme on HIV/AIDS
ZMB	Zambia
ZWE	Zimbabwe

H. Appendix: HIV/AIDS – Epidemiology, Impact, and International Response[36]

HIV/AIDS refers to the human immunodeficiency virus and the associated acquired immunodeficiency syndrome, which were first recognized as a global health issue in the early 1980s. In 2006, about 40 million people globally were living with HIV/AIDS, including 25 million in sub-Saharan Africa, and the epidemic claimed almost 3 million lives in that year. The international response has involved a rapid scaling-up of aid and an expansion of prevention and treatment programs, as well as the establishment of two specialized international agencies to deal with the epidemic—the Joint United Nations Program on HIV/AIDS (UNAIDS) and the Global Fund to Fight HIV/AIDS, Tuberculosis, and Malaria (GFATM).

Epidemiology and Demographics

The most important modes of transmission of HIV are sexual contact with an infected person, sharing needles for injected drug use, mother-to-child transmission before or during birth or through breast-feeding, and transfusions of infected blood or blood clotting factors. HIV/AIDS is largely asymptomatic during the first years after infection. Over time, HIV/AIDS progressively damages the immune system, resulting in increased susceptibility to opportunistic infections (e.g., pneumonia, tuberculosis, and certain types of cancer) and, eventually, death. Antiretroviral treatment suppresses the virus and slows down the progression of the disease.

The region most affected by HIV/AIDS is sub-Saharan Africa; however, the high HIV prevalence rate of about 6 percent for the region masks very substantial differences in HIV prevalence across countries, ranging from less than 1 percent (e.g., in Senegal) to more than 20 percent in Botswana, Lesotho, Swaziland, and Zimbabwe (all data on HIV prevalence relate to the population ages 15–49, at end-2005). Although HIV prevalence appears to have stabilized in sub-Saharan Africa since around 2001, it has been spreading rapidly in Eastern Europe and Central Asia.

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[36] Reprinted from Haacker, Markus, 2008, "HIV/AIDS," *Princeton Encyclopedia of the World Economy* (Princeton NJ: Princeton University Press).

Development Impact

From an economic development perspective, the most direct impact of HIV/AIDS is the increase in mortality and consequent decline in life expectancy associated with it. For some of the most affected countries, it is estimated that HIV/AIDS has reduced life expectancy by more than 20 years. Development indexes such as the United Nations Development Program's Human Development Index, which combines measures of income, education, and health, suggest that HIV/AIDS has been the most significant single factor to adversely affect development in recent decades. Another consequence of the increase in mortality among young adults associated with HIV/AIDS is an increase in orphan rates, which are estimated to have reached 20 percent of the young population in some of the countries most affected by the epidemic.

The evidence regarding the macroeconomic impacts of HIV/AIDS is less clear. In light of the slowdown of the growth of the working-age population, there is a consensus that growth of gross domestic product (GDP) also slows as a consequence of HIV/AIDS. Studies applying a neoclassical growth model typically find that HIV/AIDS reduces GDP per capita through declining productivity and a fall in capital per worker that occurs as health-related spending lowers the national saving and investment rates. These effects are at least partly offset by the impact of increased mortality on the capital/labor ratio (mortality decreases the denominator, causing an increase in the overall ratio). The latter effect, however, partly dissipates if investment flows are sensitive to changes in the rate of return to capital.

On the microeconomic level, HIV/AIDS is associated with income losses (as household members become too sick to work and as working time is devoted to caregiving) and with increased health-related expenditures. Microeconomic data, largely from sub-Saharan Africa, therefore suggest an adverse impact of HIV/AIDS on incomes, consumption, and wealth of affected households. This is most pronounced during illness or around the time of death; households appear to partly recover later on. To understand the impact of HIV/AIDS on poverty or inequality, it is necessary to take a broader perspective, also covering households that may gain financially as they benefit from income opportunities associated with deaths in other households, most obviously when household members fill HIV/AIDS-related vacancies. Overall, the sparse evidence suggests that an increased volatility in incomes associated with higher mortality translates into an increase in poverty.

International Response

On a global level, recognition of the health, humanitarian, and development challenges posed by HIV/AIDS has translated into an unprecedented effort to contain the epidemic and expand access to treatment. Important steps of the international response were the establishment of UNAIDS and the GFATM, and the United Nations General Assembly Special Session on HIV/AIDS (2004). In financial terms, the scale of the international response to HIV/AIDS has expanded very rapidly: Consistent estimates for HIV/AIDS-related spending are available for low- and middle-income countries only; for these, spending has increased from about U.S. $300 million in 1996 to about U.S. $9 billion in 2006, of which about U.S. $6 billion were financed by external aid. The most important funding agencies are the GFATM and the U.S. President's Emergency Plan for AIDS Relief.

National responses to HIV/AIDS depend on the state of the epidemic in a country. To various extents programs emphasize public prevention measures in schools and work places, prevention and awareness measures targeted at high-risk groups, strengthening the health care system, improvements in care for people living with HIV/AIDS, measures to mitigate the social impacts (including support for orphans), and programs to expand access to treatment.

The most effective prevention measures are those targeted at groups at high risk of contracting and passing on the virus, including promotion of condom use among sex workers and provision of sterile needles to injecting drug users. Those measures, together with the perceived impact of the epidemic, have been credited with increasing awareness and reducing risky behavior. Social attitudes, particularly toward men who have sex with men, or the illegal nature of some of the risky behavior such as injecting drug use, can complicate the implementation of prevention programs, however.

In the most affected countries in Southern Africa, the epidemic is generalized, and prevention efforts are geared toward raising awareness and reducing risk behavior across the population, especially among young adults, through the education system, media and advertising campaigns, and public endorsements by leading politicians. Although HIV prevalence has risen to double-digit levels in numerous countries in spite of these efforts, in 2005–6 many of the most affected countries reported increasing HIV awareness and somewhat falling prevalence rates among young adults.

The most significant development in the early years of the 21st century regarding the response to HIV/AIDS was the decline in the costs of antiretroviral treatment. In many developing countries, certain forms of antiretroviral treatment were available in 2007 at costs of around U.S. $300 annually, down from about U.S. $10,000 in 2000. This development reflected voluntary agreements with drug companies, often under the threat of compulsory licensing to a local producer, and the fact that only a certain range of antiretroviral drugs was available at these low prices, which allowed for some market segmentation between industrialized and developing countries.

Falling prices of drugs and strong international financial support have contributed to a rapid expansion in access to treatment. UNAIDS reports that the number of people receiving antiretroviral treatment in low- and middle-income countries increased from 400,000 to 1.3 million between 2003 and 2005 (corresponding to a coverage rate of about 20 percent), with sub-Saharan Africa accounting for the bulk of the increase.

Continued spread of the disease and the longer survival of those already infected make the management of an increasing number of people requiring treatment the principal challenge in addressing the epidemic in the near future. Additional challenges include extending the gains made to countries with weaker public health systems, where progress in expanding access to treatment has been less pronounced so far, and managing the fiscal challenges and long-term commitments associated with the expansion in these health programs.

UNAIDS and the Global Fund

The perception of HIV/AIDS as a threat to global health, beyond the capacity and expertise of any single international organization, resulted in the establishment of a unique institution, UNAIDS, in 1994. UNAIDS coordinates the HIV/AIDS-related activities of its cosponsoring organizations, which are 10 (initially 6) organizations under the UN system. Although a relatively small organization on an international scale (its annual operational budget amounted to about U.S. $58 million in 2006–7), it is also financing part of the activities of its cosponsors on HIV/AIDS, as well as interagency activities (U.S. $42 million annually in 2006–7). Moreover, cosponsors include all of their HIV/AIDS-related activities in UNAIDS's Unified Workplan, which brings the total of HIV/AIDS-related spending coordinated by UNAIDS to about U.S. $1.3 billion annually for 2006–7, about one-sixth of global spending on HIV/AIDS. Additionally, UNAIDS is a key provider of public information on the epidemic, including the annual Report on the Global AIDS Epidemic, which is the most important regular publication on HIV/AIDS.

The GFATM is primarily a funding agency. It receives about 95 percent of its funding from government sources. Grants typically underwrite comprehensive country programs, which are coordinated nationally, for several years. Between 2002 and end-2006, the GFATM disbursed U.S. $3.3 billion, of which U.S. $1.35 billion was disbursed in 2006. Of the accumulated grant portfolio, HIV/AIDS accounts for the lion's share (56 percent), followed by malaria (27 percent) and tuberculosis (15 percent). Although public institutions play the most important role as implementing agencies (accounting for about half of GFATM-supported funding), many of the national responses are implemented by nongovernmental organizations (about a quarter of funding) or by faith-based and academic organizations. Reflecting the burden of disease of HIV/AIDS in the region, sub-Saharan Africa accounts more than half of GFATM funding.

Further Reading

Many key references are updated periodically and available online. Useful web sites are the ones of UNAIDS (www.unaids.org), including the annual Report on the Global AIDS Epidemic; the GFATM (www.theglobalfund.org); and the Global AIDS Program of the U.S. Centers for Disease Control and Prevention (www.cdc.gov/nchstp/od/gap/). The World Bank's website also includes much useful material, accessible from http://www.worldbank.org/aids. Other references include:

Beck, Eduard J., Nicholas Mays, Alan W. Whiteside, and Jose M. Zuniga (eds.), 2006, *The HIV Pandemic—Local and Global Implications* (Oxford: Oxford University Press).

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Haacker, Markus, (ed.), 2004, *The Macroeconomics of HIV/AIDS*, (Washington, DC: International Monetary Fund). Available online at http://www.imf.org/external/pubs/ft/aids/eng/index.htm.

Jamison, Dean T., Richard G. Feachem, Malegapuru W. Makgoba, Eduard R. Bos, Florence K. Baingana, Karen J. Hofman, and Khama O. Rogo (eds.), 2006, *Disease and Mortality in Sub-Saharan Africa*, (Washington, DC: World Bank).

II.2. Modeling the Macroeconomic Consequences of HIV/AIDS

A. Introduction

The ongoing HIV/AIDS epidemic has had a significant health and demographic impact in many countries, notably in sub-Saharan Africa, and in some countries has reversed achievements in health standards attained over many decades. These developments have motivated a number of studies addressing the macroeconomic consequences of HIV/AIDS. In light of the fact that many of the highly affected countries have moderate levels of GDP per capita, much of this literature departs from the broader literature on links between health and growth by introducing some aspects associated with macroeconomic studies in the context of economic development, notably a dual-economy structure.

The present study contributes to the literature in three areas. On the methodological side, it focuses on an incongruence between the closed-economy property of models commonly applied to the study of the economic consequences of HIV/AIDS,[37] and the economies of many of the countries highly affected by HIV/AIDS, which are characterized by a large degree of capital mobility and a prominent role of foreign direct investment. This apparent incongruence is problematic, as the closed-economy assumption is central to one of the most important channels identified in the literature, namely that the decline in population growth associated with HIV/AIDS results in an increase in the capital-output ratio. Additional contributions from a methodological perspective are a discussion of the impacts of HIV/AIDS on income per capita (in addition to output per capita), which is a consequence of our focus on an economy characterized by capital mobility, and a more explicit discussion of differences in the impact of HIV/AIDS between the formal and the informal sector than that provided by most studies of the macroeconomic impact of HIV/AIDS.

[37] The few studies known to the author which explicitly address the potential impact of reversals in investment flows are Haacker (2002a) and Haacker (2002b). One recent applied study (Ellis, Laubscher, and Smit (2006)) raises the issue in the discussion of their findings, but does not incorporate it explicitly in their analysis.

Second, our study summarizes the latest available evidence regarding different aspects of the macroeconomic impacts of HIV/AIDS, and calibrates quantitative estimates of the impacts of HIV/AIDS on key macroeconomic variables. Structural parameters were chosen in order to capture some of the characteristics of countries with high rates of HIV prevalence, and our analysis uses an HIV prevalence rate among the population of ages 15–49 of 20 percent (a level attained by some of the highly affected countries) as a benchmark.

The third area in which our study contributes to the literature regards the economic implications of increased access to antiretroviral treatment. In light of the very substantial scaling-up of antiretroviral treatment that has take place in low- and middle-income countries in recent years (reaching an average coverage rate of 30 percent at end-2007, according to WHO, UNAIDS, and UNICEF (2008), the implications of this development for the macroeconomic consequences of HIV/AIDS have become relevant. However, the academic literature has so far not reflected this recent development, and the present study is the first to fill this gap.[38] Specifically, we discuss the impacts of antiretroviral treatment on population growth, savings, and labor productivity, and draw inferences on the macroeconomic implications.

The chapter is structured as follows: Section II discusses the impact of HIV/AIDS in the closed economy. Much of the section focuses on modeling the macroeconomic impacts of HIV/AIDS in a dual economy, characterized by a formal sector with relatively high intensity of capital and skilled labor, and an informal sector that employs the majority of the population, largely drawing on unskilled labor, and generating a much lower level of output per capita than the formal sector. Section III develops the model under the assumption of perfect capital mobility, tying the return to capital to the world interest rate, and differentiating between the impact of HIV/AIDS on GDP per capita and on income per capita (i.e., GDP per capita, plus net investment income from abroad). Section IV calibrates the

[38] Two applied country-level studies (Jefferis, Siphambe, and Kinghorn (2006) for Botswana, and Ellis, Laubscher, and Smit (2006) for South Africa) included some discussion of the impact of antiretroviral treatment. These studies, however, were primarily geared towards a policy audience, and provided limited information regarding the structure of the model employed and the assumptions regarding the impact of antiretroviral treatment.

model(s), synthesizing the latest evidence on the impacts of HIV/AIDS on various economic, health-related, and demographic variables, and discussing the estimates of the impacts of HIV/AIDS under the different modeling strategies. Section V provides a discussion of the consequences of increased access to antiretroviral treatment. Section VI concludes.

B. Impact of HIV/AIDS: Closed Economy

With very few exceptions (see Haacker (2002a, 2002b)), the available studies of the macroeconomic impacts of HIV/AIDS adopt a closed-economy framework, which therefore serves as a point of departure and reference for our discussion. Within this class of models, our framework is designed to capture the implications of two characteristics of models that have been applied to studying the macroeconomic impacts of HIV/AIDS.

First, the available studies differ regarding the extent of sectoral disaggregation of the models adopted, including one-sector frameworks, models with two sectors intended to capture the "dual economy" structure of many economies highly affected by HIV/AIDS, and CGE models with a large number of sectors. Our analysis focuses on a two-sector model, which shares key features with the CGE models (reallocation of labor across sectors), but is nevertheless analytically tractable in an explicit framework. A brief discussion of a one-sector framework serves as a "springboard," to introduce some key aspects of the impact of HIV/AIDS, but also to elucidate some features of the two-sector model by means of comparison.

Second, we follow common practice by distinguishing two different types of labor, skilled and unskilled. This distinction complements the adoption of the two-sector framework, with one sector (the formal sector) relying more on skilled labor.

The One-Sector Neoclassical Growth Model

As the features of the neoclassical one-sector model are well known, we just briefly summarize the key equations. The aggregate production function takes the form

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

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.[39] The capital stock evolves according to

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

the savings rate s may comprise domestic savings, as well as (net) foreign direct investment. The supply of labor grows at rate n.[40] Transforming the model into per capita terms and solving for the steady state capital stock (k^*) and output level (y^*) yields

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

In this context, the HIV/AIDS epidemic may affect the steady-state level of income per capita through its impact on total factor productivity, capital accumulation, the growth rate of the labor force, and the efficiency of labor.[41] Specifically,

- The savings rate s may decline as expenditures are reallocated to cover the costs of care and treatment, either on the household level or through public expenditures, resulting in a decline in output per capita.

- However, a decline in the population growth rate n would result in an increase in the capital-labor ratio, this would have a positive impact on output per capita.

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[39] Without loss of generality, one of the parameters A, e_H or e_U could be normalized to equal 1. However, it is convenient to "over-specify" the model in terms of the productivity parameters as various hypotheses or estimates regarding the impact of HIV/AIDS can best be related to either of the three parameters.

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

[41] Our analysis does not capture changes in labor force participation rates, which arise if relatives care for sick family members (other than making allowances for the financial costs of care and treatment).

- Total factor productivity A may decline, reflecting disruptions to economic activity as a result of increased morbidity and mortality.

- The efficiency of the different types of labor (e_H, e_L) may decline, for various reasons. Productivity may decline owing to increased morbidity of people living with HIV/AIDS, and these effects may differ by type of labor. Increased mortality may have an impact of the efficiency of labor if a larger share of working time needs to be devoted to training, for example if a training program of a certain duration is "spread" over a reduced expected working time. Additionally, the changed composition of the working-age population may have an effect if work experience affects productivity.

- The composition of the labor force (captured by the parameters p_H, p_L) may change, if HIV prevalence of HIV/AIDS-related mortality differ across population groups.

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 previously unemployed or under-employed workers, thereby reducing unemployment and raising per capita income.[42] Several studies therefore add an informal sector, characterized by low capital intensity and a high share of unskilled workers.[43]

To study how the structure of the economy, particularly labor mobility between sectors, affects the impact of an epidemic such as HIV/AIDS, we apply a two-sector model, featuring

[42] For example, Cuddington and Hancock (1994) suggests 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."

[43] These include Over (1992), Cuddington (1993b), Cuddington and Hancock (1994), Haacker (2002b). The reasoning is also applied in CGE models like those of Laubscher and others (2001) and Ellis and others (2006).

a formal sector that uses capital, skilled labor, and unskilled labor, and an informal sector that draws on capital and unskilled labor only, and is less capital-intensive than the formal sector.[44] 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, or non-market activities not included in measured output, a parameter λ defines a wedge between wages for unskilled workers in the formal and the informal sectors,[45] which means that

$$w^*_{U,f} = \lambda w^*_{U,i}, \text{ with } \lambda \geq 1. \tag{4}$$

Under these circumstances, informal sector output takes the form

$$Y_i = A_i K_i^{\alpha_i} (e_U L_{U,i})^{\gamma_i}, \tag{5}$$

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

$$y_i^* = (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U, \tag{6}$$

$$\text{and} \quad w^*_{U,i} = \gamma_i (A_i)^{\frac{1}{\gamma_i}} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U. \tag{7}$$

For the formal sector, aggregate output takes the form

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

[45] Note that, for λ = 1, the model encompasses the case of perfect mobility of unskilled labor.

$$Y_f = A_f K_f^{\alpha_f} (e_H L_H)^{\beta_f} (e_U L_{U,f})^{\gamma_f}, \tag{8}$$

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 unskilled labor used in the formal sector is endogenous in the dual-economy model and depends on the unskilled wage rate (see Eq. (4)). Using Eq. (7) and Eq. (4) (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. (8), we obtain

$$Y_f = A_f^{\frac{1}{\alpha_f+\beta_f}} \left[\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\alpha_f+\beta_f}} K_f^{\frac{\alpha_f}{\alpha_f+\beta_f}} (e_H L_H)^{\frac{\beta_f}{\alpha_f+\beta_f}}. \tag{9}$$

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

$$\bar{k}_f = A_f^{\frac{1}{\beta_f}} \left[\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\beta_f}} \left(\frac{s_f}{\delta + n} \right)^{\frac{\alpha_f+\beta_f}{\beta_f}}, \tag{10}$$

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

$$Y_f = A_f^{\frac{1}{\beta_f}} \left[\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-\gamma_f}{\beta_f}} \left(\frac{s_f}{\delta + n} \right)^{\frac{\alpha_f}{\beta_f}} e_H L_H. \tag{11}$$

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. (4), (7), and (11), it follows that

$$e_U L_{U,f} = (A_f)^{\frac{1}{\beta_f}} \cdot \left[\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-(\beta_f + \gamma_f)}{\beta_f}} \left(\frac{s_f}{\delta + n} \right)^{\frac{\alpha_f}{\beta_f}} e_H L_H, \tag{12}$$

provided that Eq. (12) does return a solution with $e_U L_{U,f} \leq e_U L_U$. Depending on the structural parameters, corner solutions may arise as the formal sector expands (e.g., if the availability of skilled labor increases) to the point that the marginal product of labor in the formal sector exceeds $\lambda w_{U,i}^*$ for $L_{U,f} = L_U$. As we apply the model in a dual-economy context (and this will be reflected in any calibrations of the model further below), we will not entertain the case of a corner solution further.

Below, we will find it convenient to refer to the share of unskilled labor that is employed in the formal sector, which we denote as ρ and which is defined, by straightforward transformation of Eq. (12), as

$$\rho \equiv \frac{e_U L_{uf}}{e_U L_f} = (A_f)^{\frac{1}{\beta_f}} \cdot \left[\frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} \right]^{\frac{-(\beta_f + \gamma_f)}{\beta_f}} \left(\frac{s_f}{\delta + n} \right)^{\frac{\alpha_f}{\beta_f}} \frac{e_H L_H}{e_U L_U}. \tag{13}$$

As reallocations of unskilled labor between sectors may be an important aspect of the economy's response to a shock, it is useful to relate formal sector output to the amount of unskilled labor employed in the formal sector. Using Eq. (4), (7), (11) and (12), we obtain an equation decribing output in the informal sector as a multiple of the income of unskilled labor in the informal sector, with

$$Y_f = \frac{\lambda \gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f} \left(\frac{s_i}{\delta + n} \right)^{\frac{\alpha_i}{\gamma_i}} e_U L_{Uf} = \frac{\lambda w_{Ui}}{\gamma_f} L_{Uf}. \tag{14}$$

As the inputs or incomes of unskilled labor in the respective sector provide a numeraire, it is possible to arrive at a parsimonious representation of total output as a multiple of total input of unskilled labor ($L_U = L_{U,f} + L_{U,i}$), using Eqs. (6), (7), and (14).

$$Y=\left[(1-\rho)\frac{1}{\gamma_i}+\rho\frac{\lambda}{\gamma_f}\right]w_{ui}L_u=\left[\frac{1}{\gamma_i}+\left(\frac{\lambda}{\gamma_f}-\frac{1}{\gamma_i}\right)\rho\right]w_{ui}L_u. \quad (15)$$

Noting that ρ and $w_{U,i}$ are endogenous variables, the rate of change of Y in response to some shock can be summarized as

$$\frac{dY}{Y}=\frac{\left(\frac{\lambda}{\gamma_f}-\frac{1}{\gamma_i}\right)\rho}{\frac{1}{\gamma_i}+\left(\frac{\lambda}{\gamma_f}-\frac{1}{\gamma_i}\right)\rho}\frac{d\rho}{\rho}+\frac{dw_{ui}}{w_{ui}}+\frac{dL_U}{L_U}. \quad (16)$$

One important property of our model is the fact that a reallocation of labor to the formal sector (an increase in ρ) results in an increase in output per capita.[46] This would not be the case in a model with perfect capital and labor markets, as incremental reallocations of factors between the sectors would not have an impact on output owing to the envelop theorem. The two properties of our model that introduce such first-order effects from incremental reallocations of factors are the parameter λ, i.e. the assumption that incomes of unskilled labor in the formal and informal sectors may differ, and the lack of capital mobility between the formal and the informal sector, as a result of which the marginal products of capita may differ between the sectors.

Using Eq. (7) and (13) to substitute for $\frac{d\rho}{\rho}$ and $\frac{dw_{ui}}{w_{ui}}$ in Eq. (16), the response of output to a change in endowments, the economic environment, or productivity parameters can be summarized as

[46] This is the case in Eq. (16) provided that $\frac{\lambda}{\gamma_f}-\frac{1}{\gamma_i}$ is positive. A sufficient condition for this (for $\lambda \geq 1$) is that γ_i, the share of unskilled labor in the informal sector, exceeds γ_f, the share of unskilled labor in the formal sector. Equivalently, the combined shares of capital and skilled labor in the formal sector need to exceed the share of capital in the informal sector.

$$\frac{dY}{Y}=\frac{\left(\frac{\lambda\gamma_i}{\gamma_f}-1\right)\rho}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho}\left[\frac{1}{\beta_f}\frac{dA_f}{A_f}+\frac{\alpha_f}{\beta_f}\left(\frac{ds_f}{s_f}-\frac{dn}{\delta+n}\right)+\frac{de_H}{e_H}+\frac{dL_H}{L_H}\right]+\frac{1}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho}\left[\frac{de_U}{e_U}+\frac{dL_U}{L_U}\right]+ \frac{1}{\gamma_i}\left[\frac{1-\frac{\gamma_f}{\beta_f}\left(\frac{\lambda\gamma_i}{\gamma_f}-1\right)\rho}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho}\right]\left[\frac{1}{\beta_f}\frac{dA_i}{A_i}+\frac{\alpha_i}{\beta_f}\left(\frac{ds_i}{s_i}-\frac{dn}{\delta+n}\right)\right] \quad (17)$$

Eq. (17), together with Eq. (13), can be used to analyze the responsiveness of output to shocks.

- A proportional decrease in the supply of skilled and unskilled labor (L_H and L_U) would leave the allocation of unskilled labor (ρ) and output per capita unchanged. However, if the decrease is more pronounced for skilled (or unskilled) labor, then ρ and output per capita would decline (or increase).

- Similarly, a proportional decrease in the efficiency of skilled labor e_H and unskilled labor would leave the allocation of unskilled labor (ρ) unchanged, and result in a proportional decline in output.

- For the formal sector, a decrease in A_f and s_f would result in a decline in output per capita, whereas a decline in n would result in an increase, as in the closed economy model.

- Importantly, output per capita appears more responsive to changes in the parameters A_f, s_f, and n than the closed-economy model suggest, as positive or negative shocks to the formal sector are reinforced by movements of unskilled labor into or out of the formal sector.

- On the other hand, the impacts on output per capita of shocks to the informal sector are ambiguous. While a positive shock to the informal sector (an increase in A_f or s_f, or a decline in n) raises output in the informal sector, this will also result in a reallocation of unskilled labor to the informal sector, which by itself would reduce output.

C. The Open Economy

Virtually all available studies apply a closed-economy model to study the macroeconomic impacts of HIV/AIDS.[47] In a neoclassical framework, the closed-economy assumption has very significant implications for the properties of the model regarding the impacts of HIV/AIDS, as much of the immediate impacts of HIV/AIDS on output are offset by an increase in the capital-labor ratio. This, however, implies a decline in the rate of return to capital.

In light of this, excluding the potential impacts of HIV/AIDS on inbound or outbound capital flows is problematic for many economies severely affected by HIV/AIDS, as these are characterized by a large degree of capital mobility.[48] We are therefore complementing our earlier analysis, in the tradition of the main body of literature on the economic impact of HIV/AIDS as it adopts a closed-economy framework, with an analysis of the impacts of HIV/AIDS in an economy characterized by perfect capital mobility. Specifically, we assume that the returns to capital are tied to the yields of some alternative foreign asset; this means that

$$\frac{\partial Y}{\partial K} = r^*.^{49} \tag{18}$$

[47] The exception are two working papers and related publications by the author of the present study, see Haacker (2002a, 2002b).

[48] As evident from the absence of significant restrictions on capital transfers, substantial presence of multinational companies in the economy, and – in some cases – listings of key domestic companies on international stock markets.

[49] Many applications also include a risk premium. While a large epidemic like HIV/AIDS could conceivably results in an increase n uncertainty regarding economic outturns over the investment horizon, and result in an increase in the risk premium, we find no basis for quantifying any such effects and do not include them in our analysis.

Additionally, adopting an open-economy framework implies that we need to distinguish between output and income (i.e., output plus net income from an economy's net foreign investment position). As before, we first illustrate the impacts of HIV/AIDS in a one-sector model, and then adapt the two-sector model introduced above to allow for capital mobility.

The One-Sector Model

Again, the basic features of the model are well-known, and we focus on the behavior of the model in the particular context of a health shock. Key variables are defined above (see discussion of Eqs. (1), (2), and (18). As the steady-state capital-output ratio is implicitly defined by Eq. (18), the steady-state level of output becomes

$$\text{and } y=\left(\frac{\alpha}{r^*}\right)^{\frac{\alpha}{\beta+\gamma}} A^{\frac{1}{\beta+\gamma}}(e_H p_H)^{\frac{\beta}{\beta+\gamma}}(e_U p_U)^{\frac{\gamma}{\beta+\gamma}}, \tag{19}$$

with

$$k=\left(\frac{\alpha A}{r^*}\right)^{\frac{1}{\beta+\gamma}}(e_H p_H)^{\frac{\beta}{\beta+\gamma}}(e_U p_U)^{\frac{\gamma}{\beta+\gamma}}. \tag{20}$$

In some regards, the response of the economy to shocks is very similar between the open-economy and the closed-economy model, as the elasticities of output with respect to changes in total factor productivity A or the parameters related to the composition or efficiency of labor (e_H, p_H, e_U, p_U) are the same.

The key difference between the steady-state equations described by Eq. (19) and (20) and those described by Eq. (3) is the absence of terms relating to the savings rate and the population growth rate. This reflects the fact that any excess of savings over the amounts of investments that can be absorbed in the domestic economy at interest rate r^* is transferred abroad, or – if the economy is a net importer of capital – that the inflows of capital adjust so that the rate of return in the domestic economy stays in line with the returns of alternative assets abroad.

This is an important point as changes in the capital-output ratio driven by a slowdown in population growth (including the effects of higher mortality), which by themselves have a positive impact on output per capita, tend to partially offset or even reverse the negative impacts of HIV/AIDS through other channels in many assessments of the economic impacts of HIV/AIDS (which apply closed-economy frameworks). This means that closed-economy models, when applied to economies characterized by a high degree of capital mobility (as is arguably the case for many economies in sub-Saharan Africa, and especially Southern Africa), may underestimate the impacts of HIV/AIDS on GDP per capita.

While output per capita is a key indicator of the economic impacts of HIV/AIDS, in the context of an open economy it makes sense to differentiate between income and output, as savings invested abroad generate revenues, while capital income from inward foreign direct investment or portfolio investment does not accrue to residents. We therefore introduce income per capita as an additional indicator of the impacts of HIV/AIDS. Denoted z, income per capita 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).

$$z = \left[\beta+\gamma+\frac{r^* s}{\delta+n}\right]\left(\frac{\alpha}{r^*}\right)^{\frac{\alpha}{\beta+\gamma}} A^{\frac{1}{\beta+\gamma}}(e_H p_H)^{\frac{\beta}{\beta+\gamma}}(e_U p_U)^{\frac{\gamma}{\beta+\gamma}}. \tag{21}$$

While per capita output y does not respond to changes in s or n, per capita income z does.[50] Regarding the magnitude of the changes, we compare the elasticities of steady-state output y and of income per capita z with respect to a change in the savings rate (the comparison regarding changes in the population growth rate is analogous).

The elasticity of income per capita with respect to changes in the savings rate is given by

[50] 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.

$$\frac{\frac{dz^*}{z}}{\frac{ds}{s}} = \frac{\frac{r^* s}{\delta + n}}{\beta + \gamma + \frac{r^* s}{\delta + n}} \tag{22}$$

Using Eq. (3) and (22), we find that the impact of a change in the savings rate on output per capita in the closed-economy model is stronger than the impact on income per capita in the closed economy model if

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

$$\text{or, equivalently,} \quad \alpha \frac{\beta+\gamma}{\beta+\gamma-\alpha} > \frac{r^* s}{\delta + n}. \tag{23}$$

Eq. (23) 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,[51] the share of capital in domestic output, i.e. provided that the economy's net foreign assets are not too large. Very similar findings apply to the elasticities of output and income with respect to changes in the population growth rate, which is $n/(\delta + n)$ times the elasticity with respect to the savings rate.

The implication of this regarding the impact of HIV/AIDS is that a channel that offsets or even overcompensates for various negative impacts of HIV/AIDS in many studies of the macroeconomic effects of HIV/AIDS applying a closed-economy model, the positive impact of a decline in the population growth rate on GDP per capita, is not present in the open-economy model as far as GDP per capita is concerned, and is much weaker as far as income per capita is concerned.

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[51] This is a sufficient condition derived from the weaker necessary condition spelled out in Eq. (23). Notably, the elasticities are not the same for $\frac{r^* s}{\delta + n} = \alpha$ (in which case the economy's net foreign investment position is equal to zero, and $z = y$), as the rate of return to capital responds differently to changes in the stock of capital in the different settings.

These findings also touch on two aspects of the macroeconomic consequences which are marginal to the present study, which is primarily concerned with methodological aspects of modeling the macroeconomic impact of HIV/AIDS, but relevant in many policy contexts. One are the implications of HIV/AIDS for the accumulation of foreign debt. An economy with a high level of foreign debt, other things equal, is characterized by a low net foreign investment position (and a low level of $r^* s/(\delta + n)$). The (positive) impact of a slowdown in population growth on steady-state income per capita is therefore weakened, meaning that HIV/AIDS has a more negative macroeconomic impact. More intuitively, this result reflects that it is more difficult to serve a certain amount of debt when the economy slows down.[52]

Second, applying the same argument within countries, our findings point at some distributional effects of HIV/AIDS. If the impact of HIV/AIDS on incomes per capita is related to wealth (relative to income), and savings rates are correlated to income, then the proportional impact of HIV/AIDS on incomes per capita (assuming that other dimensions of the impacts are equal) is less for population groups with higher incomes.

The Dual Economy

As in the discussion of the closed 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.

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 given by Eq. (6) and (7), reprinted here for convenience:

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

[52] See Haacker (2004a) for a more comprehensive and explicit discussion of the impacts of HIV/AIDS on the sustainability of public debt, in line with the findings from the present analysis.

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

$$Y_f = (A_f)^{\frac{1}{\beta_f}} \left[\frac{\alpha_f}{r^*}\right]^{\frac{\alpha_f}{\beta_f}} \left[\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f}\left(\frac{s_i}{\delta+n}\right)^{\frac{\alpha_i}{\gamma_i}}\right]^{\frac{-\gamma_f}{\beta_f}} e_H L_H . \tag{24}$$

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

$$e_U L_{U,f} = (A_f)^{\frac{1}{\beta_f}} \left[\frac{\alpha_f}{r^*}\right]^{\frac{\alpha_f}{\beta_f}} \cdot \left(\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f}\left(\frac{s_i}{\delta+n}\right)^{\frac{\alpha_i}{\gamma_i}}\right)^{\frac{-(\beta_f+\gamma_f)}{\beta_f}} e_H L_H , \tag{25}$$

and therefore the share of unskilled workers employed in the formal sector is equal to:

$$\rho \equiv \frac{e_U L_{U,f}}{e_U L_U} = (A_f)^{\frac{1}{\beta_f}} \left[\frac{\alpha_f}{r^*}\right]^{\frac{\alpha_f}{\beta_f}} \cdot \left(\frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f}\left(\frac{s_i}{\delta+n}\right)^{\frac{\alpha_i}{\gamma_i}}\right)^{\frac{-(\beta_f+\gamma_f)}{\beta_f}} \frac{e_H L_H}{e_U L_U} . \tag{26}$$

Substituting unskilled labor for skilled labor in Eq. (24), using Eq. (25), gives output in the formal sector as a multiple (the wage rate of unskilled labor in the informal sector, multiplied by the parameter λ, and divided by the share of unskilled labor in the formal sector) of the efficiency units of unskilled labor employed in the formal sector, i.e.,

$$Y_f = \frac{\lambda\gamma_i (A_i)^{\frac{1}{\gamma_i}}}{\gamma_f}\left(\frac{s_i}{\delta+n}\right)^{\frac{\alpha_i}{\gamma_i}} e_U L_{Uf} = \frac{\lambda w_{Ui}}{\gamma_f} e_U L_{Uf} . \tag{27}$$

Eqs. (6) and (27), together with Eq. (26) which defined the endogenous share of unskilled labor employed in the formal sector, provide a equation that allows us to describe output in terms of the share of unskilled labor in the formal sector, the wage rate of unskilled labor (in the informal sector), and the supply of unskilled labor.

$$Y = \left[(1-\rho)\frac{1}{\gamma_i} + \rho\frac{\lambda}{\gamma_f} \right] w_{ui} L_u = \left[\frac{1}{\gamma_i} + \left(\frac{\lambda}{\gamma_f} - \frac{1}{\gamma_i} \right) \rho \right] w_{ui} L_u \tag{28}$$

The percentage change in output is obtained as the suitably weighted sum of the percentage changes in the share of unskilled labor in the formal sector, the wage rate of unskilled labor, and the supply of unskilled labor.

$$\frac{dY}{Y} = \frac{\left(\frac{\lambda}{\gamma_f} - \frac{1}{\gamma_i} \right)\rho}{\frac{1}{\gamma_i} + \left(\frac{\lambda}{\gamma_f} - \frac{1}{\gamma_i} \right)\rho} \frac{d\rho}{\rho} + \frac{dw_{ui}}{w_{ui}} + \frac{dL_U}{L_U}. \tag{29}$$

Substituting for $\frac{d\rho}{\rho}$ (using Eq. 26) and for $\frac{dw_{ui}}{w_{ui}}$ (using Eq. 7) and rearranging yields an equation that describes the variation in Y as a function of the rates of change of the variables of interest in our analysis of the economic impacts of HIV/AIDS, namely (in order of appearance) A_f, e_H, L_H, e_U, L_U, A_i, s_i, and n.

$$\begin{aligned} \frac{dY}{Y} = & \frac{\left(\frac{\lambda\gamma_i}{\gamma_f} - 1 \right)\rho}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho} \left[\frac{1}{\beta_f}\frac{dA_f}{A_f} + \frac{de_H}{e_H} + \frac{dL_H}{L_H} \right] + \frac{1}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho} \left[\frac{de_U}{e_U} + \frac{dL_U}{L_U} \right] + \\ & \frac{1}{\gamma_i} \left[\frac{1 - \frac{\gamma_f}{\beta_f}\left(\frac{\lambda\gamma_i}{\gamma_f} - 1 \right)\rho}{1-\rho+\frac{\lambda\gamma_i}{\gamma_f}\rho} \right] \left[\frac{1}{\beta_f}\frac{dA_i}{A_i} + \frac{\alpha_i}{\beta_f}\left(\frac{ds_i}{s_i} - \frac{dn}{\delta+n} \right) \right] \end{aligned} \tag{30}$$

For the dual economy, income can be presented in terms of the structural parameters of the model in a similar way as output in Eq. (28). However, owing to our assumption that capital is perfectly mobile for the formal sector, but not for the informal sector, income depends on the share of the formal sector in the economy's output, which is endogenous. While the share of the formal sector in output can easily be obtained in terms of the structural parameters of the model, using Eqs. (6), (26), and (27), this yields an unwieldy term. However, it turns out that we can gain useful insights into the response of income or income per capita to shocks without explicitly solving for the share of the formal sector in output. Income per capita can be represented as

$$z = \left[1 + \sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right) \right] y, \qquad (31)$$

where σ represents the share of the formal sector in output. Differentiating through Eq. (31) yields

$$\frac{dz}{z} = \frac{dy}{y} + \frac{\sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right)}{1 + \sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right)} \frac{d\sigma}{\sigma} + \frac{\sigma \frac{r^* s_f}{\delta + n}}{1 + \sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right)} \left(\frac{ds_f}{s_f} - \frac{n}{\delta + n} \frac{dn}{n} \right), \qquad (32)$$

We can draw the following conclusions from Eq. (32).[53] For the special case in which net income from abroad is equal to zero, $\frac{r^* s_f}{\delta + n} = \alpha_f$, and Eq. (32) reduces to

$$\frac{dz}{z} = \frac{dy}{y} + \frac{\sigma \frac{r^* s_f}{\delta + n}}{1 + \sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right)} \left(\frac{ds_f}{s_f} - \frac{n}{\delta + n} \frac{dn}{n} \right),$$

i.e., income is more responsive to shocks to the savings rate in the formal sector and the population growth rate than output is,[54] and as responsive as output for any other shocks.

[53] Throughout our argument, we assume that $1 + \sigma \left(\frac{r^* s_f}{\delta + n} - \alpha_f \right) > 0$, a sound assumption for the range of parameters plausible in a macroeconomic setting.

[54] This argument implies that $\frac{dy}{ds_f} > 0$ and $\frac{dy}{dn} < 0$, which can be established in a straightforward way from Eq. (24).

Further, we see that income is more responsive to changes in the savings rate for the formal sector, as Eq. (32) reduces to

$$\frac{dz}{z}=\frac{dy}{y}+\frac{\sigma\dfrac{r^{*}s_f}{\delta+n}}{1+\sigma\left(\dfrac{r^{*}s_f}{\delta+n}-\alpha_f\right)}\frac{ds_f}{s_f}.$$

in this special case.[55] For any shocks *not* involving s_f or n, the response of income to shocks depends on the shock to output, whether net income from abroad is positive or negative, and whether the shock results in an increase or decrease in the share of the formal sector in output.

[55] This argument uses that $\dfrac{d\sigma}{ds_f}=0$ for the dual economy model.

D. Calibrating the Macroeconomic Impact of HIV/AIDS

In order to arrive at quantitative estimates for the macroeconomic impact of HIV/AIDS, and to understand the implications of different modeling strategies considered in the present study, we construct an example that eflects macroeconomic features of some of countries in sub-Saharan Africa highly affected by HIV/AIDS. Below, we summarize key macroeconomic properties of the economy. The underlying parameters are provided in Table 1. We then calibrate the impact of HIV/AIDS on key parameters of the model, and discuss the macroeconomic impacts of HIV/AIDS under the different modeling strategies discussed above.

Key Properties of Model

GDP per capita (before incorporating the impact of HIV/AIDS is set at US$1,000 (in 2005 prices), or about $2,000 at PPP US$.[56] The informal sector accounts for one-third of GDP, but provides for the livelihoods of two-thirds of the population (i.e., GDP per capita for the informal sector is US$500).[57] We assume that dependency ratios in the formal and informal sector are the same, and equal to 100 percent (i.e., there is one dependent old or young person for each working person).[58] The share of skilled labor in the working population is set equal to 20 percent.

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[56] Average GDP per capita in sub-Saharan Africa was about $900 in 2007 (in 2005 prices), according to data from IMF (2008) and United Nations Population Division (2007), and about $1,900 at PPP exchange rates. Choosing a somewhat higher value makes sense, as many countries with high HIV prevalence have a level of GDP per capita that is higher than the regional average.

[57] The rule that the informal sector accounts for one-third of GDP, but provides for two-thirds of the population, is partly motivated by shares for the agricultural sector in some countries with high HIV prevalence (which, however, also includes some formal-sector activities). An additional consideration was that average incomes in the informal sector should be consistent with a share of the population below certain poverty lines that is somewhat lower as compared to those reported by Chen and Ravallion (2008) for sub-Saharan Africa.

[58] For examples of dependency rates in countries with high HIV prevalence, and a discussion of the impacts of HIV/AIDS, see Haacker (2004b) and Epstein (2004).

Annual income of each working person (including an imputation for capital services) in the informal sector, including an imputation for capital services is US$1,000 (to be shared with one dependent on average). Assuming a share of capita for the informal sector of 20 percent, the wage rate in the informal sector (or income minus an imputation for capital services) comes out at US$800. GDP per capita (accruing to capital and labor) in the formal sector is equal to US$2000, or US$4,000 for each working person (assuming again a dependency ratio of 100 percent). The share of capital in the formal sector is equal to 40 percent; in addition to the 20 percent of the working population classified as skilled, 13.3 percent of the working population are employed in the formal sector as unskilled workers.[59] Assuming a premium of 25 percent between salaries of unskilled workers in the formal sector over the informal sector implies an annual wage of US$1,000 for unskilled workers in the formal sector. The average wage rate of skilled workers in the formal sector is equal to US$3,333.

Regarding the one-sector model, parameters are set in line with the outcomes for the dual-economy model described above. Notably, income per capita for unskilled workers is set at US$833, the average of unskilled wage rates for the informal and the formal sector in the dual-economy model. For the study of the open-economy, we focus on a setting in which the net foreign asset position of the economy is equal to zero.

Table 1 summarizes the characteristics of the economy. On the top, we provide some parameters which are common across sectors, or do not pertain to any specific sector. The middle part of Table 1 describes the dual-economy model, providing the values of parameters for the informal and formal sectors, as well as some "common parameters" pertaining to the economy overall, and summarizes key macroeconomic variables returned by the model. The lower part of Table 1 documents the parameters for the one-sector model (calibrated to match key aggregate features and outcomes of the dual-economy model).

[59] The study by Senhadji (2000), which we use elsewhere to motivate the choice of the parameter determinating the share of capital, is not very helpful here, with estimates of the share of capital for the group of countries of primary interest (those with high HIV prevalence rates) ranging from 0.25 (Tanzania) to 0.82 (Zimbabwe).

Table 1. Summary of Key Parameters

Common Parameters			
δ	8 percent	L_h / L	0.2
n	2 percent	Dependency ratio	100 percent
Dual Economy Model			
Informal Sector		Key Outcomes	
A_i	251.19 [1]	GDP per capita	$1,000
s_i	10 percent	GDP per worker	$2,000
α_i	0.2	$Y_i / L_{u,i}$	$1,000
γ_i	0.8	$L_{u,i} / L$	0.67
e_u	1	$w_{u,i}$	$800
		$Y_f / (L_h + L_{u,f})$	$4,000
Formal Sector		$L_{u,f} / L$	0.13
A_f	155.43 [1]	$w_{u,f}$	$1,000
s_f	20 percent	$w_{h,f}$	$3,333
α_f	0.4	$r_f = r_i$	20 percent [2]
β_f	0.5		
γ_i	0.1	Common parameters	
e_h	1	λ	1.25
e_u	1		
One-Sector Model [3]		Key Outcomes [3]	
A	246.6 [1]	GDP per capita	$1,000
s	16.7 percent	GDP per worker	$2,000
α	0.33	w_u	$833
β	0.33	w_h	$3,333
γ	0.33		

Source: Author's calculations and assumptions, as explained in text.
[1] In 2005 U.S. dollars.
[2] Gross rate of return to capital, i.e., marginal product of capital net of depreciation rate.
[3] Parameters and outcomes not shown for the one-sector model are the same as those shown for the dual-economy model.

Impact of HIV/AIDS on Key Parameters

The most important determinant of the macroeconomic impacts of HIV/AIDS is arguably the scale of the epidemic. Our scenario is motivated by the economic situation in Southern Africa, where some of the countries with the highest HIV prevalence rates are located (this was already reflected in the choices of parameters for the macroeconomic model). In line with the most recent estimates of the state of the global HIV epidemic,[60] we use an HIV prevalence rate of 20 percent as a point of reference.

Regarding the impact of HIV/AIDS on population growth, we follow the demographic estimates published by the United Nations Population Division (2007), showing a decline in population growth rates of around one percentage point for countries with HIV prevalence in the neighborhood of 20 percent (i.e., population growth, in our scenario, declines from 2 percent annually to 1 percent annually.

An important determinant of the macroeconomic impacts of HIV/AIDS is the extent to which HIV prevalence and mortality differs across population groups. For example, HIV prevalence might differ by race, sex, social context, or wealth. This could introduce differences in the impacts of HIV/AIDS across types of labor and (in the dual economy model) across sectors. In this regard, some studies for South Africa (e.g., Ellis, Laubscher, and Smit (2006), or Laubscher, Visagie, Smit (2001)) assume that HIV prevalence is higher for unskilled workers, in line with the evidence on the socioeconomic gradient of the epidemic in that country. For other countries, however, the available evidence suggest that HIV prevalence is more or less even across population groups. Mather and others (2004), synthesizing studies from five countries (Kenya, Malawi, Mozambique, Rwanda, and Zambia), find that HIV prevalence does not seem to be correlated with income or education. On this basis, our estimates are based on the assumption that HIV prevalence and mortality is even across sectors and types of labor.

Regarding the impacts of HIV/AIDS, we follow a common approach and link the impact of HIV/AIDS to HIV/AIDS-related mortality, rather than HIV prevalence. This makes sense as HIV is asymptomatic during for many years. It is therefore common practice to calibrate the impacts of HIV/AIDS backwards from estimates of the impacts on mortality, and to use

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[60] See UNAIDS, 2008, and Table 1 in Chapter II.1.

available estimates on increased mortality also as a scale factor in assessing the aggregate costs of increased morbidity.[61]

While we assume that mortality is even across sectors and types of labor, it does differ by age, and for some purposes it is important to distinguish between mortality among the working-age population and mortality for the population overall. Based on data from countries with high prevalence rates, we will assume an increase in mortality rates for the overall population of 0.8 percentage points, and for the working-age population of 3.0 percentage points.[62]

Regarding shifts in expenditure patterns related to HIV/AIDS, it makes sense to distinguish between public expenditures and private expenditures. For public expenditures, it is important to take into account that most HIV/AIDS-related expenditures in middle- and low-income countries are financed by external grants (see UNAIDS, 2008). We do not consider the macroeconomic effects of such externally-financed expenditures,[63] but focus on the implications of domestically-financed expenditures for national savings.

Using data from UNAIDS (2008) and IMF (2008), we find that domestically financed HIV/AIDS-related public spending amounted to around one percent of GDP in some countries with very high HIV prevalence.[64] However, it is necessary to "translate" these

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[61] This practice becomes increasingly difficult as demographic estimates start to reflect the impacts of antiretroviral treatment across countries. For the period our demographic estimates relate to (2000–05), however, this is still a minor issue.

[62] For an illustration of the underlying impact of HIV/AIDS on mortality by sex and age, see Figure 1 in Chapter 2.1 which provides an example for Zambia (where mortality is estimated to have increased by just under 0.8 percentage points for the overall population, and 3.4 percentage points for the population of ages 15–59).

[63] For a more substantial discussion on the ramifications of rapid scaling-up of external aid, see Adam and Bevan (2006), Bourguignon and Sundberg (2006), Haacker (2008, discussing explicitly the scaling-up of aid in the context of HIV/AIDS), and Heller (2005).

[64] For example, we find levels of domestically financed HIV/AIDS-related public spending of 1.3 percent of GDP (2006) and 1.9 percent of GDP (2007) for Botswana, 0.7 percent of GDP (Swaziland, 2006), 0.2 percent

increases in spending in changes in public savings and investments, which is a somewhat speculative exercise as there is no counterfactual available and the availability of more disaggregated data is limited. We will assume that national savings and investment decline by one-third of an assumed increase in domestically financed HIV/AIDS-related public expenditures of one percent of GDP, i.e. by 0.33 percent of GDP.[65] For the dual economy model, we will apply this decline to each sector, even though the savings rate in the informal economy is considered lower (implying that public investment plays a proportionally higher role in the informal sector).[66]

Regarding the impact of HIV/AIDS on private savings and investment, an awkward aspect of the literature is that the available estimates are based on microeconomic studies of the impact of HIV/AIDS on the household level. Translating these estimates into a macroeconomic impact is not be straightforward, as they may not capture aspects of private savings and investment not directly entering statistics on household income and expenditure, such as corporate investment financed from retained earning, which are relevant on the macroeconomic level. "Scaling up" microeconomic estimates, relative to household income,

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of GDP (Mozambique, 2005 and 2006), 0.7 percent of GDP (2005) and 1.0 percent of GDP (2007) for Namibia, and 0.3 percent of GDP for Lesotho (2006).

[65] For example, if capital expenditure accounts for one-third of the budget, then our assumption would imply that additional expenditures would be financed without additional borrowing, crowding out investment and current expenditures proportionally. We abstract from capital expenditures included in HIV/AIDS-related spending, as much of these health-related expenditures are difficult to interpret in the context of our present model.

[66] While many of the impacts of HIV/AIDS can be considered proportional to HIV prevalence or HIV/AIDS-related mortality, this may not be the case for domestically financed HIV/AIDS-related public spending, as for lower-prevalence countries spending on HIV prevention (not tied to prevalence) may play a more pronounced role, and as the extent of external aid may differ. Another important point to note is the fact that the mix between external and domestic financing differs strongly according to income level. Whereas we focus on countries close to dividing line of low- and middle- income countries (according to World Bank, 2008), countries in the lower tier of low-income countries may shower a higher degree of external financing, and a lower level of domestically financed HIV/AIDS-related public spending, relative to GDP, than the countries considered here.

to the macroeconomic level may therefore result in exaggerated estimates of the impact of HIV/AIDS. The other drawback of household studies, for the purpose of drawing inferences regarding macroeconomic impacts of HIV/AIDS, is that these studies may capture impacts which reflect redistribution between households, and net out from a macroeconomic perspective. For example, if an individual needs to give up an employment (losing income) for HIV/AIDS-related reasons, and another individual fills the position (gaining income), we may see impacts on the balance sheet of the household affected by HIV/AIDS, although the macroeconomic impacts (in this regard) cancel out.

For this reason, we focus on household expenditures rather than incomes. Even when treatment is provided free of charge through public health services or other organizations, households have to incur the costs of caring for sick dependents and of accessing health care. Naidu and Harris (2006) summarize a number of studies finding that households affected by HIV/AIDS increase their health expenditures, while reducing other expense categories. The magnitude of these reallocations can be substantial – Steinberg and others (2002) find that households affected by HIV/AIDS spend about one-third of their income on health care, compared with a national average of 4 percent, whereas other categories of expenditures are cut, most notably clothing and electricity. Rosen and others (2007) study the costs of accessing treatment at South African health facilities, finding that the costs of health visits (such as transportation costs and fees) amounted to about US$ 100 per year. Additionally, patients were spending considerable amounts on non-prescription drugs, special foods, and other HIV/AIDS- or health-related expenditures.[67]

Overall, we assume that patients spend $300 per year on care and treatment (30 percent of GDP per capita), and that these expenses are incurred for two years before death. This means that treatment-related private expenditures can be approximated as multiple of mortality rates and GDP per capita. With an assumed increase in HIV/AIDS-related mortality of 0.8 percentage points, we therefore calibrate the private costs of treatment at 0.5 percent of GDP. Regarding the breakdown between the formal and the informal sector, we assume that the nominal costs are the same across sectors, which implies that the costs are 60 percent of

[67] Based on 6 visits per year to a health facility, at a cost of 120 rand per visit.

income per capita (not per worker) in the informal sector, and 15 percent in the formal sector. With similar rates of HIV prevalence in the informal and the formal sector, this translates into additional expenditures of 1 percent of output per capita in the informal sector, and 0.25 percent of output per capita in the formal sector.

It remains to be determined how much of this is financed out of savings. The available literature does show some crowding of other expenditures lines. However, this takes place in the context of declining income, which arguably partly reflects distributional shifts (meaning that some of the reduced spending could be offset by higher spending in other households). On the other hand, there is considerable evidence that households affected by HIV/AIDS run down their assets. Additionally, households affected by illness (and death, see below) frequently receive support from other households (so that savings could decline in these households, as well).[68]

In the absence of more substantial evidence of the impacts of the costs of treatment and care on private savings on the macroeconomic level, we will assume that one-half of the costs are financed by reduced savings, which means that the partial negative impact on the aggregate savings rate is 0.25 percentage points, reflecting a decline of 0.5 percentage points in the informal sector, and a decline of 0.125 percentage points in the formal sector.

The other important part of HIV/AIDS-related expenditure is the cost of funerals. Steinberg and others (2002) suggest that funeral expenses are, on average, equivalent to four months' salary. Booysen and others report costs corresponding to 3.4 monthly incomes. Naidu and Harris (2006), in a comprehensive survey of the literature, point at numerous studies with similar findings (although not all results can easily be related to household income). Collins and Leibbrandt (2007), in a study focusing on poor households, find that funeral costs accounted for about 7 times monthly incomes.

[68] See, for example, Lundberg, Over, and Mujinja (2000), or World Bank (1999), the latter pointing out that in a sample from the Kagera region in Tanzania, the median amount received by household within six months of the death was twice that received during the year before the death, and twice that received by households that did not suffer a death.

On this basis, we will assume that funeral expenses are equivalent to about the level of an annual average income (3 times average monthly household income for an average household size of 4 corresponds to one year's average income for one person), and that one-half of this is financed out of savings (which may include savings of friends and families contributing to the costs of funerals). With an increase in mortality of 0.8 percentage points, this means that the savings rate declines by 0.4 percentage points.

We are now in a position to calibrate the impacts of HIV/AIDS on savings rates. Public savings are reduced by 0.33 percent of GDP, which we assume to be spread proportionally (with output) across sector, i.e., savings rates decline by 0.33 percentage points both in the formal and the informal sector. The costs of care and treatment contribute 0.25 percentage points on aggregate to the decline (0.5 percentage points for the informal sector, 0.125 percentage points for the formal sector), and funeral expenses contribute 0.4 percentage points to the decline. Overall, our assumptions translate into a decline in aggregate savings of 0.98 percentage points, reflecting a decline in the savings rate of about 1.23 percentage points in the informal sector, and 0.86 percentage points for the formal sector.

Regarding the impact of HIV/AIDS on productivity, there are two different types of evidence – data on the productivity of people affected by HIV/AIDS while working and data on absenteeism (and, partially overlapping with the latter, increased vacancies related to higher job attrition).[69]

Some studies of the impact of HIV/AIDS on the company level point to substantial declines in the productivity of workers in the late stages of the disease. According to Fox and others (2004), tea pickers on an estate in Kenya who retired or died from AIDS-related causes earned 16 percent less in their penultimate year at work, and 17.7 percent less in the final year. Similarly, Morris, Burdge, and Cheevers (2001) report that about 10 percent of a sick employee's working time was lost in the two years before the worker retired in a large South African sugar mill. Comparable estimates are not available for "white-collar" jobs, where productivity is more difficult to measure.

[69] The discussion on the impacts of HIV/AIDS on productivity partially draws on Haacker (2004a, 2004b).

Some studies of the financial costs of HIV/AIDS on the company level suggest that the impact can be substantial. Rosen and others (2004) estimate that the costs for several South African companies ranged from 0.4 to 6.0 percent of the wage bill, with HIV prevalence among employees ranging from 8 percent to 25 percent. Aventin and Huard (2000) estimate the costs of HIV/AIDS to companies at 0.8 to 1.3 percent of the wage bill, with an HIV incidence among employees of 1.1 percent to 1.9 percent. These studies, however, include costs we capture elsewhere (funeral costs, domestic health spending).

The other source of information on the productivity impacts of HIV/AIDS draws on data on HIV/AIDS-related disruptions to the work processes, notably through increased absenteeism. Government of Malawi and UNDP (2002) and Grassly and others (2003) both report evidence consistent with an increase in absenteeism for medical reasons of about 2 percent of working hours (scaled from the original estimates to correspond with an HIV prevalence rate of about 20 percent, see Haacker (2004a) for details). However, these estimates are based on an increase in the number of AIDS cases of 2 percent of the working population, whereas the estimated by United Nations Population Division (2007) suggest that 3 percent would be more appropriate, which would translate into an increase in absenteeism of 3 percent of working hours for medical reasons. Another cause of absenteeism is attendance at the funerals of those who have died of AIDS. Haacker (2004a) estimates that this factor may account for an increase in absenteeism of 0.7 percentage points.

For some sectors, notably the public sector, increased utilization of sick leave may be a factor. Haacker (2004b), based on provisions for sick leave for public servants in Swaziland and Zambia, suggests that "for a country where 2 percent of public servants drop out of the service for HIV/AIDS-related reasons, about 1 to 1.5 percent of all public servants may be on sick leave at a given time as a consequence." However, these examples cannot be generalized, as provisions for sick leave differ across sectors (and countries); notably, public servants may enjoy more generous sick leave provisions than employees in the private formal sector or in the informal sector.

One major area of potential sources of impacts of HIV/AIDS on productivity and growth is the accumulation of human capital.[70] Birdsall and Hamoudi (2004), in an empirical paper, argue that life expectancy affects access to education, measured by schooling years across countries. Haacker (2004b) provides a thorough discussion of the impacts of HIV/AIDS on the costs of training. Various studies (BIDPA (2000), various papers by Cuddington) postulate an impact of HIV/AIDS on productivity through losses in experience, motivated by Mincerian wage regressions.

We do not include these effects in our analysis, as they cannot be interpreted in a straightforward way within the parameters of our model, owing to the long time lags involved, and as the empirical evidence regarding the specific impacts of HIV/AIDS in this area is very weak (owing to the different epidemiological and economic context, findings on health and life expectancy in general do not necessarily carry over to the impact of HIV/AIDS).

Based on these pieces of evidence, we will adopt the following assumptions regarding the impacts of HIV/AIDS on productivity. As the impacts we have described relate to the productivity or efficiency of labor in the first place, we assume that the parameters A, A_l and A_f remain unchanged. For the efficiency of labor on the job (parameters e_H and e_U), the studies we draw on suggest that the productivity of workers declines by 10 percent or more in the final 2 years of lives. With a mortality rate of 3 percent among the working population, this would be consistent with a decline in productivity of 0.6 percentage points. Increased absenteeism, owing to medical reasons or funeral attendance, accounts for a decline in labor productivity of 3.7 percent according to our reckoning. Allowing for some double-counting, we will assume that the efficiency of labor declines by 4 percent (somewhat lower than the sum of the two effects we have identified). As our data do not provide a basis for

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[70] These implications of the disease on human capital, and thus labor productivity and growth, are highlighted in other analytical studies on the economic impacts of HIV/AIDS highlight the, including Bell, Devarajan and Gersbach (2004, 2006), predicting a severe contraction in the level of economic activity in South Africa over the next decades. Young (2004) also allows for a negative impact of HIV/AIDS on the accumulation of human capital, but argues that other effects dominate.

differentiating between sectors or types of labor, and we assume that HIV prevalence is the same across population groups, we assume that the change in the respective efficiency parameters is the same.

Macroeconomic Impact of HIV/AIDS: Findings

We are now in a position to summarize our findings on the macroeconomic impacts of HIV/AIDS. In this regard, Table 2 summarizes the impact of HIV/AIDS on the level of output and income, applying the different modeling strategies discussed above, and breaking down the impact by source (changes in savings, the population growth rate, and labor productivity. As our model involves two types of labor, and (as far as the dual-economy version is concerned) allows for shifts between sectors, our findings could also point to some distributional aspects of HIV/AIDS. Table 3 therefore summarizes some indicators in this direction, notably the changes in wage rates for skilled and unskilled labor.

Table 2. The Macroeconomic Impact of HIV/AIDS
(In percent)

	Total impact	Impact of decline in ...		
		Savings rate [1]	Population growth rate [1]	Labor productivity [1]
One-Sector Model				
Closed Economy				
Output (=Income) per Capita	-1.3	-3.0	5.9	-4.0
Open Economy				
Output per Capita	-4.0	0.0	0.0	-4.0
Income per Capita	-3.8	-1.9	2.1	-4.0
Dual-Economy Model				
Closed Economy				
Output (=Income) per Capita	-1.3	-3.0	6.0	-4.0
Labor allocation[2]	1.0	0.1	0.9	0.0
Open Economy				
Output per Capita	-4.2	-0.9	0.8	-4.0
Income per Capita	-2.5	-2.1	3.7	-4.0
Labor allocation[2]	0.1	0.7	-0.5	0.0

Sources: Author's calculations.
[1] The table shows the impacts of changes in the savings rate (parameters s, s_i and s_f, respectively), population growth rate (parameter n) and labor productivity (parameters e_U and e_H, with A, A_i, and A_f assumed unchanged). The "partial" impacts may not add up to the total impact owing to rounding errors and cross-effects.
[2] Change in share of unskilled workers working in the formal sector (in percent of the total number of unskilled workers).

For the closed economy, our findings for the one-sector replicate the pattern proposed by many other studies (see our discussion of the impacts of HIV/AIDS on economic growth in Chapter 2.1). The direct impact of HIV/AIDS on productivity are exacerbated by the impacts of a decline in national savings on the capital-labor ratio and thus output per capita. However, much of these negative impacts are reversed by the positive impacts of a slowdown in population growth on the capital-labor ratio, almost offsetting the adverse impacts through the other two channels, so that the overall effect of HIV/AIDS on GDP per capita comes out rather small (minus 1.3 percent). The findings for the dual-economy model are very similar, but we note that the adjustment involves a reallocation of labor to the formal sector (reflecting our assumption that the decline in the savings rate in the formal sector is less pronounced).

Our estimates of the impact of HIV/AIDS in the open economy are very different from those for the closed economy. The impact on output per capita is stronger (a decline of about 4 percent both in the one-sector and dual-economy version of the model). In the open economy, however, it is also important to consider the change in the country's net investment position. As deteriorating investment opportunities in the domestic economy result in an outflow of capital, the balance of income in the economy's current account improves and the decline in income per capita is less pronounced than the decline in output per capital. For the dual-economy model, this effect is more pronounced, this reflects the incongruence in our model designs between the one-sector and dual economy model, while the former does not differentiate between different types of capital, we assume that only capital generated in the formal sector (where the savings rate declines less than in the economy overall) is mobile.

The presence of different types of labor also means that HIV/AIDS could have some implications for the distribution of income. In our model, which operates on high level of aggregation, these would take the form of different impacts on the wage rates of skilled an unskilled labor, respectively.[71] Table 3 shows that the impacts of HIV/AIDS on wages are uniform across types of labor in the one-sector model.[72] However, the impact of HIV/AIDS is more pronounced for unskilled labor than for skilled labor in the dual economy model,

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[71] In a more general model, it may also be possible to track distributional implications of a change in the rate of return to capital.

[72] This reflects the constant-factor-shares property of the aggregate production function, coupled with our assumption that the declines of labor productivity are uniform across types of labor.

owing to our assumption that savings rates decline less in the formal sector – the formal sector thus contracts less than the informal sector, also resulting in a reallocation of unskilled labor to the formal sector, which has a first-order impact on the wages of skilled labor, but a second-order impact on the wages of unskilled labor.[73]

Table 3. The Macroeconomic Impact of HIV/AIDS: Distributional Aspects

	Share of formal sector (Change in Percentage points)	Interest rate (Change in Percentage points)	Skilled wage (Change in percent)	Unskilled wage (Change in percent)
One-Sector Model				
Closed Economy	n.a.	-1.1	-1.3	-1.3
Open Economy	n.a.	0.0 [1]	-4.0	-4.0
Dual-Economy Model				
Closed Economy	1.5	-1.2	1.0	-4.6
Open Economy	0.2	0.0 [1]	-3.9	-4.6

Sources: Author's calculations.
[1] For the dual-economy model, the interest rate for the formal sector is shown.

E. Impact of Antiretroviral Treatment

Access to antiretroviral treatment has increased dramatically in low- and middle-income countries in recent years., WHO, UNAIDS and UNICEF (2008) estimate that 3 million people in need of antiretroviral therapy were receiving it as of end-2007, corresponding to a coverage rate of 30 percent, and comparing to a number receiving treatment of 2 million just one year earlier, and only 400,000 at end-2003.

The actual and potential economic impact of antiretroviral treatment has so far not been covered in the academic literature dealing with the economic impacts of HIV/AIDS, partly because the available studies precede the increase in access to treatment.[74] Among the applied studies, only Jefferis, Siphambe, and Kinghorn (2006) and Ellis, Laubscher, and Smit (2006) include an explicit discussion of the impacts of treatment. Their study, however, does

[73] The latter effect mitigates the impacts of HIV/AIDS on the wages of unskilled labor, but also contributes to reversing some of the decline in the wage of skilled labor.

[74] However, some studies may implicitly include some assumptions regarding the impact of treatment, if the demographic studies they are based on incorporate some assumptions in this direction.

not provide a full documentation of some key assumptions regarding the impact of HIV/AIDS (and by implication, antiretroviral treatment) and of important features of the model.

Assumptions on impact of antiretroviral treatment

For our estimates of the macroeconomic consequences of increased access to antiretroviral treatment, which employ models geared towards the analysis of long-run changes in GDP per capita, we would need some reasonable projections of the scale access to treatment could attain over the next years. The treatment coverage rate we adopt is 100 percent, i.e., 100 percent of people whose illness has progressed to the point where they would require treatment receive it. This may be a benchmark difficult to achieve literally (it would require that all people living with HIV/AIDS are diagnosed in time, seek treatment, and are able to access appropriate health services); however, for our region of interest, with relatively high treatment coverage rates, it provides a useful point of reference.

The health and demographic consequences of increased access to treatment have been discussed in some detail in United Nations Population Program (2007), and Over (2004, 2008) provides thorough discussions of the implications from a public health perspective. In the context of our discussion, the principal effects of increased access to antiretroviral treatment are three-fold – first, mortality related to HIV/AIDS declines, second, some of the decline in birth rates associated with HIV/AIDS is reversed, and third, the number of people living with HIV/AIDS, and in particular the number of people receiving treatment, increases. In terms of the parameters of our model, we would expect to see the following impacts of increased access to treatment:

(1) A partial reversal in the decline in the population growth rate, as mortality declines and the decline in birth rates associated with HIV/AIDS is mitigated;

(2) a partial reversal of the declines in labor productivity, owing to lower mortality and morbidity among workers;

(3) changes in the savings rate, reflecting lower average expenses on funerals, but higher spending on care and treatment.

To understand the magnitude of these effects, it is first necessary to determine the impact of treatment on mortality and birth rates. In our analysis of the macroeconomic impact of HIV/AIDS (largely excluding the impact of treatment), we assumed a decline in the rate of population growth of 1.0 percent, reflecting an increase in mortality of 0.8 percent and, by implication, a decline in the birth rate of 0.2 percent.

Antiretroviral treatment substantially increases the life span of people receiving it, but it prevents few HIV/AIDS-related deaths. Based on Lopez and others (2006), and the documentation accompanying United Nations Population Division (2007), we assume that treatment reduces the loss in life expectancy of a person living with HIV/AIDS in low- and middle- income countries from 36 years to 28 years. Assessing the implications for mortality rates is not straightforward, as HIV/AIDS-related deaths are mainly delayed rather than prevented. However, the reduction in mortality owing to treatment is related to the gain in life expectancy from it. As about one-quarter of the loss in life-years is averted by treatment, we assume that the increase in mortality owing to HIV/AIDS is reduced by one-quarter, i.e., from 0.8 percentage points to 0.6 percentage points.[75] For the potential impact of treatment on birth rates, we assume that treatment reverses the decline in birth rates from 0.2 percent to 0.1 percent. Proportionally, this is a larger reversal than the one in mortality rates, reflecting that the increase in life expectancy has a more than proportional effect on the time women living with HIV/AIDS survive during child-bearing age, and that treatment also increases the probability of successful pregnancies. Overall, we thus assume that treatment reverses the decline in the population growth rate by 0.3 percentage points (from minus 1.0 percentage points to minus 0.7 percentage points).

To assess the impact of increased access to treatment on labor productivity, we need to establish the impact of treatment on the mortality among the working-age population, recalling that, at 3.0 percentage points, the impact on mortality for this age group (ages 15–59)

[75] For mortality rates that are uniform over time, life expectancy is equal to the inverse of the mortality rate. Our approximation linearizes the link between life expectancy and mortality, and does not take fully into account complications arising from mortality rates that differ over time and from the composition of the population reflected in population averages of mortality rates.

is much more pronounced than for the overall population (0.8 percentage points). Using the same approximation as above, we assume that the reversal in the increase in mortality is proportional to the reversal in the loss in life expectancy, which would mean that mortality declines by only 2.3 percent.[76] Correspondingly, we assume that the decline in productivity amounts to only 3 percent, rather than 4 percent.

Regarding the implications of increased access to treatment on the savings rate, there are two effects going in opposite directions. As HIV/AIDS-related mortality declines (from 0.8 percentage points to 0.6 percentage points, so does the impact of funeral expenses on the savings rate (from 0.4 percentage points to 0.3 percentage points).

Our estimates of the impact of HIV/AIDS on private savings were motivated by the costs of care of treatment, assumed to occur over an average of 2 years. Antiretroviral treatment extends life-time by 8 years, and during this time costs of treatment are incurred. On the other hand, the costs of care can be expected to decline, as the state of health of the people receiving treatment improves. We therefore assume that the costs of care and treatment increase three-fold (whereas a simple scaling-up based on higher survival times would suggest a five-fold increase). This would mean that the negative impact of the private costs of care and treatment on the aggregate savings rate rises to 0.75 percentage points (from 0.25 percentage points, reflecting a decline of 1.5 percentage points in the informal sector, and a decline of 0.375 percentage points in the formal sector.

The remaining component of the impact of HIV/AIDS on national savings is the impact on government savings, which we set at 0.33 percent of GDP. In light of the prominent role of external grants in financing HIV/AIDS-related expenditures, especially regarding health

[76] Doing this, we do not take into account complications that arise as (1) a number of young people living with HIV/AIDS who would have died before reaching age 15 survive beyond this age (and increase mortality among the working-age population), and (2) for a number of relatively old people, death is postponed until after they exit the working-age population. Both effects play a relatively small role, as HIV prevalence among people under age 15 is low, and as the old cohorts in the working-age population carry account for a small share in the working-age population, and as mortality in the latter age group is lower than for the working-age population overall.

expenditures, scaling up – for our projections – domestically financed government expenditures proportionally with the number of people receiving treatment would probably exaggerate the impact of scaling-up of treatment. It is also worth noting that the reported data on HIV/AIDS-related spending already include some costs associated with provision of antiretroviral therapy, although on much low levels than suggested by our scaling-up scenario. However, the expansion in health services associated with a substantial scaling-up, and required overheads, would most probably also require an increase in domestic expenditures. In light of the dominant role of external finance, a well-founded estimate is impossible. As a "memorandum item," and in light of the considerable expansion in public health services, we assume that a comprehensive scaling-up doubles the decline in public savings associated with HIV/AIDS, from 0.33 percent of GDP to 0.67 percent of GDP.

The overall impacts of HIV/AIDS on savings rates in a scenario involving comprehensive access to antiretroviral treatment, through the three channels described, thus add up to 1.72 percentage points, ranging from 2.47 percentage points in the informal sector to 1.34 percentage points in the formal sector.

Tables 4 and 5 summarizes our findings on the macroeconomic impacts of HIV/AIDS in a setting with comprehensive access to antiretroviral treatment. Remarkably, for most scenarios (the one exception is the open-economy one-sector model), the impacts of HIV/AIDS are more pronounced in the scenario with comprehensive access to treatment, even though the adverse impacts of HIV/AIDS on health indicators are lower. The deterioration is most pronounced for the open economy, were output per capita declines by an additional 3 percentage points (both for the one-sector model and the dual-economy model. The decline in the savings rate accounts for a decline of about 2 percent, the reduced slowdown in the rate of population growth contributes another 2 percent, while these negative effects on output per capita are partly offset by the dampened impact of HIV/AIDS on productivity (reflecting lower mortality rates).

Table 4. Macroeconomic Impact of HIV/AIDS - Comprehensive Access to Treatment
(In percent)

	Total impact	Impact of decline in ... Savings rate [1]	Population growth rate [1]	Labor productivity [1]
One-Sector Model				
Closed Economy				
Output (=Income) per Capita	-4.1	-5.0	4.0	-3.0
Open Economy				
Output per Capita	-3.0	0.0	0.0	-3.0
Income per Capita	-4.4	-3.3	1.8	-3.0
Dual-Economy Model				
Closed Economy				
Output (=Income) per Capita	-4.2	-5.2	4.1	-3.0
Labor allocation[2]	1.1	0.5	0.6	0.0
Open Economy				
Output per Capita	-4.4	-1.9	0.5	-3.0
Income per Capita	-4.3	-3.7	2.5	-3.0
Labor allocation[2]	1.1	1.5	-0.4	0.0

Sources: Author's calculations.
[1] The table shows the impacts of changes in the savings rate (parameters s, s_i and s_h respectively), population growth rate (parameter n) and labor productivity (parameters e_U and eH, with A, A_i and A_f assumed unchanged). The "partial" impacts may not add up to the total impact owing to rounding errors and cross-effects.
[2] Change in share of unskilled workers working in the formal sector (in percent of the total number of unskilled workers).

For the open-economy model, the changes in per-capita output and income associated with the scaling-up of antiretroviral treatment are less pronounced. In the one-sector model, savings rates and population growth rates have no impact on output per capita, and the decline in output per capita is equal to the change in labor productivity. However, the decline in income per capita becomes more pronounced in a setting with comprehensive access to treatment, as the decline in the savings rate and the reduced impact on the population growth rate affects the rate of accumulation of assets.

Table 5. Distributional Aspects – Comprehensive Access to Treatment

	Share of formal sector (Change in Percentage points)	Interest rate [1] (Change in Percentage points)	Skilled wage (Change in percent)	Unskilled wage (Change in percent)
One-Sector Model				
Closed Economy	n.a.	0.5	-4.1	-4.1
Open Economy	n.a.	0.0	-3.0	-3.0
Dual-Economy Model				
Closed Economy	1.7	-0.1	-1.7	-8.0
Open Economy	1.7	0.0	2.0	-8.0

Sources: Author's calculations.
[1] For the dual-economy model, the interest rate for the formal sector is shown.

For the dual-economy model, the scenario with comprehensive access to treatment also is characterized by a deterioration of incomes in the informal sector (and for unskilled labor more generally), reflecting the asymmetric impacts of the costs of treatment between the informal and the formal sector (as the costs of care and access to treatment account for a larger share of income in the informal sector). As a result, the wage rate for unskilled labor declines by 8 percent, whereas wages of skilled labor decline by only 1.7 percent in the closed-economy setting. For the dual (open) economy, the decline in wages for unskilled labor, and a reallocation of unskilled labor to the formal sector, result in an increase in the wages of skilled labor of 2 percent (while the wages of unskilled labor decline by 8 percent, as in the closed-economy setting).

F. Conclusions

Our findings can be grouped along four themes. First, in line with previous studies, we find that the size of the macroeconomic impacts of HIV/AIDS so far is not of the same order of magnitude as the impacts on health and mortality. Our analysis suggests that the impacts of HIV/AIDS, so far, are consistent with a decline in the steady-state level of output per capita of between one and four percent. Considering that the adjustment to steady-state takes times, and that the impact of HIV/AIDS on mortality has evolved gradually, the implications of our steady-state calculations for the rate of growth of GDP per capita are small – a few tenths of a percentage point.

Second, our findings relate to concerns about distributional impacts of HIV/AIDS, notably regarding a disproportional impact of HV/AIDS on low-income groups. In our framework, the disproportional costs of care and treatment for low-income groups translate into a decline in savings rates, which results in a decline in output per capita in the informal sector. However, it can be argued that the most important aspect of the distributional impacts of HIV/AIDS occur on the household level,[77] and our approach focusing on aggregate macroeconomic variables offers few insights in this direction.

Third, our findings highlight the critical role that the "closed-economy" assumption plays in many studies of the impacts of HIV/AIDS, where an increase in the capital-labor ratio offsets much of the otherwise negative impacts of HIV/AIDS on output per capita. This point is also relevant for considerations regarding the long-term impacts of HIV/AIDS, including possible effects on education choices, human capital, or fertility. With gradual adjustment in capital flows, our open-economy model is particularly relevant for the long-run analysis; studies of the long-run effects of HIV/AIDS relying on an increase in the returns to labor associated with an increase in the capital-labor ratio may therefore be built on shaky premises.

Fourth, our findings suggest that increased access to antiretroviral treatment does not or will not mitigate the adverse impacts of HIV/AIDS on GDP per capita. While mitigating some of the direct effects (e.g., those associated with increased mortality), the economic burden associated with the costs of treatment and care increases, resulting in a somewhat higher decline in GDP per capita. Notably, in our analysis the implications of the increased costs of accessing care and treatment are more pronounced for the informal sector, suggesting an adverse impact on the distribution of income.

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[77] See Haacker (2008, 2004b).

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III.1. HEALTH, LIFE EXPECTANCY, WELFARE (LITERATURE SURVEY)

A. Introduction

Higher incomes are associated with better health, over time or across countries. Over time, improvements in incomes tend to be accompanied by increases in life expectancy and other key indicators of public health. Across countries, life expectancy increases steeply with income (Preston (1975), Deaton (2003)), especially for low-income countries; the "Preston curve" flattens but keeps increasing for higher-income countries.

However, the interactions between health, economic development, living standards, and other economic variables are complex and manifold. While higher incomes can "buy" better health services, improved public health also contributes to productivity, income, and economic growth (see our discussion in Chapter 2.1). From an economic development perspective, health is regarded as an objective and constituent aspect of "well-being," as well as a means to achieving development outcomes, with improved health outcomes enabling agents to pursue gainful activities, thereby contributing to the attainment of development objectives in various areas (Sen, 1999).

Our discussion focuses the contributions of health from a specific angle, drawing on the microeconomic theory of consumption, in which consumers maximize the utility derived from consumption over their planning (life) horizons. In this setting, agents generally value declines in mortality and improvements in life expectancy, as they can attain a higher life-time utility (especially if the increases in life expectancy and improvements in health are associated with an increase in the productive period in agents' lives). Rather than assessing the impacts of health on income, or vice versa, we thus evaluate development outcomes in income or health, irrespective of any interdependencies that may exist between income and health.

Drawing on the literature on the "value of statistical life," which provides empirical estimates of valuations of mortality risks, the framework of the intertemporally maximizing consumer can be used to assess the contributions of increased life expectancy to living standards (i.e., the expected utility over an agent's life). To this end, the literature generally uses income (proxied by GDP per capita) as a meter, adapting the microeconomic framework to obtain estimates of the value of improved life expectancy relative to changes in income. This approach, in different forms, has been used in numerous studies, for example to adjust GDP growth with a contribution of increased life expectancy (e.g., Crafts (1997, 2007), and Nordhaus (2003)) or adding an allowance for increased "health capital" to the level of GDP (Murphy and Topel, 2006).

Against this background, our study is structured in 4 main sections. We set out with a discussion of health from a macroeconomic or economic development perspective (Section 2).[78] While focusing on a subset of this literature subsequently, the purpose of the section is to place this specific area of the literature in a broader context, and to define the contributions to the broader literature of our studies of primary interest, as well as their limitations, more clearly.

Regarding the literature applying the microeconomic framework of the intertemporally maximizing consumer to studying the contributions of improved life expectancy to living standards, many papers provide methodological innovations, as well as concrete estimates of the contributions of increased life expectancy. Nevertheless, we find it useful for expository purposes to initially focus on the methodological aspects of the literature (Section 3).

Section 4 surveys the empirical literature estimating the "value of statistical life," as well as some approaches used to calibrate the parameters of the utility function (which are related to the value of statistical life) in studies estimating the contributions of increased life expectancy to living standards.

Section 5 discusses a number of studies which apply the microeconomic framework of the intertemporally maximizing consumer and estimates of individuals' valuations of mortality risk or the "value of statistical life" to study the impacts of changes in life expectancy on living standards in different contexts. Much of this literature addresses increases in life expectancy and income in industrialized countries, largely in specific

[78] References on the linkages between health and economic growth are cursory, as these are discussed in some detail elsewhere in this volume (see Chapter 2.1).

countries, with periods of coverage that could go back as far as 1900, or 1870 in some cases. A second area of interest is the small literature that extends the approach to a large number of countries, to allow for cross-country comparisons or, in one notable paper (Becker and others, 2005), to study the evolution of world inequality, allowing for the contribution of increasing life expectancies across countries. One specific area in which the approach we focus on has been applied usefully is the study of the impacts of the HIV/AIDS epidemic, which represents the most serious example of an event reversing gains in life expectancies in individual countries or regions for a sustained period of time.

Section 6 concludes.

B. Health and Welfare – A Macroeconomic Perspective[79]

While our discussion in subsequent sections focuses on specific aspects of the contribution of improved health on living standards, the present section provides some broader context. From a broad economic development perspective, for example in the framework developed by Sen (1999), improved health would be regarded as a constituent aspect of development and a development objective in its own right. At the same time, improved health contributes to the attainment of other development objectives, including income (most directly, as healthy people are more productive) and education. The view of health as a constituent aspect of development, and a key instrument in attaining improved material living standards is also reflected in catalogues of development objectives such as the United Nations' Millennium Development Goals (MDGs), with 3 of the 9 MDGs directly referring to public health issues.[80]

More specifically regarding the linkages between income and health, Commission on Macroeconomics and Health, Working Group I (2002), which provides a comprehensive

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[79] The section on "Health and Welfare – A Macroeconomic Perspective" partly draws on Haacker, Markus, 2008a, "Health and Globalization," in: Reinert, Kenneth A., Ramkishen S. Rajan, Lewis Davis, And Amy Glass (eds.), 2008, *Princeton Encyclopedia of the World Economy* (Princeton NJ: Princeton University Press).

[80] See Haacker (2008b) for further reading. The relevant MDGs are MDG 4 ("Reduce child mortality"), MDG 5 ("Improve Maternal Health"), and MDG 6 ("Combat HIV/AIDS, Malaria, and Other Diseases").

review of the academic literature on the links between income, health, and poverty, focuses on four macroeconomic aspects of health.[81] (1) A successful demographic transition from high to low fertility depends in large part on improvement in health. (2) Healthier workers are physically and mentally more energetic and robust, and thus more productive. A healthy environment is also conducive to children's education. (3) Across the world ill health disproportionally afflicts poor people. At the same time, as the main asset of the poor, their body, is left without insurance, ill health imposes a higher level of risk on the poor than on people with more assets. (4) The report points at income inequality as key determinant of mortality in higher-income countries, with income inequality indicating the quality of social arrangements, stress, and mortality.

The linkages between income or GDP per capita on one hand, and health on the other hand, have been explored by numerous authors with a more narrow macroeconomic focus. Early influential studies include Pritchett and Summers (1996) and Pritchett (1997), which highlight the positive correlation between income and life expectancy. Recent studies by Deaton (2003, 2006) and Cutler, Deaton, and Lleras-Muney (2006) generally propose more complex interactions between income, health, and other economic variables. Deaton (2003) focuses on links between inequality and health. While finding that income inequality becomes relatively more important as a cause of death at higher income levels, the evidence does not support an independent role for income inequality as a major determinant of population health. Instead, inequality appears to affect health as it is associated with poverty.

Deaton (2006) and Cutler, Deaton, and Lleras-Muney (2006) offer a more complex view of the relationship between health and income. Deaton (2006) suggests that "health improvements in poor countries are not primarily driven by income, nor even by improvements in health knowledge and technology. Knowledge has certainly been important in the long run. But over periods as long as decades, it is the social factors that make for effective delivery of health that are vital, particularly levels of education, and the

[81] The following list largely quotes from Commission on Macroeconomics and Health, Working Group I (2002). However, it draws a few key sentences from and thus edits a longer discussion, our summary should therefore not be interpreted as a literal quote.

development of population health as a political priority, which itself depends on better education and on the widespread idea that better health is both a possibility and a right."

Relatedly, Cutler, Deaton, and Lleras-Muney (2006), analyzing the determinants and correlates of mortality, find that "over the broad sweep of history, improvements in health and income are both the consequence of new ideas and new technology, and one might or might not cause the other. Between rich and poor countries, health comes from institutional ability and political willingness to implement known technologies, neither of which is an automatic consequence of rising incomes. Within countries, the lower earnings of people who are sick explain much of the correlation between income and health, rather than a causal relationship from higher income to better health."

In addition to the role of health as a determinant of GDP per capita (discussed in more detail in Chapter 2.1), and the interactions between health and GDP per capita, the recognition of health as a key development outcome has motivated the construction of development indicators that incorporate measures of the state of public health, in addition to income (and, in some cases, other variables).[82]

The best-known of these indicators is the Human Development Index (HDI) developed by the United Nations Development Program.[83] It combines indices representing the state of public health (based on life expectancy), educational attainment (based on literacy rates and enrolment rates), and income per capita.

Bourguignon and Morrison (2002) adopt a more informal approach, analyzing and comparing long-term trends across countries over long periods (1820–1992). They find that global income inequality has increased throughout the period under consideration, although at a slower pace in the period following World War II. While most inequality was due to differences between countries in the early 19th century, most differences were accounted for

[82] A good survey of different approaches is included in Crafts (2007).

[83] For the latest version, see United Nations Development Program (2007). For a thorough discussion of underlying methodology, see United Nations Development Program (1993)

by cross-country differences in later periods. Meanwhile, inequality in longevity increased during the 19th century, but the increase was (more than) reversed between 1920 and 1970.[84]

Composite indices like the HDI, or "parallel" analyses like the one in Bourguignon and Morrison (2002), reflect a recognition of the state of health as a central determinant or component of economic development. The literature that we discuss further below differs from these approaches in two (related) regards. First, the assessments of the contribution of health to economic living standards, based on a framework with intertemporally maximizing agents, is motivated by microeconomic evidence regarding individual's valuations of reduced mortality or improved life expectancy, drawing on the literature on the "value of statistical life" and other microeconomic studies.[85] Second, attaching a value to improvements in life expectancy enables researchers to use income as a common meter for improvements in living standards, calibrating, for example, "corrected" or "adjusted" growth figures, measuring gains in living standards by "full income," including an imputation for increased life expectancy, or estimating the (stock) value of increases in life expectancy, and attributing a value to the outcomes of medical research (as in Murphy and Topel (2003b, 2006)).

While – in terms of social valuations of increases in life expectancy – assessments based on microeconomic evidence may offer some advantages,[86] it is important to stress what this type of analysis can and cannot achieve. If one accepts a specific utility function as representative of individuals' preferences, the framework provides valuations of improvements in income per capita and in life expectancy using a common meter (usually projecting health improvements into equivalent income changes). However, it provides

[84] Inequality in income appears to have reached a trough in 1980, according to Fig. (3) in Bourguignon and Morrison (2002), this is not discussed explicitly in their study.

[85] See Section IV for a more extensive discussion.

[86] As discussed in more detail further below, translating the microeconomic evidence into the context of macroeconomic evaluations is not unproblematic, as the microeconomic data across countries is scarce, as the context of the surveys and the individuals sampled may not be representative of the economy as a whole, and as assessments across countries or over longer time periods are afflicted by problems associated with out-of-sample projection.

valuations of the contributions of health to improved living standards only in a reduced form, or in terms of final outcomes of income per capita and life expectancy, and bypasses the issues raised in the discussions of the interdependencies of income, health, and other economic variables outlined above.

C. Microeconomic Context

The body of theoretical literature we draw from starts with Schelling (1968), which is frequently quoted as an influential source in the subsequent literature, and which establishes three principles which characterize the literature on the value of statistical life. First, while establishing valuations of life or actual death is difficult, such issues can usually be approached based on incremental mortality risks (and decision-making problems typically relate to the latter). Second, inferences regarding valuations of life can be made based on "market evidence of what people will pay to avoid their own death" (i.e., reduce the probability of a fatality). Third, Schelling conjectures that such valuations would exceed the value of the expected income over an agent's remaining life. Additionally, Schelling points out potential frictions between individual valuations of life (depending on an agent's wealth) and social preferences (using a hospital as an example).

The approach sketched by Schelling has been formalized by several authors, adopting frameworks in which agents are endowed with an explicit set of preferences over time and states of nature, and in which valuations of mortality risks are "evaluated [...] by reference to what each member of the community is willing to pay or to receive for the estimated change of risk" (Mishan, 1971). Mishan also introduces the links between the valuation of life the Hicksian "compensating variation" in income, and spells out the links of this approach to valuing life to the concept of Pareto optimality). Jones-Lee (1974) contributes a more refined "analysis of compensating variations for changes in the probability of an individual's own fatal accident," using a framework with two states of nature ("life" and "death"). The 1976 book by Jones-Lee on "The Value of Life – An Economic Analysis" provides a thorough discussion of some earlier literature not covered here, and provides an extensive discussion of "the value of changes in safety and longevity" against the background to the theory of choice under uncertainty. The book also links the theory to the practice of life insurance, and provides some discussion of an experimental approach to estimating valuations of life. Jones-Lee (1994) provides an accessible introduction to issues regarding "the economics of safety and physical risk."

Arthur's "Economics of Risks to Life" (1981) analyzes valuations of mortality risks in the context of agents' expected life horizon, focusing on the "willingness to pay" for reductions in mortality risk. A subtle difference between Arthur's approach and the earlier ones is that the valuation of risks to life in his paper are based on an equivalent, rather than a compensating, variation in income. The key contribution of Arthur's study, however, is an explicit link between remaining life expectancy and the valuation of life, as "a life lost at a younger age forfeits more than one at an older age."

Rosen (1981) links valuations of life of occupational health risks, and provides an expository model in which wage differentials are related to employment-specific mortality risks. At the time, few studies of valuations of life implicit in wage differentials were available, but the contribution is significant as it established the principle of which much of the subsequent literature on the "value of statistical life" builds (see our discussion further below). Rosen (1988) provides a more explicit framework, emphasizing age-dependent variations in the value of life (as in Arthur, 1981), and explicitly linking the valuation of life to certain properties or parameters of agents' preferences (compare our discussion of direct vs. indirect estimates of the value of statistical life, further below). Rosen (1986) formalizes the links between employment-based mortality risks and the value of life in an integrated framework in which employment opportunities are characterized as bundles of different types of attributes, including associated incomes and health risks.

Usher (1973, 1980) provided a macroeconomic perspective to the literature on the value of statistical life, relating income growth and advances in life expectancy to obtain estimates of a "growth rate of income inclusive of an imputation for increased life expectancy." Usher (1973), the more extensive of the two studies, also provides estimates of the contribution of life expectancy in 5 countries (while Usher (1980) focuses on Canada only), and discusses some of the properties of valuations of life in a life-cycle context (including age-dependency).

D. Studies of the Value of Statistical Life

There are two distinct approaches to estimating the "value of statistical life," i.e., the valuation of life implied by observed economic valuations of incremental changes in mortality risks. One method is closely aligned with the definition of the value of statistical life, and draws on empirical studies relating differences in wage data or other economic data to observed differences in mortality across a sample. The other approach involves drawing on evidence on the structure of agents' preferences. To see how the two approaches are related, we employ a simplified version of the life-cycle model of consumption, with

$$U = \int_0^{\infty} e^{-\mu t} u(c) dt = \frac{u(c)}{\mu}, \tag{1}$$

where c represents the level of consumption (assumed to be constant over time) μ stands for the mortality rate (also assumed to be constant, which means that life expectancy is equal to $1/\mu$). The presentation of preferences in Eq. (1) also implies an assumption that the rate of time preference, which is not essential for the present exercise, is equal to zero.
Differentiating through and dividing by U gives

$$\frac{dU}{U} = -\frac{d\mu}{\mu} + \frac{u'(c) \cdot c}{u(c)} \frac{dc}{c}. \tag{2}$$

The equivalent variation in the level of consumption that would leave U unchanged, in response to a change in μ, is

$$\left. \frac{dc}{c} \right|_{U=\bar{U}} = \left(\frac{u'(c) \cdot c}{u(c)} \right)^{-1} \frac{d\mu}{\mu}. \tag{3}$$

A version of Eq. (3) is commonly used in empirical studies of the value of statistical life, usually in the form

$$dy = \alpha_1 d\mu + other\ variables + error\ terms, \tag{4}$$

where the estimated coefficient α_1, corresponding to $\left(\frac{u'(c) \cdot c}{u(c)} \right)^{-1} \frac{c}{\mu}$ in the above expository framework, represents the value of statistical life. Our simple framework also suggests that the value of statistical life also changes with the level of income, mortality, or life expectancy ($1/\mu$), which needs to be taken into account when adapting parameters from regressions as in Eq. (4) to different settings, or applying the framework in settings where the level of income or life expectancy may differ over time or across units of analysis (individuals, groups, countries, etc.).

The alternative approach for calibrating the value of statistical life also departs from Eq. (3). As $\left(\frac{u'(c)\cdot c}{u(c)}\right)$, the elasticity of the utility function with respect to the level of consumption, is closely related to the shape of the utility function, and can be represented in terms of key parameters of specifications of utility functions commonly used in macroeconomic or microeconomic analysis, it is also possible to derive estimates of the value of statistical life from that literature. (Another closely related economic variable is the elasticity of intertemporal substitution, $-\left(\frac{u'(c)}{c\cdot u''(c)}\right)$, estimates of which could also be utilized to determine parameters of the utility function and thus the value of statistical life.)

Direct Estimates of the Value of Statistical Life

As our primary interest is the study of the value of statistical life across countries or over time, we focus on the literature building on estimates from individual studies and analyzing the variations in estimates of the value of statistical life across studies (i.e., over time and across countries). The most comprehensive of such "meta" studies is Viscusi and Aldy (2003), on which we will focus below, following an earlier study by Viscusi (1993); another study that is sometimes used to motivate estimates of the value of statistical life across countries is Miller (2000). Bowland and Beghin (2001) is notable for our purposes, in light of their objective of deriving estimates for the value of statistical life for developing countries from a sample that is dominated by industrialized countries. Liu, Hammitt, and Liu (1997), in addition to estimating the value of statistical life based on data from Taiwan, also provide some cross-country analysis.[87]

The study by Miller (2000) is noteworthy as it represented, at the time, the most serious effort aimed at studying the determinants of the value of statistical life across countries, including low-income countries. To this end, the empirical analysis in Miller (2000) focuses on GDP per capita or GNP per capita as a determinant of the value of statistical life; additionally, he conducts sensitivity checks regarding the over-representation of certain countries, most notably the United States, in the sample. For various specifications, his estimates of the elasticity of the value of statistical life range from 0.95 to 0.96 for GDP per capita, 0.85 to 0.95 for GNP per capita, and 0.89 for PPP-adjusted GDP per capita. For a simpler specification, based on country averages for the value of statistical life rather than individual observations, the estimated elasticities with respect to GNP per capita range from 0.92 to 1.0, and imply a value of statistical life of about 136.7 times GNP per capita (see Crafts and Haacker (2004); the estimate is based on regression (4) from Miller (2000).

Bowland and Beghin (2001, and the 1998 working paper version which provides a more extensive documentation of some of the econometric specifications) discuss some of the problems in drawing inferences from available studies of the value of statistical life (largely from industrialized countries – Bowland and Beghin (1998, 2001) adopt the dataset from Viscusi (1993). Specifically, they focus on explanatory variables (such as income, indicators for human capital, and estimates of demographic characteristics) which are available for a wide set of developing countries, and apply some weighting techniques to analyze the sensitivity of their findings to outliers. Their preferred specifications return estimates of the elasticity of the value of statistical life of 1.52, 1.66, and 2.27.

Our discussion uses Viscusi and Aldy as a focal point, not only because it includes the latest and most comprehensive discussion of available studies to date, but also because it

[87] We do not provide a further discussion of the findings from the cross-country analysis in Liu, Hammitt, and Liu (1997), as the presentation and discussion is very brief (11 lines) and serves primarily as a brief "sanity check" of the authors' findings from studying the Taiwanese data.

discusses and re-estimates some of the models in Miller (2000) and Bowland and Beghin (2001) using the larger set of observations covered by their survey.[88]

The study by Viscusi and Aldy covers 30 studies of compensating wage differentials for mortality risk from the U.S. labor market, and 21 studies from other labor markets.[89] Of the latter studies, the bulk regards industrialized countries, while 7 cover emerging or developing economies (including 3 successive studies by the same author, using the same dataset from India). The earliest studies for the U.S. date back to the mid-70s, and only 10 were published in 1990 or later, while most studies of non-U.S. economies (17) were published after 1990.

The heavy reliance on U.S. studies, especially for the years before 1990, is problematic when these studies are used to draw inference regarding the value of statistical life across countries or over time. A key variable in this regard is the level of income or GDP per capita; finding a stable relationship between the estimated value of statistical life and income would inspire some measure of confidence in applying the estimates obtained from analyzing the estimates of the value of statistical life from country-level studies.

Using their expanded sample of country-level studies, Viscusi and Aldy (2003) update the earlier analyses by Liu, Hammitt, and Liu (1997), Miller (2000), and Bowland and Beghin (2001), finding elasticities of the value of statistical life (estimate from original studies in parentheses) with respect to income of 0.53 (0.51) for the model used in Liu and others (1997), 0.53 (0.89) for Miller (2000), and 0.61 (1.66) for Bowland and Beghin (2001).

The similarities of the estimates produced by Viscusi and Aldy (2003), across specifications, suggest that the composition of the sample may play a key role in explaining

[88] Another "meta study" of variations in the value of statistical life across studies covered by Aldy and Viscusi (2003) that we do not discuss here is Mrozek and Taylor (2001) and largely focuses on the U.S. economy, and which applies a specification that cannot not be extended to a large set of countries, owing to limited data availability.

[89] Additionally, Aldy and Viscusi (2003) survey studies of the value of statistical life using other methods (property values and health risks, risk-reducing expenditures), and studies addressing wage differentials associated with injury risk.

the differences between the estimates by Viscusi and Aldy and the original studies, while the value of statistical life, in Viscusi and Aldy (2003), appears to be fairly robust across specifications. The large weight of observations from the U.S. alone in Viscusi and Aldy (2003) does not appear to be the primary reason for the differences between their study and the earlier ones, as Liu and others (1997) and Miller (2000) show similar imbalances, and as Miller (2000) produces similar estimates for the elasticity of the value of statistical life with respect to income in regressions based on the country averages of the estimated value of statistical life.[90]

More recently, Becker and Elias (2007) revisited the estimates produced by Viscusi and Aldy (2003). Becker and Elias (2007) emphasize the role of outliers in the sample used by Viscusi and Aldy, notably the estimated values of statistical life from 3 studies from India, which are very high relative to the sample average of income levels, - the average level of income in the three studies from India included by Viscusi and Aldy (2003) is US$778, while the estimates of the value of statistical life range from US$1.0 million to US$4.1 million, corresponding to between 1285 and 5270 times the level of income, i.e., about 10 to 40 times the level produced by most other studies. Moreover, these outliers have a large effect on the estimated elasticities as India is an outlier in the sample used by Viscusi and Aldy in terms of GDP per capita. Becker and Elias (2007) therefore re-estimate the elasticities produced by Viscusi and Aldy excluding the estimates from India, and obtain elasticities in the vicinity of unity.

Another test regarding the plausibility of estimates of the value of statistical life across countries is whether the estimates make sense when applied to countries at either end of the distribution of income across countries. To this end, we use the U.S., with an estimated GNI per capita of about $45,850 in 2007, as a benchmark for high-income countries and an average low-income country, with GDP per capita estimated at about $1,441 (in current US$, at PPP exchange rates, see World Bank (2007). [Note: For drafting purposes, this section actually used GNI. Need to update numbers.] As a benchmark for the value of statistical life

[90] Bowland and Beghin (2001) do not provide a straightforward documentation of their sample, and therefore does not allow for similar comparisons.

for the U.S., we use a value of US$ 5.5 million (corresponding to 120 times GDP per capita), based on the latest estimates of the value of statistical life adopted by the U.S. Environmental Protection Agency (EPA).[91] An income elasticity of the value of statistical life of 0.53 (the lower of the values estimated by Viscusi and Aldy (2003) would translate into a value of statistical life of US$0.98 million, or 677 times GDP per capita.[92] At a value of statistical life as high as this (in relative terms, 5.5 times the level for the U.S.), public health would probably become the dominant domestic policy issue, and it can be argued that the evidence from low-income countries does not support such a premium in the relative value of public health. Conversely, an income elasticity of the value of statistical life of 1.66, as in Bowland and Beghin (2001), would translate into an estimated value of statistical life of US$17,600, corresponding to about 12 times GDP per capita. This is implausible as the (annualized) value of statistical life is below the level of income.[93,94]

Indirect Estimates Based on Parameters of Utility Function

The second approach to determining the value of statistical life that is used in the literature builds on macroeconomic or microeconomic empirical studies evaluating the shape of the utility function (or studies pursuing a different objective, but with implications for the shape

[91] See Borenstein, 2008.

[92] Note that the actual or estimated value of statistical life, depending on the context, would also depend on the level of life expectancy. Our comparison focuses on the role of income and abstracts from the level of life expectancy.

[93] Published estimates of the value of statistical life are typically based on samples dominated by working-age people, and a remaining life expectancy of 40 years for that group is a good approximation. A value of statistical life of 12 times GDP per capita, for a remaining life expectancy of 40 years, would only correspond to a small fraction of expected income over the remaining life span, whereas most individual studies return a value of statistical life that considerably exceeds the expected income over the remaining life span.

[94] The studies by Becker, Philipson, and Soares (2005), and Philipson and Soares (2005), discussed further below, make even more radical assumptions, assuming that the value of statistical life turns negative (i.e., that death is preferred to life) for some of the poorest low-income countries.

of the utility function). The most influential paper adopting this approach is Murphy and Topel (2006), building on earlier work by the authors Murphy and Topel (e.g., 2003b). They adopt the utility function (somewhat adapted for our purposes)

$$u(c) = \frac{c^{1-\sigma^{-1}} - c_0^{1-\sigma^{-1}}}{1-\sigma^{-1}}, \tag{1}$$

where σ is the elasticity of intertemporal substitution, and c_0 is the consumption level below which the utility flow from consumption would turn negative. Regarding σ, Murphy and Topel (2006) motivate their parameter choices based on the econometric evidence surveyed by Browning, Hansen, and Heckman (1999), who – according to Murphy and Topel (2006)[95] – "conclude that σ is 'a bit' larger than 1.0,"[96] although the preferred value adopted by Murphy and Topel is 0.8. Regarding the value of c_0, Murphy and Topel argue that this could differ across countries or over time, setting c_0 at 10 percent of GDP per capita for each period they consider. Becker, Philipson, and Soares (2005), and Philipson and Soares (2005) motivated by Murphy and Topel (2003), adopt a similar approach to parameterizing the value of statistical life. The key difference to the approach take by Murphy and Topel (2006) is that Becker, Philipson, and Soares (2005), and Philipson and Soares (2005), do not allow for differences in the parameter c_0 over time or across countries. As a consequence, they postulate that agents with an annual income c_0 of less than US$353 (in 1990 US$, PPP-adjusted) are assumed to derive negative utility from their consumption, implying that a very substantial proportion of the population of low-income countries their study focuses on would be better off dead. This, however, is problematic for a study focusing on sub-Saharan Africa, where a significant share of the population lives on incomes at or below that level – Chen and Ravallion (2008), in a study at least implicitly endorsed by the World Bank, estimate that close to 40 percent of the population in sub-Saharan Africa live at incomes

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[95] In our reading, Browning, Hansen, and Heckman (1999) is ambiguous on this point.

[96] Another conclusion emphasized by Browning, Hansen, and Heckman (1999) is that "the elasticity of intertemporal substitution as determined from consumption is usually poorly determined."

below $1 a day in 2005 US$, PPP-adjusted, roughly corresponding to the level at which the utility from being alive turns negative according to Philipson and Soares (2005).

An earlier study that provides a thorough microeconomic foundation of the estimates of the value of statistical life is Rosen (1988). However, while building estimates of the valuation of life from an explicit microeconomic framework, he uses an estimate of the value of statistical life from an earlier study (Thaler and Rosen, 1975). This is used to calculate values for key parameters (including the elasticity of the utility function with respect to consumption) under different assumptions regarding discount rates. For example, he obtains an elasticity of 0.36 for a discount rate of 8 percent. Nevertheless, the framework spelled out by Roses (1988) could also be used to "reverse-engineer" estimates of the value of statistical life from the microeconomic parameters of the framework, and the paper has been an influential point of reference for later work.

E. Applied Studies[97]

In recent years, there has been a number of studies applying the literature on the value of statistical life to assess the contributions of improved health (i.e., longer life expectancy) to living standards.[98] Among factors motivating this research are the observation that the increase in material living standards over the 20th century has coincided with a very substantial drop in mortality rates or, equivalently, an increase in life expectancy, the fact that the evolution of the pattern of income across countries is different from trends in the pattern of mortality rates across countries, the high costs of health services in the United States, and the appalling declines in life expectancy associated with the HIV epidemic, notably in several countries in sub-Saharan Africa.

[97] While the classification is not always clear-cut, we group studies in this section which are primarily geared towards calibrating the contributions of health to living standards in a country or a set of countries, and which largely refer to prior work to motivate the functional form and key parameters adopted.

[98] Some of these studies were already referred to earlier as they also provide contributions regarding the underlying theory or estimating the value of statistical life.

Among the most influential contributions to the literature is the work of Murphy and Topel (2003b, 2006), which is concerned with "the economics of improving health and the returns to medical research" (Murphy and Topel, 2003a), primarily with regard to the United States.[99] In the tradition of studies like Arthur (1988) and Rosen (1988, 1994), Murphy and Topel (2006) use a framework in which remaining lifetime expected utility of an individual of age a is characterized by

$$\int_a^\infty H_t u(c_t, l_t) \frac{S_t}{S_a} e^{-\rho(t-a)} dt, \tag{2}$$

where H_t represents an individual's state of health at age t,[100] current utility u depends on consumption c_t and leisure l_t, the probability S_t of surviving through age t, and the discount rate ρ. To estimate the value of a life year, Murphy and Topel adopt a specific functional form for the role of consumption in current utility, with

$$u_c = \frac{z^{1-\sigma^{-1}} - z_0^{1-\sigma^{-1}}}{1-\sigma^{-1}}, \tag{3}$$

where σ is the elasticity of substitution and is assumed constant.[101] Using an estimate of 0.8 for σ and $6,000 for z_0 (the annual consumption level below which utility u turns negative), Murphy and Topel obtain a value of a life year at age 50 of $373,000, and a value of statistical life that peaks at about US$7 million around age 30, declining to about US$5 million by age 50, and US$2 million by age 70. Using this framework, Murphy and

[99] Our discussion focuses on Murphy and Topel (2006), which largely supersedes the earlier publications.

[100] As Murphy and Topel focus on the role of the survival function S_t, the health state plays a marginal state in their analysis and is not discussed below.

[101] This presentation of utility as a function of consumption implies as assumption that the elasticity of substitution between consumption and leisure in $u(c,l)$ is constant.

Topel estimate the economic gains from reductions in mortality between 1970 and 2000 at US$64 trillion for the 2000 U.S. population.[102]

Murphy and Topel also provide estimates of the value of improved life expectancy relative to GDP over time, adopting a somewhat different approach, scaling the parameter z_0 in proportion with GDP.[103] Arguing that improvements in life expectancy should be interpreted as an increase in health *capital*, they add the increases in the "stock" of health capital to the level of GDP. For the first half of the 20th century, the value of the improvements in life expectancy amount to between 70 percent of GDP and 90 percent of GDP. For the second half of the 20th century, the role of improvements in health is much less pronounced, accounting for 25 percent of GDP to 30 percent of GDP in most decades.

Table 1. GDP and Increases in Health Capital, 1900–2000 (Murphy and Topel, 2006) (2004 U.S. dollars)

	1900–10	1910–20	1920–30	1930–40	1940–50
GDP	6,011	7,239	7,703	7,578	13,592
Increase in health capital	4,987	2,754	5,513	6,062	12,314
(In percent of GDP)	83.0	38.0	71.6	80.0	90.6
Total	10,998	9,993	13,216	13,640	25,912
	1950–60	1960–70	1970–80	1980–90	1990–2000
GDP	15,856	20,343	25,342	28,381	32,057
Increase in health capital	4,951	2,381	12,839	7,305	8,240
(In percent of total)	31.2	11.7	50.7	25.7	25.7
Total	20,807	22,724	38,181	35,686	40,297

Source: Murphy and Topel, 2006.

An earlier influential study discussing the value of health improvements in the United States (Cutler and Richardson, 1997) points to three relevant factors – "an increase in the length of the typical life, a greater prevalence of disease during that life, and an improvement in the mental and physical aspects of health conditional on disease." Using an estimate of the value of a life year of US$ 100,000 in 1990 U.S. dollars, assumed to be constant over time, Cutler and Richardson estimate that the value of extended life expectancy amounted to between US$ 55,000 (at age 0) and US$ 108,000 (at age 65) over the 1950–70 period, and

[102] Interestingly, but beyond the scope of the current discussion, Murphy and Topel also discuss gains in life expectancy in the context of health expenditures, and potential gains from medical progress in certain categories of diseases.

[103] See Murphy and Topel, 2006, p. 891.

between US$ 77,000 (at age 0) and US$ 159,000 (at age 65) over the 1950–70 period, whereas the contributions of changes in the (health) quality of life were modest.[104] Burström, Johannesson, and Diderichsen (2003), in a study on Sweden between 1980/81 and 1996/97, adopt the benchmark value of $100,000 per life year from Cutler and Richardson. They find similar gains, and also point out that the gains in life expectancy over these years have been more pronounced for males than for females.

A different line of the literature focuses on the contribution of improved health to living standards, relative to or in addition to GDP growth. The literature on the value of statistical life has been adapted early to analyze the evolution of "full income" (i.e., GDP plus an allowance to account for the improved level of population health), notably by Usher (1973, 1980). Usher (1973), using a specification where $u(c) = c^{\beta}$, provides estimates for the growth rate of GNP, including "an imputation for life expectancy increases," for five countries (Ceylon, Chile, France, Japan, and Taiwan), for different periods. For different choices of parameters, [105] he finds that the contribution of increased life expectancy exceeded that of GNP growth for Ceylon (1946–63), and almost attained the same level as GNP growth in Chile (1931–65). The weights of increases in life expectancy were more moderate in the more advanced economies, accounting for only about 0.6 percentage points in France (1911–64). Usher (1980) updates the earlier paper and extends the analysis to 10 countries, (different periods), focusing on Canada, and also providing less extensive estimates for Chile, Costa Rica, France, Mauritius, Japan, Singapore, Sri Lanka, Thailand, and the United States. The contributions of increased life expectancy to the "growth rate of GNP inclusive of an imputation for increased life expectancy" appear lowest for the most advanced economies, at about 0.6–0.7 percentage points for the United States (1930–1974), and 0.8–1.0 percentage

[104] See also Cutler and Richardson (1998) for a concise summary of their main findings from the 1997 study. Cutler and Richardson (1999), which largely draws on the authors' earlier 1997 study in terms of analytical content, provide a more extensive discussion of health expenditure and health policy issues.

[105] Usher (1973) explores does not settle on specific parameters, but applies values for the elasticity β ranging from 0.25 to 0.45, and values for the discount rate ranging from 1 percent to 5 percent.

points for France (1911–1972), but generally exceed 1 percentage point for the other countries, ranging to up to 2 percentage points for Sri Lanka (1946–1968).

Crafts (1997) adopts an approach similar to Usher's, calibrating the rate of growth of "GDP, adjusted for mortality" as a weighted sum of the rate of growth of GDP and the rate of growth of life expectancy. Principal contributions of Crafts (1997) include the discussion of adjustments to GDP as measure of living standards to account for changing life expectancy against the background of some alternative indicators, such as UNDP's Human Development Index. Additionally, Crafts adds a long-term perspective, focusing on a sample of industrialized countries for which estimates of GDP and other data are available from the 1870s.[106] He estimates the unweighted mean of the contribution of reduced mortality to the annual growth of "GDP/head, adjusted for mortality," at 0.5 percentage points for 1870–1913, at 0.8 percentage points for 1913–1950, at 0.4 percentage points for 1950–1973, and at 0.5 percentage points for 1973–1992.

Subsequent work by Nordhaus (2003, following up on and updating a 2002 working paper version) and Crafts (2005, partly based on a 2001 working paper) follows a somewhat different approach, attaching a certain value (which may change in line with the level of GDP per capita) to an increase in life expectancy or a reduction in mortality (similar to the approach taken by Cutler and Richardson, 1997, which is referred to in Nordhaus's study). Nordhaus (2003) addresses the impact of improved life expectancy on economic welfare in the United States over the period 1900–1995. He estimates that the contribution of increased life expectancy or, similarly, reduced mortality, to improving living standards was of a similar magnitude as consumption growth.

Crafts (2005, and, similarly, but covering broader ground, 2007), with reference to Nordhaus's work, applies a similar analysis to the growth of living standards in the United Kingdom over the years 1870–2001, finding that "greater longevity was a major contributor to the growth of living standards during the twentieth century." One refinement that Crafts (2005) adds to the analysis is an adjustment for the age structure of the population, taking

[106] The GDP data were obtained from Maddison (1995).

account of the fact that increases in (remaining) life expectancy differ by age. Overall, Crafts estimates that the contribution of reduced mortality to living standards considerably exceeded the contributions from increased income between 1870 and 1950 (by up to a factor 2), and that they were of similar magnitude as the contributions from increased income between 1950 and 2001.

As discussed above, Becker, Philipson, and Soares (2005) adopt a specification similar to the one proposed by Murphy and Topel (2003b, 2006). Based on the observation that increasing incomes have been associated with increased live expectancy, they discuss the implications of changes in life expectancy for the evolution of cross-country inequality. [107] Similar to Bourguignon and Morrison (2002), they find that trends in inequality across countries evolved differently regarding income and health – "incorporating longevity gains changes traditional results; countries starting with lower income tended to grow faster than countries starting with higher income. [They] estimate an average yearly growth in 'full income' of 4.1 percent for the poorest 50 percent of countries in 1960, of which 1.7 percentage points are due to health, as opposed to a growth of 2.6 percent for the richest 50 percent of countries, of which only 0.4 percentage points are due to health" (Becker, Philipson, and Soares (2005), p. 277).

The experience of severe declines in life expectancy in many countries associated with the evolving HIV/AIDS epidemic has motivated several studies assessing the losses in living standards caused by the increased mortality. The earlist of these studies is Jamison, Sachs, and Wang (2001), a background study for the Commission on Macroeconomics and Health. With reference to the "mortality" approach used (by an early version of) Nordhaus (2003), and a value of statistical life assumed at 100 times GDP per capita, the welfare losses from increased mortality are calculated as the change in adult mortality (in percent), multiplied by the share of adults in the population and the factor 100. Jamison, Sachs, and Wang estimate that living standards in sub-Saharan Africa declined by 2.6 percent annually in 1990–2000,

[107] Philipson and Soares (2002) provide a more informal discussion of similar issues. See Deaton (2003, 2006) for background and further references, and Bourguignon and Morrison (2002) for a less formal discussion of the contribution of incomes and health to changes in inequality across countries.

broken down in an annual rate of GDP growth of –0.9 percent, and a contribution of increasing mortality of –1.7 percent. For some countries with high HIV prevalence, they estimate the rate of decline in living standards owing to increased mortality at between minus 5 and minus 8 percent annually in 1985–2000.

Crafts and Haacker (2003, 2004) use an expected utility framework, and derive a link between the percentage change in life expectancy and the equivalent loss in GDP per capita, and use this framework to calculate the welfare losses in 7 countries. They find that HIV/AIDS results in a welfare loss of about 90 percent in the worst affected countries. However, even for countries with fairly low HIV prevalence rates the welfare losses can be substantial – for Vietnam, with an estimated HIV prevalence rate of 0.4 percent, Crafts and Haacker estimate a welfare loss of 2.9 percent. Usefully, Crafts and Haacker also provide a discussion of issues regarding the application of studies of the value of statistical life (largely from developed countries) to developing countries with much lower levels of GDP per capita.

Philipson and Soares (2005) also spell out an explicit expected-utility framework. To evaluate the impacts of changing life expectancy, they adopt the specification and parameters from Becker, Philipson and Soares (2005), which in turn are based on empirical work on the U.S. economy. Notably, the utility framework assumes that individuals with an annual income of $353 in 1996 PPP U.S. dollars would be indifferent between being alive or dead, and individuals with an income below that level would be better off dead (unless they expect that their income will rise in the near future, making expected lifetime utility positive). Using GDP per capita (and thus averaging income across populations, thus mitigating the apparent problem) to calculate the welfare losses, they find that HIV/AIDS is welfare-improving (because it shortens miserable lives) in one country (Democratic Republic of Congo), more generally, Philipson and Soares propose that the social value of AIDS eradication (i.e., the compensating variation), relative to GDP, is considerably lower in low-income countries than in middle-income countries included in the sample (after controlling for HIV prevalence).

F. Conclusions

Against the background of the literature on the role of improvements in health standards in increasing living standards, this survey discusses attempts to expand indicators of material living standards such as the level or the rate of growth of GDP per capita with indicators for public health, notably life expectancy. At the same time, the applied studies discussed in this survey change the perspective from a focus on current income or consumption flows to a forward-looking approach assessing the value of a consumption stream over an agent's expected life-cycle.

The principal point of departure from the studies discussed here is the heterogeneity of methods adopted to implement estimates of the value of statistical life in assessments of the level of or progress in living standards. Some of this heterogeneity reflects the different purposes the analytical frameworks adopted in different studies are designed for. For example, a study dealing with the benefits of improvements in health standards in a particular country at some point in time would not have to be designed with considerations regarding comparability across countries or consistency over time in mind.

However, differences in methodologies also extend to studies covering long periods of time (such as the studies covering gains in living standards over periods as long as a century) involve cross-sections of heterogeneous countries (from low-income to high-income countries), or cover periods characterized by extreme changes in the indicators for public health (such as the dramatic drops in life expectancy experienced in some countries severely affected by HIV/AIDS).

A study evaluating the existing approaches against an explicit analytical framework could therefore contribute to identifying best practices in analyzing the contributions of improved health standards to living standards across countries and over time, and clarify discrepancies between existing studies. Notably, we would expect additional insights regarding cross-country studies covering countries with vastly different levels of GDP per capita, and studies addressing the impacts of catastrophic health events, where the implications of the noted methodological differences are most pronounced.

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III.2. Contribution of Increased Life Expectancy to Living Standards

A. Introduction

The present study assesses the role of changes in life expectancy in various episodes of economic development, notably the increases in life expectancy that have accompanied increases in material living standards in (today's) major industrialized countries, and the declines in living standards that can be associated with a major epidemic (HIV/AIDS).

The analysis builds on a body of literature that draws on the microeconomic theory of consumption to assess the contributions of improved health, in addition to rising incomes, to living standards.[108] The approach is based on the concept of an intertemporal utility function, which describes lifetime utility as the utility streams derived from consumption at future dates, discounted by a factor that reflects the rate of time preference and survival probabilities to the respective dates, e.g.

$$U = \int_0^\infty S_t e^{-\delta t} u(c_t) dt, \qquad (1)$$

where S_t represents the survival probability through time t, δ is the discount rate, and $u(c_t)$ represents the utility flow derived from c_t, the consumption stream at time t. In this setting, economic growth affects (life-time) living standards U as it enables an upward shift in the trajectory of consumption levels c_t over an individual's time horizon. At the same time, individuals value an increase in survival probabilities as this enhances the value, in terms of life-time utility U, of a given consumption trajectory (additionally, a change in the trajectory of S_t may also result in a reallocation of consumption over time).

The framework outlined here has been applied by numerous researchers to estimate the contribution of improved health to changes in living standards, most notably to analyze the sources of improvements in living standards over longer periods of time. More recently, HIV/AIDS – which has resulted in pronounced declines in life expectancy in a number of

[108] See Chapter 3.1 for a comprehensive discussion of the relevant literature.

countries, especially in sub-Saharan Africa – has motivated several studies addressing the implications of the resulting increase in mortality on living standards.

These studies commonly use GDP and GDP growth as yardsticks for changes in living standards. The contribution of changes in life expectancy is then calibrated also using GDP as a meter, either as a change in living standards that is equivalent to a change in GDP growth that would result in the same change in living standards *U*, or as the increment to GDP growth that would compensate for a change in life expectancy, leaving *U* unchanged.

A key challenge in using the framework sketched here for an analysis of the contribution of changes in mortality rates to living standards is the choice of an appropriate functional form and parameters of the intertemporal utility function. Most available studies draw on estimates of the "value of statistical life," based on empirical studies that relate wage differentials to differences in employment-related mortality risk. Translating such wage differentials into assumptions regarding the general population, however, is difficult, as the wage differentials relate to a non-representative subset of the population.[109] Moreover, most studies of the "value of statistical life" relate to a few industrialized countries for relatively recent years, attempt to evaluate the contributions of improved life expectancy to living standards over long periods of time (e.g., from 1870) or for a large set of countries, including low-income countries, therefore amount to out-of-sample-projection, implying large margins of error.

Our analysis below sets out with an outline of earlier studies (Section 2), highlighting areas in which our study contributes to the body of literature. Section 3 introduces our theoretical framework, and motivates our choice of parameters for the intertemporal utility function (and thus the weight of increases in life expectancy, relative to income gains, in improving living standards). Section 4 discusses the contribution of increased life expectancy in 17 industrialized countries in 1870–2006, and for a larger group of 136 countries for the 1950–2006 period. Section 5 analyzes the adverse impacts of HIV/AIDS across countries.

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[109] Chapter 3.1 provides a more substantial discussion of the methodology.

(The assumptions underlying the demographic estimates used in our analysis of the impact of HIV/AIDS are summarized in an appendix.) Section 6 concludes.

B. Background

Our analysis builds on various strands of the economic literature, notably the theoretical contributions deriving individual or welfare implications of changes in health variables from utility functions of forward-looking (representative) consumers, and applied work that draws on the theoretical contributions to analyze the value of medical research, the contributions of increased life expectancy, alongside with growth of GDP per capita, to rising living standards, and – more recently – studies addressing the adverse impacts of HIV/AIDS, which has slowed down or resulted in reversals in gains in live expectancy in many countries.

Methodologically, our study builds on an analytical framework that goes back to Schelling (1968), an informal analysis that is credited in much of the later work for established the principle that inferences regarding valuations of life can be made based on incremental changes in mortality risks, and the amounts individuals are prepared to pay or forfeit to avoid such risks. This concept has been formalized in microeconomic papers by Mishan (1971), Jones-Lee (1974), and Arthur (1981), using a framework in which lifetime utility derives from the expected utility of future consumption streams, discounted and weighted by survival probabilities.

This approach has subsequently been adapted to a macroeconomic context, and been used to assess the contributions of increased life expectancy (as well as GDP or GNI per capita) to the growth of living standards. The earliest contributions in this direction were those by Usher (1973, 1980), the recent contributions most relevant in our context include Nordhaus (2003), Crafts (2007, 2005, and 1997), dealing with the role of increasing life expectancy during industrial development), and Murphy and Topel (2006). Bourguignon and Morrison (2002) and Becker, Philipson, and Soares (2005) have addressed aspects of the contribution of improved health to living standards in the post-WWII period across a broader set of countries, building on the dataset compiled by Maddison (2004, 1995). A spin-off from this literature has been motivated by the experience of increased mortality owing to HIV/AIDS in many countries, the most comprehensive studies in this direction are Crafts and Haacker (2003, 2004) and Philipson and Soares (2005).

A related strand of literature that the macroeconomic studies of the contribution of increased life expectancy to living standards draws on and partly overlaps with are studies analyzing variations in the valuation of changes in mortality risks (and hence the "value of statistical life") across countries, over time, or for different income levels, which is a necessary ingredient of studies analyzing the contributions of increased life expectancy over time and across countries. There are two different approaches to assessing variations in the value of statistical life in relation to other economic variables (notably GDP or income per capita). As the value of statistical life, as we discuss further below, is related to properties of the utility function, some studies draw on micro-econometric studies on properties of the utility function; a notable recent example of a study adopting this approach is Murphy and Topel (2006); Usher (1973, 1980), without the benefit of the later micro-econometric work, also took a related approach. The other approach focuses on the findings from employment-based individual studies, and involves analyzing the differences in such estimates of the value of statistical life in relation to a set of explanatory variables. Notable studies following this approach include Miller (2000) and Viscusi and Aldy (2003), which also includes the most comprehensive survey of the literature so far.

Against this background, our analysis adds to the existing literature in several areas. Methodologically, our analysis builds on an explicit microeconomic framework with forward-looking consumers. From this framework we derive a reduced form that allows us to estimate the contributions of increasing life expectancy to living standards in a straightforward manner. Additionally, we derive a method to assess the implications of large changes in life expectancy (relevant, e.g., for comparisons over long time intervals, or the analysis of catastrophic health events significantly reducing life expectancy) which, we argue, represents an improvement to much of the applied literature.

From this platform, we revisit two branches of the applied literature. First, we build on studies addressing the contribution of increased life expectancy to living standards in the context of industrial development, such as Nordhaus (2003) and Crafts (2007, 2005, and

1997). Notably, we build on and update the work by Crafts (1997), reviewing the contribution of increasing life expectancy to living standards for a group of 17 industrialized countries from 1870, and discuss the contributions of improved health to living standards on a global scale since 1950, focusing on the contributions of health to the growth of living standards (unlike Bourguignon and Morrison (2002), and Becker, Philipson, and Soares (2005), who place more emphasis on the evolution of inequalities in living standards across countries).

The second strand of applied literature we contribute to is the literature on the economic impacts of HIV/AIDS, building, most directly, on the work by Crafts and Haacker (2003, 2004), and benefiting from our analytical framework that facilitates the analysis of impacts of large changes in life expectancy. One aspect that distinguishes our analysis from earlier studies is an explicit analysis of the implications of access to antiretroviral treatment, reflecting the increase in access to treatment experienced in many countries severely afflicted by HIV/AIDS in recent years.

C. Theoretical Framework and Choice of Parameters

The discussion of our analytical framework proceeds in four steps. First, we discuss the role of changes in mortality and life expectancy in a fairly general framework in which expected life time utility is determined by the utility flows derived from consumption in future periods, weighted by a discount rate and applicable survival probabilities. Second, we introduce a specific functional form, and discuss the relation between key parameters of our model and the value of statistical life. Third, we draw on the empirical literature estimating the value of statistical life, as well as other approaches, to populate the parameters of the model. Fourth, we discuss some properties of the model regarding the analysis of the implications of discrete changes in life expectancy (while most of our analysis uses differential techniques).

Basic Theoretical Framework

We analyze the link between living standards and life expectancy or mortality from a straightforward microeconomic model of consumption, in which an individual values consumption and life expectancy according to the lifetime utility function

$$U[\{c_t\},\{\mu_{s,t}\},\rho,s]=\int_s^{\infty}u(c_t)e^{-\int_s^t(\rho+\mu_{s,v})dv}dt, \tag{2}$$

where $\{c_t\}$ denotes the individual's consumption stream over time, s stands for the individual's initial age, $\{\mu_{s,t}\}$ is the set of time-varying mortality rates of an individual with initial age s at time t, with $t\in[s,\infty)$, and ρ gives the discount rate. The function $u(...)$ has the usual properties, with $u'(...)>0$ and $u''(...)<0$.

The individual's budget constraint is

$$\int_s^{\infty}c_te^{-\int_s^t r_vdv}dt=\int_s^{\infty}y_te^{-\int_s^t r_vdv}dt=\int_s^{\infty}y^*e^{-\int_s^t r_vdv}dt, \tag{3}$$

where y_t stands for the individual's income at time t, r_t is the real interest rate at time t, and y^* is the constant income stream that yields the same present discounted value as the (possibly time-varying) income stream $\{y_t\}$. Let $\{c_t^*\}$ be the consumption stream that maximizes (2), subject to (3), and $V=U[\{c_t^*\},\{\mu_{s,t}\},\rho,s]$. The solution to the optimization problem implies a link between V and y*, say, $\frac{dV}{dy^*}=\lambda$, derived from the Lagrange multiplier associated with the lifetime budget constraint. The incremental change in y^* that would have the same effect on V as an incremental change in the mortality pattern $\{\mu_{s,t}\}$ then is equal to

$$dy^*=\frac{-1}{\lambda}\int_s^{\infty}u(c_t)\int_s^t d\mu_{s,v}dv\,e^{-\int_s^t(\rho+\mu_{s,v})dv}dt. \tag{4}$$

However, in the framework outlined above, (incremental) changes in the pattern of mortality, $\{\mu_{s,t}\}$, result in (incremental) changes in the pattern of consumption, $\{c_t^*\}$. Whereas the envelope theorem implies that the impact of these incremental changes of $\{c_t^*\}$ is second order around the maximum, this does not apply to discrete changes. Moreover, in our context data do not normally arrive in a form assumed in Eq. (4), as data on mortality are usually lumped by cohort or age group or arrive in the form of summary indicators like life expectancy. Similarly, we are dealing with summary indicators of income like GDP or GNI per capita, rather than data on individuals' income flows over time. For these reasons, we are going to simplify the model in various directions, in order to obtain a better match between the data at our disposal and key variables of the model, and to obtain a more straightforward link between changes in mortality and equivalent variations in income than the one presented in Eq. (4).

Specifically, we assume that lifetime utility can be represented in terms of permanent income, i.e. we present utility in terms of a consumption stream that is equal to permanent income and constant over time. This means that utility V can be represented in the form

$$V(\{\mu_{s,t}\}, y^*, \rho, s) = u(y^*) \int_s^\infty e^{-\int_s^t (\rho+\mu_{s,v})dv} dt, \tag{5}$$

where the first term on the right-hand side represents the utility flow. The integral in Eq. (5) represents life expectancy (discounted by the rate of time preference, and equal to actual life expectancy in the special case of $\rho = 0$), which we will denote as *LE*. Eq. (5) can therefore be rearranged as

$$V(\{\mu_{s,t}\}, y^*, \rho, s) = u(y^*) LE(\{\mu_{s,t}\}, \rho, s), \tag{6}$$

$$\text{with} \quad LE(\{\mu_{s,t}\}, \rho, s) = \int_s^\infty e^{-\int_s^t (\rho+\mu_{s,v})dv} dt, \tag{7}$$

i.e., lifetime utility is represented as the utility flow from permanent income (or the consumption level consistent with it), multiplied by (discounted) life expectancy.

Specifically, we will use GDP per capita as the measure of choice for income in various applications further below, which implies the assumption that consumption moves in line with GDP per capita, at least over the long periods which are the focus of our analysis.

Functional Form

The second type of restrictions we impose regards the structure of preferences. A functional form that will turn out convenient in terms of identifying the value of statistical life based on model parameters (and model parameters based on empirical evidence on the value of statistical life) is the one adopted by Murphy and Topel (2006), which is also sufficiently general to encompass different specifications adopted in studies by Crafts and Haacker (2003, 2004), Philipson and Soares (2005), and Crafts (1997). In this framework, the utility flow from consumption is determined by

$$u(c) = \frac{c^{1-\frac{1}{\sigma}} - c_o^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}, \tag{8}$$

where c_0 presents a level of extreme poverty below which the utility flow from consumption c becomes negative, and $\sigma = -\frac{u'(c)}{cu''(c)}$, the elasticity of substitution, is assumed constant. For reasons that will become apparent further below, we transform the utility function, using

$$u(c) = c^{\frac{1}{\gamma}} - c_o^{\frac{1}{\gamma}}, \tag{9}$$

which, apart from a linear transformation, is identical to the Murphy and Topel (2006) specification, with $\gamma = \frac{\sigma}{\sigma-1}$.

The objective of our analysis is the analysis of changes in health standards, specifically mortality rates and life expectancy, on living standards, i.e., the expected value of lifetime utility, and to be able to express the gains or costs associated with changes in mortality patterns and life expectancy in terms of equivalent changes in income. To this end, we substitute for $u(y^*)$ in Eq. (6) from Eq. (9), and differentiate, obtaining

$$dV = \frac{1}{\gamma}(y^*)^{\frac{1}{\gamma}-1} LEdy^* + \left((y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}} \right) dLE. \tag{10}$$

The variation in income that is *equivalent* to a change in life expectancy is obtained as the minus one times the variation that would leave lifetime utility V unchanged (i.e., the *compensating* variation), following an incremental change in life expectancy. Setting dV equal to zero in Eq. (10), and solving for dy^*, first yields the *compensating* variation in income as

$$\left.\frac{dy^*}{y^*}\right|_{dV=0} = -\gamma \frac{(y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}}{(y^*)^{\frac{1}{\gamma}}} \frac{dLE}{LE}. \tag{11}$$

The *equivalent* variation is then obtained by simply reversing the sign, i.e.

$$\left.\frac{dy^*}{y^*}\right|_{EQU} = \gamma \frac{(y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}}{(y^*)^{\frac{1}{\gamma}}} \frac{dLE}{LE}. \tag{12}$$

In Eq. (12), the multiplier that determines the percentage change in income equivalent to some percentage change in life expectancy consists of two parts – the parameter γ and a term that depends on the level of income relative to income level y_0. Specifically, for large levels of y^* (relative to y_0), or very low levels of y_0, the multiplier approaches γ, whereas it declines to zero (or below zero) as y^* approaches (or falls below) y_0.

It remains to show how the parameters in our specification relate to the value of statistical life. The concept of the value of statistical life builds on the idea that expenditures, wage differentials, or similar costs or compensations that compensate for or avoid differences in mortality risks bear information regarding the valuation of life. The best researched aspect of the value of statistical life, and also the version that relates most directly to our subject, is the link between differences in income and associated differences in employment-based mortality risk. Concretely, if a mortality risk of one-tenth of a percent over a year is associated with a 15 percent premium in terms of annual income, then the value of statistical life would be equal to 150 times (15 percent, divided by one-tenth of a percent) annual income.

Rather than dealing with mortality as a trajectory of time-variant mortality rates (as in Eqs. (2) – (7)), we simplify the analysis by representing such trajectories by an average mortality rate that is time-invariant over an infinite time horizon). "Average mortality" is then related to life expectancy as

$$LE = \int_0^{\infty} e^{-\mu t} dt = \frac{1}{\mu}, \tag{13}$$

i.e., the average mortality rate is equal to the inverse of life expectancy. Substituting for life expectancy in Eq. (11) gives the compensating variation in income as

$$\frac{dy^*}{y^*} = \gamma \frac{(y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}}{(y^*)^{\frac{1}{\gamma}}} \frac{d\mu}{\mu}, \tag{14}$$

$$dy^* = \left[\gamma \frac{(y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}}{(y^*)^{\frac{1}{\gamma}}} LE \cdot y^* \right] d\mu . \tag{15}$$

From Eq. (15) and the definition of the value of statistical life as the incremental change in income that compensates for an incremental change in mortality, denoted below as *VSL*, it follows that

$$VSL = \gamma \frac{(y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}}{(y^*)^{\frac{1}{\gamma}}} LE \cdot y^*, \tag{16}$$

i.e., the value of statistical life is equal to the product of a term reflecting the shape of the utility function and expected lifetime income $LE \cdot y^*$. Starting from estimates of the value of statistical life, and making allowances for the sample levels of income and remaining life expectancy, it is therefore possible to draw inferences regarding the structure of preferences.

Choice of Parameters

For our purposes, the principal challenge in finding an appropriate functional form and parameters arises from the fact that we wish to apply our analysis to the study of changes in life expectancy over long periods of time (back to 1870 or 1950, depending on the context) and a large number of countries, including low-income countries, whereas the empirical evidence on the value of statistical life is heavily geared towards high-income countries and largely confined to the last few decades. Thus, in drawing on the available evidence, we encounter problems similar to those associated with out-of-sample projections in an econometric context.

One important contribution to the literature is Murphy and Topel (2006), whose specification we adapted above in Eq. (9) as it encompasses those of many other studies, reprinted here (with y^* and y_0 substituted for the respective consumption levels).

$$u(y^*) = (y^*)^{\frac{1}{\gamma}} - y_o^{\frac{1}{\gamma}}. \quad (17)$$

It is convenient to distinguish two considerations, in line with the key parameters in Eq. (17) – the parameter γ that can be described as a scale parameter for the value of statistical life, and the parameter y_0 that determines how the value of statistical life changes with income (bounded upwards by γ for large values of y*, relative to y_0).

One prior consideration we need to take into account is the fact that we will be analyzing trends across countries characterized by large differences in GDP per capita (in excess of a factor 20), and trends over time periods in which incomes in the countries under consideration has changed dramatically (for the 17 countries covered in Appendix Table 2, GDP per capita has increased by a factor of 11.7 between 1870 and 2006, and for Japan it has increased by a factor close to 30). This would mean that an elasticity of the value of statistical life far from one would be problematic, as it would translate into radically different trade-offs between health and income in developing countries vs. leading industrialized countries, or for industrialized countries over time. For example, an elasticity of the value of statistical life with respect to income of 0.5 would mean that the value of statistical life, in relation to income, is 4.7 times higher in a country with an income level of $1,000, as compared to a country with an income level of 20,000.

Murphy and Topel (2006) choose a very low level for y_0 (10 percent of "normal" income). Importantly, for Murphy and Topel, the "critical" value depends on the economic and social context; for their analysis of the contributions of improved health standards to living standards over time they therefore scale it in line with GDP per capita, so that the value of statistical life, de facto, is proportional to GDP per capita in their long-term analysis. Other analyses (the early work by Usher (1973, 1980), Crafts (1997), and Crafts and Haacker (2003, 2004)) specify the value of statistical life as proportional to income, which would correspond to setting y_0 equal to zero in Eq. (17).

One outlier regarding the analysis of the contribution of improved life expectancy to living standards is the work by Becker, Philipson, and Soares (2005) and Philipson and Soares (2005). With reference to Murphy and Topel, they adopt a utility function as described in Eq. (17), but do not allow for changes in this parameter depending on the economic context, setting it at US$353 at 1996 prices and purchasing power parity. This is problematic for the study of low-income countries (to which their analysis extends), as a considerable proportion of inhabitants of these countries – in their view – do not derive utility from consumption, or derive negative utility and would be better off dead. To illustrate the scale of this problem, we draw on estimates by Chen and Ravallion (2008) of the number of people living below US$1 per day (i.e., US$ 365 per year) at 2005 prices and purchasing power parity, roughly corresponding to the threshold proposed by Becker, Philipson and Soares (2005) and Philipson and Soares (2005). According to Chen and Ravallion (2008), 16 percent of the population of the developing world was living below the US$1 threshold in 2005, notably in Africa and South Asia, where 39 percent and 24 percent of the population were living at or below US$1 per day. For 1981, Chen and Ravallion estimate the proportion of people living below US$1 per day at 42 percent (an issue for the study by Becker, Philipson, and Soares (2005), which considers a period going back to 1950).

Regarding the empirical evidence, setting the parameter y_0 equal to zero is equivalent (within the constraints of the Murphy and Topel framework) to postulating that the elasticity of the value of statistical life with respect to income is equal to 1, i.e., the value of statistical life is proportional to income. Various analyses of estimates of the value of statistical life returned estimates of the elasticity of the value of statistical life with respect to income around one (Miller, 2000), at about one-half (Liu and others, 1997), or close to 1.7 (Bowland and Beghin, 2001). Viscusi and Aldy, re-estimating the earlier work by these other authors based on an expanded sample and offering an alternative specification, estimate the elasticity of the value of statistical life with respect to income at between 0.5 and 0.6. However, Becker and Elias (2007) point at three observations from India (by the same author) proposing values of the statistical life which are outliers, with estimates of the value of statistical life, in relation to income, which are between 10 and 40 times higher than those of most other studies. With these observations are excluded, Becker and Elias estimate the elasticity of the value of statistical life with respect to income at 1.15.

Overall, we find the data situation regarding the elasticity of the value of statistical life with respect to income very weak. In light of prior considerations (a value of the elasticity far from one would result in radically different tradeoffs between health variables and income in low-income and high-income countries), and the fact that a value of the elasticity of one is well within the range of the available estimates of the elasticity, we adopt a value of one for the elasticity of the value of statistical life with respect to income, implying a value of the parameter y_0 of zero. In terms of the functional form adopted, our analysis thus is closest to that of Usher (1973, 1980), Crafts (1997), Crafts and Haacker (2004), and Murphy and Topel (2006, in light of their approach of scaling the parameter y_0 in line with average income per capita).

One advantage of the functional form we adopt (with $y_0 = 0$) is that it yields a very tractable representation of the contribution of increases in GDP per capita (or income) and life expectancy to living standards. With $y_0 = 0$, Eqs. (6) and (17) yield

$$V = (y^*)^{\frac{1}{\gamma}} LE. \quad (18)$$

As we would like to express the contribution of increasing (or falling) life expectancy to living standards using GDP per capita as a meter, it is convenient to apply a monotonous transformation to Eq. (18). By raising both sides of Eq. (18) to the power of γ, we obtain a measure $\bar{V} = V^{\gamma}$ of living standards that is linear in (y^*), i.e.,

$$\bar{V} = (y^*)LE^{\gamma}. \tag{19}$$

The contributions of growth of income and of life expectancy to living standards can then be represented as

$$\frac{d\bar{V}}{\bar{V}} = \frac{dy^*}{y^*} + \gamma \frac{dLE}{LE}, \tag{20}$$

i.e., the rate of growth of living standards is equal to the rate of growth of income, plus the growth rate of life expectancy, weighted by parameter γ.

Regarding the parameter γ, there are two approaches for choosing appropriate values. One approach draws on the literature on the value of statistical life, the other on macro- or micro-econometric evidence regarding the parameters of the utility function. For the approach that draws of the empirical literature estimating the value of statistical life, we first note that – owing to our choice of a value of zero for the parameter y_0 – Eqs. (15) and (16) reduce to

$$dy^* = \gamma LE \cdot y^* d\mu \tag{21}$$

from Eq. (15), implying that

$$VSL = \gamma LE \cdot y^*, \tag{22}$$

or, equivalently,

$$\gamma = \frac{VSL}{LE \cdot y^*}, \tag{23}$$

i.e., the parameter γ can be calibrated from an estimate of the value of statistical life, divided by income and the remaining life expectancy for the sample on which the estimate of the value of statistical life is based. Alternatively, if an estimate of the value of statistical life is specified as a percentage of income, the parameter γ can be calibrated by dividing this by remaining life expectancy.

Nordhaus (2003) adopts a value of statistical life of US$3 million, based on 1990 income and prices, based on the value of statistical life used in policy evaluations by different U.S. government agencies. As this number is an average applied across the U.S. population, the appropriate scale variable is GDP per capita; and the value adopted by Nordhaus (2003) corresponds to 129.3 times GDP per capita.[110] To derive model parameters, Nordhaus uses working men at age 40 as a benchmark, pointing out that most empirical studies of the value of statistical life are based on working-age men, and approximates the remaining life expectancy for men of age 40 at an additional 40 years,[111] which would imply a value of the parameter γ of 3.23.[112]

As the study by Nordhaus has been influential (in the final or previous working paper versions), we offer some variations on his estimates. Using more precise estimates of remaining life expectancy for males at age 40 (35.09 years, according to NCHS (1997)) would result in a estimate of the parameter γ of 3.68. More fundamentally, it can be argued that life expectancy of males at age 40 is not the correct reference point for interpreting the value of statistical life adopted by Nordhaus, as it is derived from a value adopted by U.S. agencies for policy evaluations, and is not directly obtained from labor market data. Therefore, the average remaining life expectancy for the U.S. population (total, including non-males) may be a more appropriate measure of remaining life expectancy. Merging data from United States Bureau of Census (1992) and NCHS (1997), we obtain an average life expectancy of 43.8 years in 1990, which would translate into a value for the parameter γ of 3.00.

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[110] Author's calculation, based on a value for U.S. GDP per capita of $23,208 from IMF (2008).

[111] More precisely, he uses an average mortality rate of 0.025, the remaining life expectancy is obtained as the inverse of this number.

[112] Author's calculation, as Nordhaus uses a different specification.

While the estimates by Nordhaus could be outdated by now (being based on 1990 data), the basic framework described in Eqs. (22) and (23) provides a straightforward tool to obtain estimates of the parameter γ based on estimates of the value of statistical life applied by U.S. government agencies more recently. For example, the U.S. Environmental protection Agency currently adopts a value of statistical life of US$ 6.9 million for policy analyses[113] which relates to a level of GDP per capita of US$ 43,541 (IMF, 2008) and an average remaining life expectancy of about 44 years.[114] The value of statistical life thus corresponds to 158 times GDP per capita. Dividing by average remaining life expectancy yields an estimate of the parameter γ of 3.60.

While the value of statistical life (and corresponding parameters) for the United States is an important point of reference, as much of the empirical literature is based on U.S. data, our primary interest is the evidence on the value of statistical life across countries. The primary resource in this regard is the study by Viscusi and Aldy (2003), who compile estimates of the value of statistical life from across the world, already discussed above and in chapter 3.1. Of the studies compiled by Viscusi and Aldy, we focus on 28 studies for the United States and 22 studies from other countries for which sufficient summary data are available for our purposes. One of the features of the data is the notable dispersion in estimates for the value of statistical life from non-U.S. studies, ranging from 37 times average income (for the underlying sample) to 5270 times average sample income. One way of addressing this wide dispersion in the data, adopted by Becker and Elias (2007), is the elimination of obvious outliers. In light of the apparent role of outliers, we focus on the median value of statistical life, in relation to the average sample income. For those studies where Viscusi and Aldy report a range for the value of statistical life, we adopt the midpoint of that range.

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[113] The value of statistical life applied by the U.S. Environmental Protection Agency (EPA) is not officially released. The number of U.S. 6.9 million was reported by Associated Press based on recent cost-benefit analyses conducted by the EPA. See Borenstein, 2008.

[114] The remaining life expectancy was calculated by the author based on projections of the U.S. population by age for 2008 from United States Bureau of Census, Population Division (2008) and estimates of life expectancy by age for the 2005–2010 period from United Nations Population Division (2007b). The latter have not been adjusted, as 2008 is close to the midpoint of the 2005–2010 period.

For the United States, the median value of statistical life among the studies compiled by Viscusi and Aldy is 234 times sample income for the respective studies, for other countries, is 287 times sample income, and for the combined dataset, the median value of statistical life is 257 times sample income. Finding an appropriate value for the remaining life expectancy for the Viscusi/Aldy (2003) dataset is difficult, as the estimates of the value of statistical life relate to different years (and countries). If a value of remaining life expectancy of around 40 is assumed, then a value of statistical life of 257 times sample income would imply a parameter γ of about 6.4.

An alternative source of evidence on the value of statistical life are empirical studies targeting parameters of the utility function in econometric studies, either on a microeconomic or macroeconomic level. One notable study following this approach is Murphy and Topel (2006), drawing on a study by a Browning, Hansen, and Heckman (1999) which concludes that the elasticity of substitution is "a bit" larger than 1 (see our discussion of the parameter σ in Eq. (8)). This would be consistent with estimates of the value of statistical life as those suggested by the discussion above. However, Murphy and Topel (2006) also point at evidence from macro-econometric studies suggesting a lower level of σ, which cannot easily be reconciled with our framework with $y_0 = 0$, but is less problematic in Murphy and Topel's framework.[115]

Overall, we will base our estimates below on a value of the parameter γ of 3.6, as suggested by the U.S. data for 2008. Three considerations were relevant for this choice. (1) The estimate is based on consistent data and fairly detailed data on life expectancy (whereas we need to make guesses regarding life expectancy in the Viscusi and Aldy (2003) dataset), (2) the apparent heterogeneity of the available empirical studies of the value of statistical life across countries, and (3) a certain bias towards the established – our choice of a value of 3.6 for the parameter γ is not far off from those adopted in earlier studies.

[115] On the other hand, the discrepancies between the macroeconometric studies referred to by Browning, Hansen, and Heckman (1999), and Murphy and Topel, and the microeconometric evidence on the value of statistical life may point at some anomalies of utility functions where death is concerned, which may not adequately be captured in our framework.

Analyzing Discrete Changes in Life Expectancy

As the above framework is specified in terms of incremental changes while most applications are based on data describing discrete (and sometimes large) changes in the underling variables, it is useful to show explicitly under which circumstances the framework based on incremental changes dy^* and dLE may be applied to discrete data, without introducing significant bias.

Using the utility function specified in Eq. (18), the incremental change in lifetime utility owing to changes is given by Eq. (20). For discrete changes, we note that

$$\frac{\Delta\overline{V}}{\overline{V}}=\left[1+\frac{\Delta y^*}{y^*}\right]\left[1+\frac{\Delta LE}{LE}\right]^{\gamma}-1. \tag{24}$$

By Taylor expansion, the term involving LE can be represented as

$$\left[1+\frac{\Delta LE}{LE}\right]^{\gamma}=1+\gamma\frac{\Delta LE}{LE}+\gamma(\gamma-1)\left[\frac{\Delta LE}{LE}\right]^{2}+\textit{higher order terms}, \tag{25}$$

so that discrete changes can be approximated by

$$\frac{\Delta\overline{V}}{\overline{V}}=\frac{\Delta y^*}{y^*}+\gamma\frac{\Delta LE}{LE}, \tag{26}$$

provided that the cross term $\frac{\Delta y^*}{y^*}\frac{\Delta LE}{LE}$, and the higher-order terms involving $\frac{\Delta LE}{LE}$ are small. In many cases covered by the literature, adopting Eq. (13) to analyze discrete changes in GDP per capita and in life expectancy would therefore be appropriate. For larger changes in GDP per capita, it would be possible to calculate the changes in living standards explicitly as the change in the value of $\overline{V}=(y^*)LE^{\gamma}$, although it would then not be possible to clearly attribute the overall change to either (y^*) or LE.

One important application of our approach regards settings in which the principal area of interest are the implications for living standards of certain health events or interventions, for example the benefits of a health investment under consideration or – an area which we will discuss in some detail below – the welfare implications of increased mortality owing to a major epidemic like HIV/AIDS. In these cases, our framework yields a simple way of deriving the welfare costs exactly (conditional on our framework and parameters applied) as

$$\left.\frac{\Delta\overline{V}}{\overline{V}}\right|_{y^*=const.} = \left[1+\frac{\Delta LE}{LE}\right]^{\gamma} - 1. \tag{27}$$

One important advantage of the approach to estimating the contributions of changes in GDP per capita and life expectancy summarized in Eqs. (26) and (27) is the robustness, when applied over large changes in GDP per capita or life expectancy, to linearized models which are sometimes applied in the literature (e.g., Nordhaus (2003), Crafts (2001), Cutler and Richardson (1999)). The variation in income that is equivalent to a change in mortality or life expectancy is

$$dy^* = -\left[\frac{\gamma y^*}{\mu}\right] d\mu \tag{28}$$

$$dy^* = \left[\frac{\gamma y^*}{LE}\right] dLE \tag{29}$$

Consider that a specific value is adopted for an increment in mortality or an addition life year. This may work well for small changes. The problem with the linearized approach that is apparent from Eq. (28) and (29) is that the terms inside the squared brackets do not remain constant as life expectancy (and income) change. A linearized approach that assumes constancy of the terms inside the square brackets in Eqs. (28) and (29) is therefore likely to produce biased estimates.

D. Contribution of Increased Life Expectancy to Living Standards

The model described above provides a framework for analyzing the contributions of increasing life expectancy to living standards over time and across countries, and several studies have used similar approaches to this end. The study that is, in terms of scope and methodology, closest to the framework adopted in the present paper, is Crafts (1997), which applies a reduced form similar to Eq. (20) to "adjust" growth rates of GDP per capita for changes in mortality, covering 16 countries for the years 1870–1992.[116] Other notable studies covering long periods of time are Nordhaus (2003), covering the years 1990–95 for the United States, attributing a monetary value to a life year gained (or, in an alternative approach, to an increment in mortality), and Crafts (2005, 2007), which applies an approach similar to Nordhaus's to the United Kingdom for the years 1870–2001. Another important study is Becker and others (2005), covering a larger number of countries (96), but a much shorter period (1960–2000), focusing primarily at the role of health improvements in the evolution of world inequality.

Table 1 reports our findings regarding the implications of growth in GDP per capita and in life expectancy for living standards for a set of 17 countries, based on source data summarized in Appendix Tables 1 and 2. It largely builds on (and partly replicates) the analysis by Crafts (1997), extending the final period to 2006 and increasing the country coverage by one.[117] The only substantial difference from the earlier analysis regards the weight of changes in life expectancy, which has been updated in line with more recent empirical evidence (see our discussion above).

The estimates summarized in Table 1 illustrate the crucial role of both increases in GDP per capita and in life expectancy in increasing living standards since 1870. Over the entire period, the contributions of growth in GDP per capita (at 1.8 percentage points) and life expectancy (at 1.9 percentage points) were roughly even.[118] Over time, however, the relative contributions of growth in GDP per capita and in life expectancy, respectively, have changed. Until about 1950, the most important source of improvements in living standards were improvements in longevity, especially over the years 1913–1950, where it contributed 3

[116] Crafts (1997) also considers the impact of changes in hours worked (imputing a value of leisure), an issue that is beyond the scope of the present study.

[117] The summary tables in Crafts (1997) exclude Spain, as they also cover the role of changes in working hours, data on which were unavailable for that country.

[118] Calculated based on the unweighted averages for the levels of GDP per capita and life expectancy, respectively, as shown in Appendix Tables 1 and 2.

percentage points to an annual rate of growth of living standards of 4 percent.[119] The relative roles of GDP growth and improvements in public health in raising standards were reversed in the second half of the 20th century, when improvements in life expectancy slowed down, while GDP growth accelerated, notably between 1950 and 1973.

[119] For a discussion of innovations in public health from a macroeconomic perspective, see Acemoglu and Johnson (2007).

Table 1. Contributions of GDP per Capita and Life Expectancy to Living Standards, 17 Countries, 1870–2006

	1870–1913				1913–1950			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Australia	1.1	0.5	1.8	2.8	1.0	0.4	1.6	2.6
Austria	1.5	0.7	2.5	3.9	0.2	1.2	4.4	4.6
Belgium	1.1	0.5	1.8	2.9	0.7	0.8	3.1	3.8
Canada	2.3	0.5	1.8	4.1	1.3	0.7	2.7	4.1
Denmark	1.6	0.6	2.0	3.6	1.6	0.6	2.1	3.6
Finland	1.4	0.5	2.0	3.5	1.9	1.0	3.6	5.5
France	1.5	0.4	1.6	3.0	1.1	0.8	2.8	3.9
Germany	1.6	0.7	2.6	4.2	0.2	0.9	3.2	3.4
Italy	1.3	1.2	4.5	5.8	0.8	0.9	3.3	4.2
Japan	1.5	0.4	1.6	3.0	0.9	1.0	3.7	4.5
Netherlands	0.9	0.9	3.1	4.0	1.1	0.7	2.5	3.6
Norway	1.3	0.3	1.3	2.6	2.1	0.7	2.4	4.5
Spain	1.2	0.5	1.8	3.1	0.2	1.2	4.2	4.4
Sweden	1.5	0.5	1.9	3.3	2.1	0.6	2.3	4.4
Switzerland	1.7	0.6	2.1	3.7	2.1	0.8	2.8	4.9
United Kingdom	1.0	0.6	2.2	3.2	0.9	0.7	2.6	3.5
United States	1.8	0.4	1.4	3.2	1.6	0.8	2.9	4.5
Average	1.4	0.6	2.1	3.5	1.2	0.8	3.0	4.1

	1950–1973				1973–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Australia	2.4	0.1	0.5	2.9	1.9	0.4	1.4	3.2
Austria	4.9	0.3	1.1	6.1	2.0	0.4	1.4	3.4
Belgium	3.5	0.2	0.9	4.4	1.9	0.3	1.2	3.1
Canada	2.8	0.2	0.9	3.7	1.7	0.3	1.1	2.8
Denmark	3.1	0.2	0.6	3.7	1.8	0.2	0.7	2.4
Finland	4.3	0.3	1.0	5.3	2.3	0.3	1.3	3.6
France	4.0	0.4	1.4	5.4	1.6	0.3	1.2	2.8
Germany	5.0	0.2	0.7	5.7	1.5	0.3	1.3	2.8
Italy	4.9	0.4	1.4	6.4	1.8	0.4	1.3	3.1
Japan	8.1	0.6	2.2	10.2	2.1	0.4	1.3	3.4
Netherlands	3.5	0.1	0.4	3.9	1.7	0.2	0.8	2.5
Norway	3.2	0.1	0.4	3.6	2.7	0.2	0.9	3.5
Spain	5.6	0.6	2.1	7.7	2.4	0.3	1.1	3.6
Sweden	3.1	0.2	0.6	3.7	1.7	0.2	0.9	2.5
Switzerland	3.1	0.3	1.0	4.1	0.7	0.3	1.1	1.8
United Kingdom	2.4	0.2	0.6	3.1	1.9	0.3	1.1	3.0
United States	2.5	0.1	0.5	3.0	1.9	0.3	1.0	2.8
Average	3.9	0.3	1.0	4.9	1.9	0.3	1.1	3.0

Source: Author's calculations. For data sources, see Appendix Tables 1 and 2. Averages are unweighted.

One notable feature of the trends in GDP growth across countries is the role of conflict-related disruptions. Among the notable outliers among the trends described in Table 1 are low rates in GDP growth in the 1913–1950 period for Austria and Germany, presumably owing to economic disruptions related to World War II. Another notable outlier is the period of rapid growth in Japan between 1950 and 1973, when GDP per capita grew six-fold, or at a yearly rate of just over 8 percent. Meanwhile, the growth of life expectancy does not show outliers of a similar magnitude as those observed for growth rates GDP per capita, which may reflect the prominent role of cross-country diffusion of health innovations.[120]

A principal limitation of the analysis of long-term trends going back as far as 1870 is that macroeconomic and health data are available for only a handful of countries, largely leading industrialized countries (or leading industrializing countries, where the beginning of the sample period is concerned), partly because many countries (re)gained independence only in the second half of the 20th century. The "group of 17" countries discussed here therefore is a fairly small and homogeneous set of countries. The analysis of long-term trends for the small group of 17 countries can therefore usefully be complemented with an analysis of trends income and health trends since 1950, where data are available for a much larger group of countries.[121]

To this end, Figure 1 summarizes trends in life expectancy and GDP per capita for major world regions from 1950 to 2005 (for life expectancy) or 2001 (for GDP per capita). (As the emphasis of the present study is on the contribution of improving health standards to living standards, the presentation focuses on life expectancy). Regarding the evolution of life expectancy, Figure 1.1 shows a pattern of steady increases over the entire period and for all regions, with two exceptions. Most significantly, life expectancy in Africa, which had barely kept up with the global average in 1950–1990, has slowed down and actually declined

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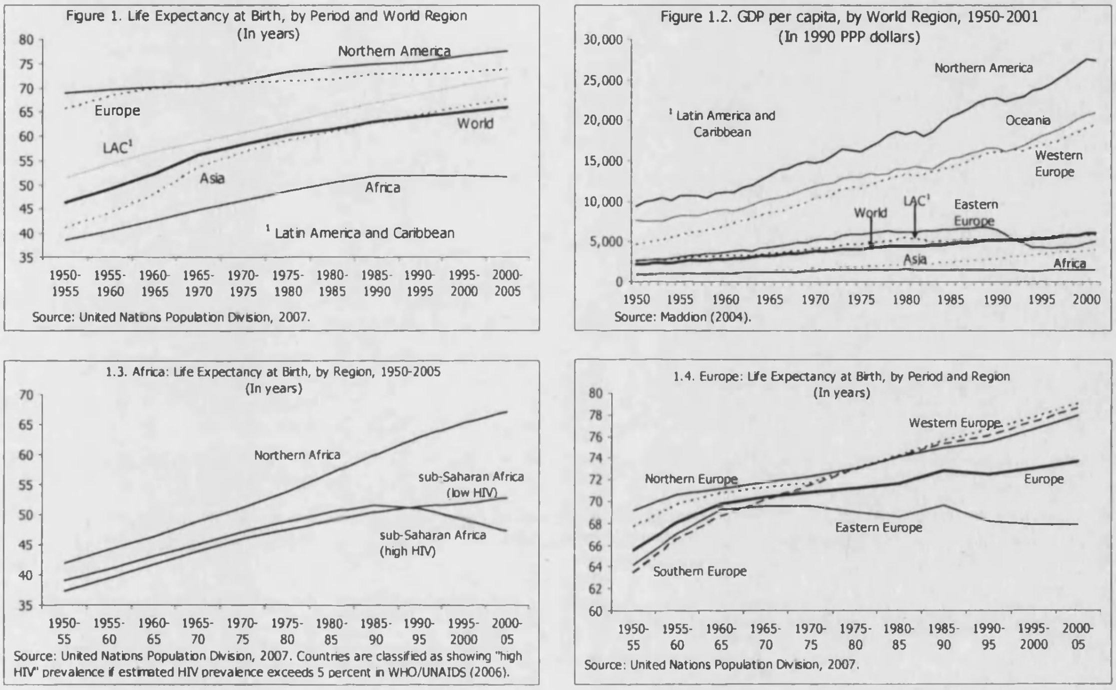
[120] For a more extensive discussion of convergence and divergence of health and income indicators, see Deaton (2006).

[121] Regarding GDP per capita, data series for most developing countries in Maddison (2004) start in 1950. Regarding life expectancy, the World Population Prospects database (see United Nations Population Division, 2007b) includes demographic estimates starting with the 1950–55 period.

somewhat during 1990–2005 (while the global average of life expectancy increased by about 2 years).[122] The other notable exception is the "bump" in the trajectory of life expectancy for Europe in 1990–95.

Figure 1. Life Expectancy and GDP per Capita, Major World Regions, 1950–2005



Similar to life expectancy, GDP per capita has increased throughout the post-1950 period as far as the global average is concerned. On the global scale, it is important to note that the increases in GDP per capita were more pronounced than the increases in life expectancy – while the former increased by a factor of almost 3 (from US$ 2,111 to US$ 6,049, at PPP and in 1990 prices), life expectancy increased by 44 percent, from 46 years to 66 years. For our purposes, the most significant deviations from trends in the global average occur among regions with relatively low levels of GDP per capita, including the sharp decline in GDP per capita of about one-third in Eastern Europe between 1989 and 1996, the relatively high rates

[122] Life expectancy in Africa attained a peak at about 51.9 years around 1990, and declined to 51.6 years for the 2000–05 period, while the global average increased from about 64 years to 66 years.

of growth in Asia, especially after 1973, and the persistence of the stagnation in Africa since about 1980 (with a moderate rebound in recent years).

Regarding the declines in life expectancy observed in Africa and Europe, Figure 1.3 illustrates the role of the ongoing HIV/AIDS epidemic, showing that the declines in life expectancy were most pronounced in countries with high HIV prevalence, while life expectancy stagnated overall in the sub-Saharan countries with HIV prevalence of up to 5 percent at end-2005.[123] Meanwhile, North Africa (with very low rates of HIV prevalence, and also much higher levels of life expectancy at the outset) experienced substantial increases in life expectancy. Figure 1.4 breaks down trends in life expectancy by subregion in Europe. Notably, the "bump" in life expectancy in Europe observed earlier can be attributed to a decline in life expectancy concurrent with the economic contraction in the early 1990s. Perhaps more significant are the longer-term discrepancies between Eastern and Southern Europe – while life expectancies in Eastern and Southern Europe were on a similar level and appeared to catch up with other European regions between 1950 and 1965, life expectancy stagnated in Eastern Europe since 1965, fluctuating at about the same level for the next 25 years (while life expectancy increased by 7 years in Southern Europe), followed by the noted decline in the early 1990s.

The substantial increases in life expectancy and GDP per capita across countries in the post-1950 period, as well as the apparent differences across regions and over time, suggest that the framework developed above could also gainfully be applied in this context. Based on the data summarized in Figure 1 and discussed above, we therefore construct estimates of the contributions of growth of GDP per capita and life expectancy to living standards. For recent years (through 2006), though, we extend the data on GDP per capita from Maddison (2004), which extend to 2001 only, by applying the estimated growth rates of real GDP per capita

[123] The demographic estimates in United Nations Population Program (2007) are based on estimated HIV prevalence rate in UNAIDS (2006). While the latter estimates have subsequently been revised for a number of countries, we use UNAIDS (2006) estimates of HIV prevalence in order to interpret the demographic estimates in United Nations Population Program (2007).

from World Bank (2008). Similarly, we use estimates of life expectancy in 2006 from World Bank (2008).[124]

Estimates of the contribution of growth of GDP per capita and life expectancy, respectively, to living standards are summarized in Table 2, showing population-weighted averages by major world region, as well as estimates for a group of large countries (by population size), and four smaller countries with high rates of HIV prevalence. In light of our previous discussion, we distinguish North Africa and sub-Saharan Africa, and show estimates for Eastern Europe separately.

Regarding global trends, the findings from our comprehensive sample are quite different from those presented earlier for a sample dominated by major industrialized economies. Improvements in life expectancy played a major part in rising living standards in the 1950–73 period, contributing 4.6 percentage points to an overall growth rate of 7.4 percent. However, the contribution of increased life expectancy declines in subsequent periods (to 2.4 percentage points in 1973–90, and 1.3 percentage points in 1990–2006). This pattern would be consistent with a delayed dissemination of major health innovations in developing countries, which had already resulted in major increases in life expectancy in leading economies before 1950 (the impact of which on the rate of growth of life expectancy had tapered off post-1950 in these economies), but still resulted in pronounced improvements in developing countries between 1950 and 1973.[125]

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[124] Merging the dataset from United Nations Population Division (2007) and World Bank (2008) creates a problem regarding the consistency of estimates between the two databases. For almost all countries and periods, data from United Nations Population Division (2007) and World Bank (2008) are very close, with differences of less than three months (as the UN data are averaged over 5-year periods, while the World Bank reports estimates for specific years, usually in two- or three-year intervals, some discrepancies would arise even if the underlying estimates were identical). However, for a few Eastern European countries, the estimated levels of life expectancy differ by 2 or 3 years between the UN and the World Bank data. For the final period under consideration (1990–2006), we therefore use the growth rate of life expectancy from World Bank (2008) for that period.

[125] For context, see Acemoglu and Johnson (2007) and Deaton (2006).

Meanwhile, the contribution of growth of GDP per capita, just above 2.5 percentage points in 1950–90, accelerated to 3.8 percentage points between 1990 and 2006. Much of the acceleration in growth can be attributed to an acceleration in growth in Asia, notably in China and India (which dominate the population-weighted average for Asia, and also carry considerable weight on the global scale). Regarding the (cor)relation of GDP growth and growth in life expectancy, we note that periods of strong growth in individual countries – e.g., China (1973–90 and 1990–2006, India (1990–2006), Vietnam (1990–2006), or Botswana (1973–1990) – were not characterized by high rates of growth of life expectancy, suggesting that there is no simple causal relationship, going either way, between GDP per capita and life expectancy.[126]

[126] This point is further elaborated by Deaton (2003, also providing a comprehensive discussion of relevant literature) and Deaton (2006).

Table 2. Contributions of GDP per Capita and Life Expectancy to Living Standards, Selected Countries and Regions, 1950–2006

	1950–1973				1973–1990				1990–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Bangladesh	-0.4	0.9	3.5	3.1	1.5	1.1	4.0	5.5	3.3	0.9	3.3	6.6
Brazil	3.7	0.8	2.9	6.6	1.4	0.6	2.3	3.7	1.3	0.5	1.7	3.1
China,P.R.: Mainland	2.9	2.2	8.2	11.0	4.8	0.4	1.6	6.4	7.1	0.3	1.0	8.1
India	1.4	1.5	5.6	7.0	2.5	0.9	3.5	6.0	4.5	0.5	1.9	6.4
Indonesia	2.6	1.4	5.0	7.6	3.1	1.3	4.8	7.9	2.8	0.6	2.2	5.0
Mexico	3.2	1.0	3.8	7.0	1.4	0.7	2.7	4.0	1.5	0.3	1.1	2.5
Nigeria	2.7	0.8	3.0	5.7	-1.0	0.6	2.1	1.1	1.1	-0.1	-0.2	0.9
Pakistan	1.7	0.9	3.3	5.0	3.1	0.8	3.0	6.1	2.4	0.6	2.1	4.5
Philippines	2.7	1.0	3.6	6.3	0.7	0.7	2.6	3.3	1.5	0.5	1.8	3.3
Russia	n.a.	0.3	1.2	n.a.	1.0	-0.1	-0.4	0.5	-0.1	-0.3	-1.1	-1.2
South Africa	2.2	0.9	3.3	5.5	-0.3	0.8	2.9	2.6	1.4	-1.2	-4.3	-2.9
Vietnam	1.0	1.1	4.0	5.1	1.3	1.5	5.7	7.0	5.7	0.5	1.9	7.7
Botswana	5.2	0.8	3.0	8.2	6.3	0.7	2.6	9.0	3.4	-1.4	-5.1	-1.7
Namibia	2.1	1.3	4.7	6.8	-0.4	0.8	2.9	2.5	2.0	-0.9	-3.4	-1.4
Swaziland	5.1	0.9	3.3	8.4	0.4	0.9	3.5	3.9	0.8	-1.9	-7.0	-6.2
Zambia	2.1	0.9	3.2	5.3	-1.5	-0.2	-0.7	-2.3	-0.1	-0.8	-3.1	-3.2
North Africa	1.7	1.0	3.8	5.5	3.0	1.1	4.2	7.2	1.7	0.7	2.4	4.1
Sub-Saharan Africa	1.8	0.9	3.4	5.2	-0.8	0.6	2.1	1.3	1.2	0.0	-0.1	1.1
Latin America and Caribbean	2.9	0.9	3.3	6.2	1.0	0.7	2.5	3.5	1.5	0.4	1.5	3.0
North America	2.5	0.2	0.7	3.2	1.9	0.3	1.1	3.0	1.7	0.2	0.8	2.5
Asia	2.6	1.7	6.1	8.7	3.4	0.7	2.7	6.1	5.0	0.4	1.6	6.5
Eastern Europe	n.a.	0.5	2.0	n.a.	0.7	0.1	0.3	1.0	0.8	0.0	0.1	0.9
Europe, excluding Eastern Europe	4.3	0.3	1.3	5.6	2.1	0.3	1.2	3.3	1.6	0.3	1.1	2.6
World, excluding Eastern Europe	2.8	1.3	4.6	7.4	2.6	0.7	2.4	5.0	3.8	0.4	1.3	5.1

Sources: Author's estimates and calculations, as described in text, based on data from Maddison (2004) and United Nations Population Division (2007). Regional averages are weighted by population size. For aggregation purposes, former member states of the USSR are assigned to Eastern Europe. Aggregates exclude former Yugoslavia and successor states. To ensure comparability between periods, the global average does exclude Eastern Europe, where estimates of GDP growth are unavailable for the 1950–73 period. A full set of country-level estimates is available in Appendix Table 3

The country-level estimates also allow us to interpret developments in regions or countries where life expectancy evolved notably differently from global trends. For Eastern Europe, we see that improvements in life expectancy played a very limited role, with a contribution to the growth of living standards of 0.3 percentage points in 1973–1990 and 0.1 percentage points in 1990–2006, and life expectancy actually declined in key economies in the region (Russia and Ukraine, see Appendix Table 3) both in 1973–1990 and in 1990–2006.

The other significant adverse health event identified above is the impact on life expectancy of the evolving HIV epidemic, notably in sub-Saharan Africa, which results in a stagnation in average life expectancy in the region in 1990–2006 (a decline of 0.3 percent, or 0.02 percent annually). However, in line with the wide discrepancies in HIV prevalence in the region,[127] the impact of HIV/AIDS is also very uneven, and the average masks very serious declines in life expectancy in some countries, while life expectancy increased in others. For the 5 countries with high HIV prevalence included in Table 2, the increases in mortality and associated declines in life expectancy were of a magnitude to wipe out any increases in living standards owing to increased GDP per capita, and in two cases (South Africa and Swaziland), the impact of declining life expectancy was enough to wipe out any improvements in living standards achieved since 1973.

E. Impact of HIV/AIDS

The economic and development impact of HIV/AIDS has received considerable attention, not only because of the serious impact of HIV/AIDS on mortality, life expectancy, and other health indicators, but also because the impact of the epidemic has been most pronounced in countries with a relatively low level of economic development, thus frustrating or reversing efforts to improve living standards in these countries, and because the impacts of HIV/AIDS within countries are generally more pronounced for population groups which are also economically vulnerable.

[127] According to UNAIDS (2006), which includes the estimates of HIV prevalence underlying the demographic estimates used here, HIV prevalence among the population of ages 15–49 in sub-Saharan Africa ranged from less than 1 percent to 33 percent at end-2005.

With these considerations in mind, we expand our analysis of the impact of HIV/AIDS on living standards in two directions. First, in order to assess the impact of HIV/AIDS, it is necessary to base the analysis on a well-defined counterfactual, i.e., a scenario that excludes the impact of HIV/AIDS. Our analysis is therefore based on the data and estimates compiled by the United Nations Population Division (2007b), which includes a counterfactual "No-AIDS" scenario. Second, we complement the analysis of the impacts of HIV/AIDS on the rate of growth of living standards with an assessment of its overall (i.e., accumulated) welfare effects, obtaining estimates of the welfare costs of HIV/AIDS in relation to the level of GDP per capita.

Context

The analysis builds on or relates to several earlier studies of the "welfare effects of HIV/AIDS," such as Jamison, Sachs, and Wang (2001), Crafts and Haacker (2003, 2004), and Philippson and Soares (2005). As the study of the impact of HIV/AIDS involves the analysis of extreme changes in life expectancy, it also represents a robustness test of the different approaches used to analyzes the implications for living standards of changes in mortality or life expectancy.

Jamison, Sachs, and Wang (2001) adopt a linearized approach similar to Nordhaus (2003). As pointed out in the presentation of our analytical framework, this linearized approach – while representing a convenient reduced form that is useful in some circumstances – can yield biased estimates if applied over periods involving large changes in life expectancy (as the theoretical analysis suggests that a log-linear specification is more appropriate). In case of HIV/AIDS, the magnitude of the observed declines in life expectancy means that the cost of HIV/AIDS, as measured by an "equivalent variation" in income, may exceed total income in countries with very high rates of HIV prevalence. Adopting a log-linear specification, as our study, and similar to the Crafts and Haacker (2003, 2004), yields a similarly convenient reduced form that avoids the shortcomings of the linear(ized) approach adopted by Nordhaus (2003) or Jamison, Sachs, and Wang (2001).

The key difference to the work by Philippson and Soares (2005) regards the specification of the utility function. As observed earlier, Philippson and Soares (2005) adopt a specification in which the value of statistical life declines with the level of income, turning negative for very low levels of income (US$353 at 1996 prices and purchasing power parity). As noted earlier, we find that this specification is unsuitable for the study of the economic impacts of HIV/AIDS. Not only is it inconsistent with evidence on well-being from developing countries (see, for example, Deaton (2007), it also means that increased mortality would not have an adverse impact on well-being for a large proportion of the population in many countries with high HIV prevalence. As argued above, the poverty line of $1 in 2005 prices from Chen and Ravallion is a fairly good approximation of the threshold below which the utility flow from being alive turns negative in the study by Philippson and Soares (2005). This would mean that for 39 percent of the population in sub-Saharan Africa (as of 2005), the welfare impact of HIV/AIDS would be neutral or positive as it shortens the disutility from being alive, which is an unacceptable proposition for empirical (Deaton, 2007) and ethical reasons.[128]

One "strategic" choice we make at the outset regards the weighting of welfare losses by age and population groups. We measure the impact of HIV/AIDS on living standards through its impact on life expectancy at birth. Some of the theoretical and applied literature (e.g., Arthur (1981), Rosen (1988), Cutler and Richardson (1998, 1999), and Murphy and Topel (2006)) emphasizes the age-dependence of the value of statistical life – the shorter the remaining life span, the lower the utility derived from it. Some researchers (e.g., Crafts and Haacker (2004), or Philippson and Soares (2005)) therefore base their estimates of the impacts of HIV/AIDS on living standards on suitably weighted population averages, with Crafts and Haacker (2004) applying a one-man-one-vote principle, assigning the same weight to each individual, and Philippson and Soares (2005) deriving the weights from the remaining lifetime utility.

In the present study, while recognizing the value of the alternative approaches, we focus on life expectancy at birth (as Jamison, Sachs, and Wang (2001), alternative estimates in Crafts and Haacker (2004), and much of the literature analyzing long-term changes in living

[128] On the ethical dimension, see the literature on the concept of "life unworthy of life," for example Glass (1997) or Binding and Hoche (1920).

standards, such as Nordhaus (2006)), based on three considerations.[129] First, the age structures across the countries we analyze differ considerably, notably reflecting differences in birth and population growth rates. Differences across countries in the estimated impact of HIV/AIDS, weighted by the size of population age-cohorts, therefore reflect both health and demographic variables, and are difficult to interpret. Second, the quality of demographic data in many of the countries of interest is weak, and the estimates at our disposal are generated from generic demographic models fitted to the limited data available for the respective countries. The use of indirectly generated demographic variables thus compounds the complexities of interpreting the differences in (estimated) age structures across countries.[130] Third, HIV/AIDS-related mortality, by thinning out the cohorts in which the impacts of HIV/AIDS are most pronounced, mitigates the adverse impacts of HIV/AIDS (weighted by the size of age-cohorts) on living standards over time, adding another layer of complexity to the interpretation of estimates of the impacts of HIV/AIDS on living standards, weighted by the size of age-cohorts.

On a technical level, focusing on life expectancy at birth thus normalizes the estimates of the impacts of HIV/AIDS on living standards with respect to the three elements just described.[131] In terms of analytical substance, our analysis provides a "cleaner" measure of the implications of the health impacts of HIV/AIDS, over the life span of a representative individual.

One remaining problem that is particularly relevant for the analysis of the economic and development impacts of HIV/AIDS, as it primarily regards low- and middle-income countries, is the "extrapolation" issue discussed earlier. As there is very little direct evidence

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[129] Additionally, we take note of the complexities of deriving appropriate weights, an issues that we cannot adequately discuss within the scope of the present study.

[130] For a discussion of the pitfalls of using generated demographic variables in economic analysis, in a somewhat different context, see Deaton (2006).

[131] An alternative approach, with similar advantages (and disadvantages) as our analysis based on changes in life expectancy at birth, involves using life expectancy at a certain age (e.g. 15) as a benchmark. See Crafts and Haacker (2004) for an example.

on the value of statistical life in low-and middle-income countries, our analysis, regarding the weight of changes in life expectancy in living standards, amounts to out-of-sample projections, i.e., it is subject to large margins of error.

Estimates of the Impact of HIV/AIDS Across Countries

Our estimates of the adverse impacts on living standards of reduced life expectancy owing to HIV/AIDS are based on demographic estimates, including a counterfactual "no-AIDS" scenario, obtained from United Nations Population Division (2007b). These estimates are based on a complex demographic model explicitly incorporating the impact of HIV/AIDS. Underlying assumptions regarding the impact of HIV/AIDS are presented in the Appendix; the estimates incorporate the latest available information regarding the impact of and access to antiretroviral treatment, this is important as improved access to antiretroviral treatment can make a significant impact on HIV/AIDS-related mortality.

To illustrate the implications of benchmarking trends in life expectancy against a counterfactual scenario, rather than just measuring actual declines in life expectancy, Figure 2 illustrates the estimates of trends in life expectancy (actual and according to the "no-AIDS" scenario) for Tanzania (with an HIV prevalence rate among the population of ages 15–49 of 6.5 percent as of end-2005) and South Africa (with an HIV prevalence rate of 18.8 percent), according to UNAIDS (2006).[132] Clearly, an analysis based on changes in actual life expectancy, rather than changes relative to a no-AIDS scenario, would severely underestimate the impact of the epidemic, especially for countries with relatively low HIV prevalence.

[132] Estimates of HIV prevalence were updated in UNAIDS (2008). For Tanzania and South Africa, the earlier estimates of HIV prevalence (see UNAIDS, 2006) underlying the estimates in United Nations Population Division (2007b) are very close to the updated ones.

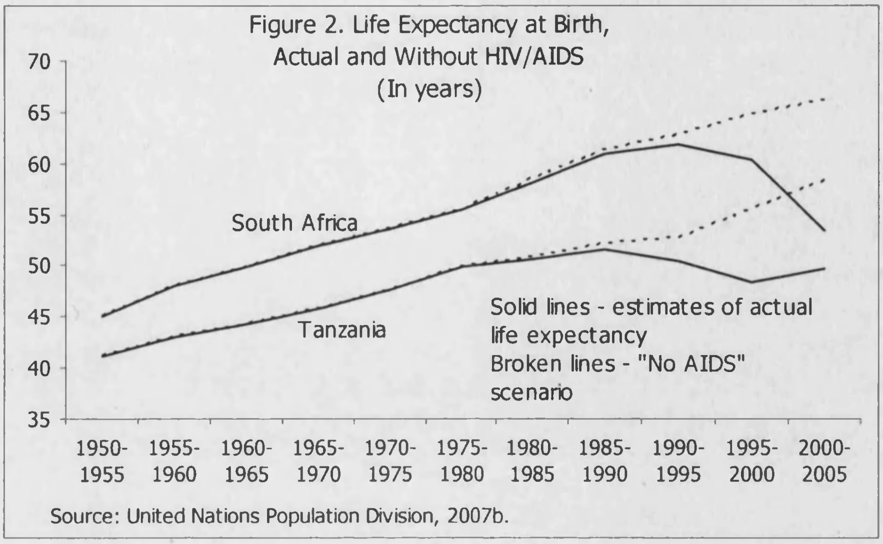

Figure 2. Life Expectancy at Birth, Actual and Without HIV/AIDS (In years)

Source: United Nations Population Division, 2007b.

Table 3 summarizes our estimates of the impacts of increased mortality owing to HIV/AIDS on living standards.[133] For sub-Saharan Africa, life expectancy at birth declines by 7 years relative to a no-AIDS scenario, from 55.6 to 48.8 years, translating into a loss in living standards equivalent to 38 percent of GDP. For some of the countries with very high HIV prevalence, the losses are much more pronounced, exceeding 70 percent for Botswana, Lesotho, Swaziland, Zambia, and Zimbabwe.

These losses may appear extreme at first sight. It is important, however, to recognize that the underlying changes in mortality and life expectancy are extremely large, as well. For many countries in sub-Saharan Africa, HIV/AIDS has reduced life expectancy to the vicinity of levels which were common in 1950 (or falling below them in Botswana, Zambia, and Zimbabwe).[134] An analogy from a different context may also be helpful to illustrate the

[133] For each region, Table 3 shows a mix of countries with relatively high HIV prevalence and countries with large populations. China and India, which would "qualify" based on population size, are not covered, the former because of limited data and very low estimated HIV prevalence, the latter because ongoing substantial revisions in the estimates of the number and composition of people living with HIV/AIDS in India imply that the estimates by United Nations Population Division are now obsolete. For a discussion of estimates of the dmeographic impact of HIV/AIDS and its implications in India and other Asian countries, see Haacker (2008).

[134] United Nations Population Division (2007) estimates that life expectancy at birth in 1950–55 was 37.6 years in sub-Saharan Africa, and 44.7 years in Southern Africa.

magnitude of the losses in life expectancy experienced in Africa – the declines experienced in some severely afflicted countries, from life expectancies above 60 years to life expectancies in the vicinity of 40 years, corresponds to the (reversal of) the gains experienced by some of the industrialized countries discussed earlier between 1870 and 1950, or the (reversal of) the gains experienced in these countries between 1913 and 2006 in relative terms.[135]

Table 3. Impact of HIV/AIDS on Living Standards (Levels), Selected Countries

Country	HIV Prevalence	Life Expectancy		Welfare Loss
	(In percent of population, age 15–49, end-2005)[1]	(In Years, without AIDS, 2000–05)	(In Years, actual, 2000–05)	(Level change by 2000–05, in percent of GDP
Sub-Saharan Africa	5.2 (6.1)	55.6	48.8	-38.3
Botswana	24.9 (24.1)	67.1	46.6	-73.8
DRC	n.a. (n.a.)	48.0	45.0	-21.4
Ethiopia	2.1 (n.a.)	53.2	50.7	-16.0
Kenya	7.1 (6.1)[2]	60.5	51.0	-46.7
Lesotho	23.4 (23.2)	63.9	44.6	-73.4
Malawi	12.3 (14.1)	61.5	45.0	-68.3
Mozambique	12.2 (16.1)	52.9	44.0	-49.3
Namibia	15.3 (19.6)	68.3	51.5	-64.6
Nigeria	3.2 (3.9)	49.0	46.6	-16.6
South Africa	18.2 (18.8)	66.1	53.4	-54.5
Swaziland	26.4 (33.4)	63.6	43.9	-74.6
Tanzania	6.4 (6.5)	58.3	49.7	-44.5
Zambia	15.0 (17.0)	54.8	39.2	-70.9
Zimbabwe	19.0 (20.1)	65.7	40.0	-84.0
Thailand	1.4 (1.4)	70.9	68.6	-11.7
Myanmar	0.8 (1.3)	61.4	59.9	-8.9
Russia	1.1 (1.1)	64.9	64.8	-0.5
Ukraine	1.5 (1.4)	68.1	67.6	-2.6
Brazil	0.6 (0.5)	71.5	71.0	-2.3
Haiti	2.2 (3.8)	64.2	58.1	-30.7
Honduras	0.7 (1.5)	71.0	68.6	-11.9

[1] Estimates of HIV prevalence shown first are from UNAIDS (2008), estimates from UNAIDS (2006), on which the estimates of life expectancy are based, are shown in brackets.
[2] For Kenya, UNAIDS (2008) does not offer a point estimate. The number shown is the midpoint of the upper- and lower-range estimates (6.1 percent and 8.1 percent, respectively).
Source: UNAIDS (2008, 2006), United Nations Population Division (2007), and author's estimates.

[135] The unweighted averages of life expectancy for the set of 17 industrialized countries covered in Appendix Table 2 are 40.1 years (1870), 51.0 years (1913), 68.3 years (1950), and 80.1 years (2006). A reversal of the gains between 1870 and 1950 would imply a decline in life expectancy of 28 years or 41 percent, a reversal of the gains between 1913 and 2006 would imply a decline of 29 years or 36 percent.

Table 3 also illustrates that the consequences of HIV/AIDS for living standards are by no means negligible for the countries with relatively low HIV prevalence rates. For example, in Ethiopia, with an estimates HIV prevalence rate of about 2 percent, a loss in life expectancy of 2.5 years translates in to a welfare loss equivalent to 16 percent of GDP, and for Thailand (HIV prevalence: 1.4 percent), life expectancy declines by 2.3 years, corresponding to a loss in living standards equivalent to 12 percent of GDP.

Impact on Growth Rates

The preceding section analyzes the size of the impact of HIV/AIDS on living standards. As the impact of HIV/AIDS evolves over time, this perspective can usefully be complemented by an analysis of the contribution of HIV/AIDS to changes in living standards over time, notably in relation to the growth rate of GDP per capita. To this end, Table 3 summarizes the estimates of the contributions of growth of GDP per capita and life expectancy to living standards over the period 1990–2005, in which the impact of HIV/AIDS on mortality escalated in many countries.

For sub-Saharan Africa overall, HIV/AIDS has been a drag on the growth rate of living standards. While GDP per capita increased at a modest rate of 0.6 percent, life expectancy declined modestly, so that the living standards improved only at a rate of 0.4 percent annually. However, the apparently modest masks two development going in opposite directions – considerable improvements in public health which made a substantial positive contribution to living standards , but which got more than offset by the adverse impact of HIV/AIDS.

For sub-Saharan countries featuring high prevalence rates (disproportionally represented in Table 3), the period of 1990–2005 appears as one of declining living standards, with HIV/AIDS more than offsetting gains in GDP (or, in some countries, exacerbating a decline owing to negative growth of GDP per capita). In the two Asian countries covered, the role of improvements in life expectancy (with or without the impact of HIV/AIDS) was limited compared to the contributions of fairly high rates of growth of GDP per capita. In Russia and Ukraine, declining life expectancy exacerbated the decline in GDP, but HIV/AIDS played a minor role in this. Interestingly, Brazil shows a positive "contribution" to the growth of life expectancy from HIV/AIDS, which reflects early and comprehensive health sector response and near complete access to antiretroviral treatment, which have reduced HIV/AIDS-related mortality in Brazil between 1990 and 2005.[136]

Table 4. Impact of HIV/AIDS on the Growth of Living Standards, Selected Countries

Country	Growth of GDP per capita	Growth in Life Expectancy	Of which: HIV/ AIDS	Growth in Living Standards	Of which: HIV/ AIDS
	(In percent, annual average, 1990–2005)	(In percent, annual average, 1990–2005)	(In percent, annual average, 1990–2005)	(In percent, annual average, 1990–2005)	(In percent, annual average, 1990–2005)
SSA	0.6	-0.05	-0.6	0.4	-2.2
Botswana	3.9	-1.7	-2.0	-2.5	-7.2
DRC	-5.3	-0.1	-0.2	-5.7	-0.7
Ethiopia	1.1	0.6	-0.2	3.3	-0.9
Kenya	-0.4	-0.8	-0.9	-3.3	-3.1
Lesotho	1.9	-1.9	-2.5	-5.3	-9.3
Malawi	0.3	-0.2	-1.8	-0.6	-6.6
Mozambique	3.2	-0.1	-1.5	3.0	-5.5
Namibia	2.0	-1.1	-1.8	-2.0	-6.5
Nigeria	1.0	-0.1	-0.4	0.7	-1.3
South Africa	0.6	-1.2	-1.7	-3.8	-6.1
Swaziland	0.3	-2.2	-2.8	-7.8	-10.2
Tanzania	1.3	0.01	-0.8	1.3	-2.8
Zambia	-0.3	-1.1	-1.5	-4.5	-5.6
Zimbabwe	-2.7	-2.5	-2.6	-12.0	-9.7
Thailand	3.6	0.3	-0.1	4.7	-0.5
Myanmar	6.2	0.2	-0.2	7.1	-0.6
Russia	-2.4	-0.2	-0.03	-3.3	-0.1
Ukraine	-0.4	-0.2	-0.1	-1.0	-0.3
Brazil	1.1	0.5	0.02	3.0	0.1
Haiti	-2.8	0.6	-0.4	-0.6	-1.4
Honduras	1.1	0.4	-0.1	2.5	-0.4

Source: Authors estimates, based on data from World Bank (2008) and United Nations Population Division (2007b). Data may not add up across columns due to rounding. For life expectancy, growth rates are based on "point estimates" for 1990 and 2005 approximated as averages for the surrounding periods (1985–90 and 1990–95 for 1990, and 2000–05 and 2005–10 for 2005) from United Nations Population Division (2007b). The impact of HIV/AIDS on growth rates of life expectancy is calculated as the difference in growth rates between the estimates of actual life expectancy and the "no AIDS" counterfactual scenario from United Nations Population Division (2007b).

[136] On access to antiretroviral treatment in Brazil and other countries, see WHO, UNAIDS, and UNICEF (2008).

Implications of Access to Antiretroviral Treatment

One important extension of the analysis of the impacts of HIV/AIDS summarized in Table 3 is an assessment of the potential of increased access to antiretroviral treatment to mitigate these impacts. These are already partly reflected in the estimates of life expectancy shown in Table 3, although the impact presumably is rather small as access to antiretroviral treatment in developing countries substantially accelerated only towards the end of the 2000–2005 period (see WHO and UNAIDS (2006), and WHO, UNAIDS, and UNICEF (2008)).

While a full analysis is beyond the scope of this paper, as we do not have estimates of the impact of HIV/AIDS on life expectancy identifying the impact of antiretroviral treatment, we can nevertheless provide a numerical example based on the assumptions regarding the impact of antiretroviral treatment used in United Nations Population Division (2007), which are summarized in the Appendix. Overall, we assume that antiretroviral treatment extends the life expectancy of an individual living with HIV/AIDS by 8 years.[137] In a country with an HIV prevalence rate of 15 percent, it is a reasonable approximation that 30 percent of a new cohort will become infected over their life span.[138] Assuming a coverage rate of antiretroviral treatment of 80 percent, once required, life expectancy for 24 percent of a new cohort increases by 8 years, i.e., life expectancy at birth increases by about 2 years. This is a relatively small reversal compared to the losses in life expectancy reported in Table 3, which shows declines in life expectancy, at similar HIV prevalence rates as the 15 percent assumed for the numerical example, of between 9 years (Mozambique) and 16 years (Malawi).

A different way of calculating the impact of comprehensive access to antiretroviral treatment on life expectancy is based on available burden of disease indicators. Lopez and others (2006), in an authoritative study supported by the World Bank and the WHO, estimate

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[137] This is obtained based on an estimated increase in the average lifespean of 7.5 years for adults (accounting for about 90 percent of people living with HIV/AIDS) and between 5.5 and 18 years for children.

[138] The share of people expected to become infected over their life span is much higher than the commonly quoted HIV prevalence rate for the population of ages 15–49, as the latter does not include infected children who die before adulthood, adult members of a cohort who have already died, and adults who statistically can be expected to become infected in the future.

that an HIV/AIDS-related death on average cost 36 life years. Access to antiretroviral treatment reduces the expected loss in life years for an individual to 28 years; assuming a coverage rate of 80 percent, the average expected loss in life years per person infected would fall by 6.4 years to just under 30 years.

Motivated by the latter example, we assess the potential reversal in the impact of HIV/AIDS on living standards associated with comprehensive access to antiretroviral treatment for selected countries covered in Table 3, assuming that comprehensive treatment reduces the decline in life expectancy by 18 percent (6.4 years of saved life years, divided by 36 years without antiretroviral treatment).[139]

Table 5. Potential Impact of Antiretroviral Treatment

	Actual		Comprehensive Treatment		Difference "Treatment" vs. "Actual"[1]	Gains from Treatment[1]
	Loss in...		Loss in...			
Country	Life Expectancy	Living Standards	Life Expectancy	Living Standards	Living Standards	Living Standards
	(Years)	(Percent of GDP)	(Years)	(Percent of GDP)	(Percent of GDP)	(Percent of GDP)
Sub-Saharan Africa	-6.8	-38.3	-5.6	-32.5	5.9	9.5
Lesotho	-19.3	-73.4	-15.9	-65.1	8.3	31.4
Malawi	-16.5	-68.3	-13.6	-60.0	8.3	26.2
Mozambique	-8.9	-49.3	-7.3	-42.2	7.1	13.9
Namibia	-16.8	-64.6	-13.8	-56.4	8.2	23.0
Nigeria	-2.4	-16.6	-1.9	-13.8	2.8	3.3
South Africa	-12.7	-54.5	-10.5	-47.0	7.5	16.5
Swaziland	-19.8	-74.6	-16.3	-66.2	8.3	32.8
Tanzania	-8.6	-44.5	-7.1	-38.0	6.6	11.8
Zambia	-15.6	-70.9	-12.8	-62.6	8.3	28.6
Zimbabwe	-25.8	-84.0	-21.2	-76.1	7.9	49.0

[1] "Difference 'Treatment vs. Actual'" is expressed in terms of the costs of HIV/AIDS (relative to a counterfactual with no AIDS). "Gains from Treatment" are defined relative to the reduced level of living standards in the absence of treatment, and are derived as 100 times "Difference 'Treatment vs. Actual,'" divided by (100 minus the percentage loss in living standards from "actual" scenario).
Source: United Nations Population Division (2007), and author's estimates. Table 5 does not provide estimates for Botswana, as our estimates of the impacts of HIV/AIDS on life expectancy for otswana, much more than for other countries in the region, already include an impact of antiretroviral treatment

[139] One caveat regarding our analysis regards the role of antiretroviral treatment in the estimates of actual life expectancy in 2000–05 on which our illustrative scenario is based does already incorporate some small impact of antiretroviral treatment, and the "comprehensive treatment" scenario may therefore include some double-counting. However, these sources in bias in the respective scenarios cancel out in our measures of the potential *impact* of antiretroviral treatment, which is based on the *difference* between the two scenarios.

Table 5 shows that the benefits from comprehensive access to treatment are substantial. For Sub-Saharan Africa as a whole, comprehensive treatment mitigates the impact of HIV/AIDS on living standards by 5.9 percentage points, which translates into a gain from treatment of 9.5 percent of GDP. For many countries with high HIV prevalence, the gains that can be achieved with comprehensive access to treatment exceed 20 or even 30 percent of GDP, and reach close to 50 percent of GDP in one case.

The bad news is that the costs of HIV/AIDS remain very substantial, even in a comprehensive treatment scenario. A welfare improvement equivalent to 50 percent of GDP is fantastic, but not so much if it raises living standards by 50 percent from a level at which it is depressed by 84 percent owing to a massive increase in mortality, to a level at which living standards are reduced by "only" 76 percent.

In addition to an assessment of the welfare gains associated with comprehensive access to antiretroviral treatment (which we find to be large, but – at the same time – small relative to the overall welfare costs of the impact of HIV/AIDS) thus also provides insight regarding the roles of prevention programs. Returning to our example of a country with an HIV prevalence rate of 15 percent, in which 30 percent of a new cohort can be expected to become infected over their life span, we see that HIV/AIDS may reduce life expectancy by 10.8 years (assuming that an HIV/AIDS-related death costs 36 life years, as estimated by Lopez and others (2006). Comprehensive access to treatment, with a coverage rate of 80 percent, mitigates the loss in life expectancy to 8.9 years (if antiretroviral treatment extends life expectancy by an average 8 years). The same gain be achieved by a program that succeeds in preventing 18 percent of new infections, reducing the probability of becoming infected from 30 percent to just under 25 percent.

F. Conclusions

The present paper covers some methodological ground regarding measuring the contributions of increased life expectancy to living standards, based on the literature on the value of statistical life and its macroeconomic interpretations, and discusses the contribution of increased life expectancy to living standards in three different contexts.

Methodologically, we build an explicit framework that – we argue – has certain advantages compared to other recent studies, as it provides a reduced form well-suited for analyzing periods characterized by substantial changes in life expectancy. One objective of our analysis is a meaningful analysis of changes in life expectancy on a global scale, including in low-income countries, and we address some shortcomings in the existing literature in this direction as well.

Regarding the contributions to living standards of increased life expectancy over a long period of economic development in 17 of toady's leading industrialized economies, we find that the contributions of increased incomes and improved health to living standards were roughly even over the 1870–2006 period. The relative importance of increasing income and improved health, however, have shifted after 1950. While improvements in living standards were primarily driven by improved health before 1950, growing GDP per capita accounted for most of the improvements since then. Further, improvements in health showed less volatility and appeared to follow a common trend across countries, suggesting that the factors driving health improvements are different from factors driving GDP growth, and that there is no simple relationship between GDP per capita and health attainments.

Based on a larger sample of 136 countries from 1950, we find that improvements in life expectancy played a major part in rising living standards in the 1950–73 period, but the contribution of increased life expectancy declines in subsequent periods. This pattern would be consistent with a delayed dissemination of health innovations which already had a major impact in the leading industrialized countries between 1913 and 1950. The most recent acceleration in the growth of GDP per capita globally (1990–2006) can be attributed to an acceleration in growth in Asia, notably in China and India. Regarding the (cor)relation of GDP growth and growth in life expectancy, we find that periods of strong growth in individual countries were not characterized by high rates of growth of life expectancy, reinforcing our earlier point that suggesting that there is no simple causal relationship, going either way, between GDP per capita and life expectancy.

The analysis of the adverse impact of HIV/AIDS – which already showed as an extraordinary health development in our analysis of global trends – suggests that living standards have fallen in many countries in sub-Saharan Africa, with losses in life expectancy more than offsetting any gains in GDP per capita, and that the average losses to living standards in sub-Saharan Africa may be as high as 38 percent of GDP. One feature of our analysis that is new relative to earlier work is a discussion of the implications of improved access to treatment and of HIV prevention for the impact of HIV/AIDS. We find that improved access to treatment (an assumed coverage rate of 80 percent) does mitigate the adverse impacts of HIV/AIDS, but only at a rate that would correspond to a successful prevention of 18 percent of new infections.

We see the principal shortcomings of the approach adopted in the present study in two areas. First, our measure of the contributions of increased income and increased life expectancy is based entirely on outputs of the development process and of other (e.g. health) factors. The perspective is thus one of accounting for changes in living standards, without addressing factors driving the changes in income or life expectancy. To obtain a fuller accounting of the role of increased income or higher life expectancy to living standards, it would therefore be necessary to gain a better understanding of the interactions between income ad health, and of factors that may be driving both. The limited evidence in this direction that we present in the present study suggests that this would be a complex exercise.

Second, while the approach taken in the present study has clear advantages compared to other approaches addressing ht e contribution of health to living standards, as it is based on an explicit microeconomic framework, the weak evidence regarding the underlying estimates of the value of statistical life is a matter of concern for our purposes. Notably, most of the empirical literature is based on data from industrialized countries and a few middle-income countries. Adapting such estimates to a global scale, as we do, therefore corresponds to out-of-sample projection, implying that the margin of error of our estimates is large.

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H. Appendix. Assumptions Regarding Demographic Impact of HIV/AIDS

Owing to limited availability of data, and the rapidly evolving situation regarding the availability of antiretroviral treatment, estimating the impacts of HIV/AIDS on mortality and other demographic variables is complex and subject to considerable uncertainties. The estimates by the United Nations Population Division (2007b) that our analysis draws from are based on the latest recommendations by the UNAIDS Reference Group on Estimates, Modelling and Projections, and are in turn used by UNAIDS in their publications. Below, we summarize some of the key assumptions underlying the estimates, especially regarding the availability and impact of treatment, as documented in United Nations Population Division (2007a).

The estimates by the United Nations Population Division (2007b) that we are using draws on country-level data on HIV prevalence which are used to determine parameters of a model describing the dynamics of the epidemic in the respective countries so far. In addition to to the parameters describing the scale and the dynamics of the epidemic, a key determinant of HIV/AIDS-related mortality is the coverage of various forms of treatment. Based on data from WHO and UNAIDS (2006), the proportion of adults receiving treatment averages 25 percent for the countries for which United Nations Population Division (2007b) provides estimates of the demographic impact of HIV/AIDS, and ranges from 0 percent to 100 percent. Antiretroviral treatment extends the mean survival time from 2 years to 9.5 years after the initiation of treatment, which is assumed to occur at the time the full symptoms of AIDS develop.

A second important demographic effect of antiretroviral treatment is a reduction in a number of children born HV-positive, as treatment substantially reduces the probability of mother-to-child transmission of the virus (to around 1 percent). For infected children (in utero or through breast-feeding), the average survival time with treatment is assumed to be 19.5 years, which compares to 1.3 years for children infected in utero, and 14 years for children infected through breast-feeding. Coverage rates of pediatric treatment average 9 per cent in 2005 but vary between 0 and 99 per cent among the 62 countries covered by the United Nations Population Division.

Appendix Table 1. GDP per Capita, 17 Countries, 1870–2006
(constant 2005 international dollars, at purchasing power parity)

	1870	1913	1950	1973	2006
Australia	4,732	7,455	10,714	18,616	34,450
Austria	3,014	5,608	5,997	18,180	34,936
Belgium	3,894	6,104	7,902	17,605	32,507
Canada	2,478	6,504	10,664	20,239	35,580
Denmark	2,773	5,415	9,610	19,302	34,590
Finland	1,563	2,894	5,832	15,198	32,002
France	2,628	4,883	7,387	18,377	31,005
Germany	2,945	5,841	6,214	19,160	31,324
Italy	2,211	3,779	5,163	15,678	28,156
Japan	1,019	1,917	2,655	15,805	30,961
Netherlands	4,283	6,290	9,317	20,326	35,431
Norway	2,595	4,531	9,898	20,375	48,532
Spain	1,974	3,362	3,580	12,528	27,765
Sweden	2,362	4,401	9,580	19,180	33,137
Switzerland	3,273	6,641	14,111	28,341	36,046
United Kingdom	4,564	7,039	9,927	17,202	32,066
United States	3,402	7,377	13,306	23,226	42,610
Average	2,924	5,296	8,344	18,785	34,182

Sources: World Bank (2008) for 2006, authors calculations, based on Maddison (2004) and World Bank (2006) for earlier years

Appendix Table 2. Life Expectancy at Birth, 17 Countries, 1870–2006

	1870	1913	1950	1973	2006
Australia	48.0	59.1	69.6	71.7	81.0
Austria	31.7	42.2	65.7	70.5	79.8
Belgium	40.0	49.6	67.5	71.4	79.5
Canada	42.6	52.5	69.1	73.1	80.4
Denmark	45.5	57.7	71.0	73.6	78.1
Finland	36.5	46.2	66.3	70.7	79.2
France	42.0	50.4	66.5	72.4	80.6
Germany	36.2	49.0	67.5	70.6	79.1
Italy	28.0	47.2	66.0	72.1	81.1
Japan	37.0	44.4	64.0	73.3	82.3
Netherlands	38.9	56.1	72.1	74.0	79.7
Norway	49.3	57.2	72.7	74.4	80.3
Spain	33.7	41.8	63.9	72.9	80.8
Sweden	45.8	57.0	71.8	74.7	80.8
Switzerland	41.0	52.2	69.2	73.8	81.5
United Kingdom	41.3	53.4	69.2	72.0	79.1
United States	44.0	51.6	69.0	71.3	77.8
Average (unweighted)	40.1	51.0	68.3	72.5	80.1

Sources: Crafts (1997) for 1870–1973, World Bank (2008) for 2006.

Appendix Table 3. Contributions of GDP per Capita and Life Expectancy to Living Standards, 136 Countries, 1950–2006

	1950–1973				1973–1990				1990–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Albania	3.6	1.0	3.8	7.4	0.5	0.3	1.3	1.8	2.1	0.4	1.3	3.4
Algeria	2.4	1.2	4.4	6.8	1.3	1.2	4.4	5.7	0.8	0.4	1.6	2.4
Angola	2.3	1.2	4.3	6.7	-4.0	0.4	1.3	-2.7	2.3	0.3	1.1	3.4
Argentina	2.1	0.4	1.3	3.4	-1.2	0.4	1.3	0.1	2.6	0.3	1.0	3.6
Armenia	n.a.	0.6	2.2	n.a.	-0.1	-0.2	-0.7	-0.8	2.4	0.3	1.0	3.4
Australia	2.4	0.2	0.6	3.0	1.7	0.4	1.5	3.2	2.1	0.3	1.1	3.2
Austria	4.9	0.4	1.3	6.2	2.4	0.4	1.5	3.9	1.5	0.3	1.2	2.7
Azerbaijan, Rep. of	n.a.	0.6	2.3	n.a.	0.3	0.0	0.1	0.3	1.7	0.1	0.5	2.2
Bangladesh	-0.4	0.9	3.5	3.1	1.5	1.1	4.0	5.5	3.3	0.9	3.3	6.6
Belarus	n.a.	0.4	1.5	n.a.	1.9	-0.1	-0.3	1.6	2.3	-0.2	-0.7	1.6
Belgium	3.5	0.2	0.9	4.4	2.1	0.3	1.3	3.3	1.7	0.3	1.0	2.7
Benin	-0.1	1.0	3.8	3.7	0.5	0.7	2.7	3.1	1.1	0.3	1.2	2.3
Bolivia	0.9	0.7	2.7	3.6	-0.4	1.3	4.9	4.5	1.5	0.6	2.2	3.6
Botswana	5.2	0.8	3.0	8.2	6.3	0.7	2.6	9.0	3.4	-1.4	-5.1	-1.7
Brazil	3.7	0.8	2.9	6.6	1.4	0.6	2.3	3.7	1.3	0.5	1.7	3.1
Bulgaria	5.2	0.5	1.9	7.1	0.3	0.0	0.1	0.4	2.0	0.1	0.3	2.3
Burkina Faso	1.6	1.6	5.7	7.3	0.5	0.8	2.9	3.5	1.9	0.2	0.8	2.7
Burundi	1.9	0.6	2.2	4.1	1.6	0.3	1.2	2.8	-1.8	0.4	1.4	-0.4
Cambodia	2.0	0.1	0.4	2.4	0.5	1.8	6.7	7.2	3.9	0.4	1.5	5.5
Cameroon	1.8	1.0	3.7	5.5	1.2	0.9	3.3	4.5	-0.1	-0.5	-1.8	-1.8
Canada	2.8	0.3	1.1	3.9	1.8	0.3	1.2	3.1	1.6	0.2	0.8	2.4
Cape Verde	0.7	0.9	3.1	3.9	5.1	0.7	2.8	7.9	3.4	0.5	1.8	5.2
Central African Rep.	0.4	1.0	3.8	4.1	-1.0	0.8	3.0	2.0	-1.2	-0.7	-2.5	-3.7
Chad	-0.4	0.9	3.3	2.9	-0.2	0.7	2.6	2.4	3.0	-0.1	-0.4	2.6
Chile	1.3	0.7	2.7	4.0	1.4	0.9	3.1	4.5	3.9	0.4	1.3	5.2
China,P.R.: Mainland	2.9	2.2	8.2	11.0	4.8	0.4	1.6	6.4	7.1	0.3	1.0	8.1
China,P.R.:Hong Kong	5.2	0.8	3.1	8.3	5.5	0.4	1.4	6.9	2.8	0.3	1.2	3.9
Colombia	2.1	1.0	3.6	5.8	1.9	0.6	2.2	4.1	1.2	0.4	1.3	2.5
Comoros	2.0	0.9	3.4	5.4	-1.5	0.8	3.1	1.6	-1.1	0.7	2.7	1.6
Congo, Republic of	2.2	1.3	4.9	7.1	0.7	0.2	0.8	1.5	0.3	-0.2	-0.8	-0.5
Costa Rica	3.5	0.9	3.2	6.6	0.6	0.6	2.2	2.8	2.7	0.2	0.8	3.5
Côte d'Ivoire	2.6	1.0	3.8	6.5	-1.9	0.4	1.5	-0.4	-0.8	-0.6	-2.2	-3.0
Croatia	n.a.	0.6	2.4	n.a.	n.a.	0.2	0.7	n.a.	1.0	0.3	1.1	2.1
Czech Republic	n.a.	0.2	0.8	n.a.	n.a.	0.2	0.6	n.a.	1.7	0.4	1.5	3.2
Denmark	3.1	0.2	0.7	3.7	1.7	0.1	0.4	2.1	1.9	0.3	0.9	2.8
Djibouti	1.7	1.2	4.5	6.1	-2.4	0.8	3.0	0.6	-1.2	0.4	1.4	0.3
Dominican Republic	3.0	1.3	4.8	7.8	1.2	0.7	2.6	3.9	3.5	0.3	1.2	4.7
Ecuador	2.5	1.0	3.6	6.1	1.0	0.9	3.3	4.3	1.1	0.5	1.8	2.9

Appendix Table 3. Contributions of GDP per Capita and Life Expectancy to Living Standards, 136 Countries, 1950–2006

	1950–1973				1973–1990				1990–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Egypt	1.5	1.0	3.7	5.2	4.0	1.1	4.1	8.1	1.8	0.8	2.9	4.7
El Salvador	2.0	1.3	4.7	6.6	-0.6	0.6	2.4	1.8	2.0	0.5	1.9	3.8
Equatorial Guinea	3.0	0.8	3.0	6.0	2.3	0.8	3.0	5.3	16.6	0.5	1.9	18.5
Estonia	n.a.	0.4	1.4	n.a.	1.3	-0.1	-0.4	0.9	3.2	0.3	0.9	4.2
Finland	4.3	0.3	1.2	5.4	2.5	0.4	1.3	3.8	2.1	0.3	1.2	3.3
France	4.0	0.4	1.5	5.6	1.9	0.3	1.3	3.2	1.3	0.3	1.1	2.3
Gabon	3.8	1.4	5.1	8.9	-2.4	1.3	4.8	2.4	-1.4	-0.4	-1.5	-2.9
Gambia, The	2.2	1.2	4.5	6.7	-0.8	1.7	6.2	5.4	0.5	0.8	3.1	3.6
Georgia	n.a.	0.6	2.2	n.a.	1.4	0.2	0.7	2.2	-2.5	0.0	0.1	-2.4
Germany	5.0	0.3	0.9	5.9	1.7	0.4	1.3	3.0	1.3	0.3	1.1	2.4
Ghana	1.0	0.7	2.7	3.6	-1.6	0.7	2.8	1.2	2.3	0.3	1.1	3.4
Greece	6.2	0.5	1.7	7.9	1.6	0.4	1.3	2.9	2.6	0.2	0.7	3.3
Guatemala	1.9	1.2	4.6	6.4	-0.4	0.9	3.1	2.8	0.8	0.7	2.4	3.3
Guinea	2.0	0.7	2.7	4.7	0.6	1.1	4.2	4.7	1.0	0.9	3.5	4.4
Guinea-Bissau	5.0	0.6	2.1	7.1	-0.6	0.9	3.2	2.6	-1.9	0.5	1.8	0.0
Haiti	-0.2	1.2	4.5	4.4	0.2	0.7	2.7	2.8	-2.2	0.6	2.2	0.0
Honduras	1.0	1.3	4.7	5.6	0.8	1.1	4.2	5.0	1.0	0.3	1.3	2.3
Hungary	3.6	0.4	1.6	5.2	0.8	0.0	0.0	0.9	2.3	0.3	1.1	3.4
India	1.4	1.5	5.6	7.0	2.5	0.9	3.5	6.0	4.5	0.5	1.9	6.4
Indonesia	2.6	1.4	5.0	7.6	3.1	1.3	4.8	7.9	2.8	0.6	2.2	5.0
Iran, I.R. of	5.1	1.0	3.8	9.0	-2.6	0.9	3.3	0.7	3.5	0.5	1.9	5.4
Ireland	3.0	0.3	1.2	4.2	3.2	0.3	1.1	4.3	5.3	0.4	1.4	6.7
Israel	5.5	0.5	1.7	7.2	1.8	0.4	1.4	3.1	1.6	0.3	0.9	2.6
Italy	4.9	0.4	1.6	6.6	2.5	0.4	1.4	3.9	1.0	0.3	1.2	2.1
Jamaica	5.1	0.8	3.0	8.1	-0.8	0.2	0.9	0.1	0.5	0.0	-0.1	0.4
Japan	8.1	0.7	2.5	10.6	3.0	0.4	1.6	4.6	1.1	0.3	0.9	2.0
Jordan	1.6	1.4	5.0	6.6	2.8	1.0	3.7	6.4	1.6	0.4	1.5	3.0
Kazakhstan	n.a.	0.7	2.5	n.a.	-0.2	0.3	1.1	0.9	1.2	-0.2	-0.7	0.5
Kenya	1.7	1.2	4.4	6.1	0.7	0.6	2.2	3.0	0.0	-0.6	-2.3	-2.3
Korea	5.8	1.4	5.1	11.0	6.8	0.7	2.7	9.5	4.7	0.6	2.1	6.8
Kyrgyz Republic	n.a.	0.7	2.7	n.a.	-0.2	0.5	1.7	1.5	-2.0	-0.1	-0.2	-2.2
Lao People's Dem.Rep	1.0	0.5	1.9	2.9	1.1	0.9	3.3	4.4	3.2	0.9	3.4	6.6
Latvia	n.a.	0.3	1.1	n.a.	1.4	-0.1	-0.4	1.0	1.0	0.1	0.5	1.5
Lebanon	1.1	0.8	2.9	4.0	-2.8	0.3	1.0	-1.8	4.2	0.2	0.9	5.2
Lesotho	3.4	0.8	3.1	6.5	2.7	0.9	3.5	6.2	3.2	-1.8	-6.7	-3.5
Liberia	1.4	0.5	1.9	3.3	-2.0	0.1	0.4	-1.6	-3.1	0.3	1.2	-1.9
Libya	9.3	1.1	3.9	13.2	-4.4	1.5	5.4	0.9	-1.5	0.5	1.8	0.3
Lithuania	n.a.	0.5	1.8	n.a.	0.8	0.0	-0.2	0.6	1.1	0.0	0.0	1.1

Appendix Table 3. Contributions of GDP per Capita and Life Expectancy to Living Standards, 136 Countries, 1950–2006

	1950–1973				1973–1990				1990–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Macedonia, FYR	n.a.	1.0	3.8	n.a.	n.a.	0.3	1.2	n.a.	-0.5	0.2	0.8	0.3
Madagascar	0.8	1.0	3.7	4.5	-2.1	0.7	2.7	0.6	-0.8	0.8	3.1	2.3
Malawi	2.5	0.7	2.6	5.1	-0.1	0.9	3.2	3.1	1.4	-0.1	-0.4	1.0
Malaysia	2.2	1.3	4.9	7.0	4.2	0.6	2.3	6.5	3.7	0.3	1.1	4.9
Mali	1.1	0.9	3.2	4.2	1.4	1.0	3.7	5.1	1.4	0.7	2.6	4.0
Mauritania	3.2	0.9	3.3	6.5	-0.3	1.0	3.6	3.3	1.6	0.6	2.2	3.8
Mauritius	1.7	1.1	3.9	5.6	4.0	0.6	2.1	6.0	3.8	0.3	1.1	5.0
Mexico	3.2	1.0	3.8	7.0	1.4	0.7	2.7	4.0	1.5	0.3	1.1	2.5
Moldova	n.a.	0.5	1.9	n.a.	0.8	0.2	0.9	1.7	-3.8	0.1	0.4	-3.4
Mongolia	3.0	1.2	4.5	7.5	2.6	0.7	2.7	5.3	0.5	0.4	1.5	2.0
Morocco	0.7	1.1	3.9	4.5	2.5	1.1	4.2	6.7	1.6	0.6	2.1	3.7
Mozambique	2.2	1.3	4.7	6.9	-3.0	0.5	1.7	-1.3	4.0	-0.2	-0.6	3.4
Namibia	2.1	1.3	4.7	6.8	-0.4	0.8	2.9	2.5	2.0	-0.9	-3.4	-1.4
Nepal	1.0	1.0	3.6	4.6	1.5	1.2	4.5	6.1	1.8	0.9	3.3	5.0
Netherlands	3.5	0.1	0.5	3.9	1.6	0.2	0.9	2.5	1.8	0.2	0.8	2.5
New Zealand	1.7	0.1	0.5	2.2	0.7	0.3	1.1	1.7	1.4	0.3	1.3	2.7
Nicaragua	2.6	1.3	4.9	7.5	-4.0	0.9	3.2	-0.8	1.1	0.7	2.5	3.6
Niger	-0.4	0.4	1.5	1.1	-1.6	0.7	2.7	1.1	-0.4	1.1	4.2	3.8
Nigeria	2.7	0.8	3.0	5.7	-1.0	0.6	2.1	1.1	1.1	-0.1	-0.2	0.9
Norway	3.2	0.1	0.4	3.6	3.0	0.2	0.7	3.7	2.4	0.3	1.0	3.4
Pakistan	1.7	0.9	3.3	5.0	3.1	0.8	3.0	6.1	2.4	0.6	2.1	4.5
Panama	3.5	0.9	3.4	6.9	0.3	0.5	1.8	2.1	2.8	0.2	0.9	3.6
Paraguay	1.1	0.2	0.9	2.0	2.9	0.2	0.6	3.5	-0.3	0.3	1.1	0.8
Peru	2.5	1.2	4.3	6.8	-1.7	1.0	3.6	1.9	2.7	0.5	1.7	4.4
Philippines	2.7	1.0	3.6	6.3	0.7	0.7	2.6	3.3	1.5	0.5	1.8	3.3
Poland	3.5	0.7	2.6	6.0	-0.3	0.1	0.2	0.0	3.7	0.3	1.3	5.0
Portugal	5.4	0.7	2.5	8.0	2.5	0.5	1.9	4.4	1.7	0.4	1.3	3.1
Romania	4.8	0.6	2.3	7.1	0.1	0.0	0.1	0.1	1.4	0.2	0.7	2.1
Russia	n.a.	0.3	1.2	n.a.	1.0	-0.1	-0.4	0.5	-0.1	-0.3	-1.1	-1.2
Rwanda	1.0	0.5	2.0	3.0	1.5	-1.6	-5.9	-4.5	0.8	2.1	7.9	8.7
Saudi Arabia	7.2	1.5	5.6	12.8	-1.1	1.3	4.9	3.8	-0.1	0.4	1.4	1.3
Senegal	0.2	1.0	3.8	4.0	0.2	1.3	4.8	5.0	1.0	0.5	1.9	2.9
Sierra Leone	2.2	0.8	2.9	5.1	-0.3	0.6	2.2	1.9	-3.9	0.5	1.7	-2.1
Singapore	4.4	0.7	2.6	7.0	5.3	0.4	1.6	6.8	3.8	0.4	1.6	5.3
Slovak Republic	n.a.	0.4	1.6	n.a.	n.a.	0.1	0.5	n.a.	2.0	0.3	1.0	2.9
Slovenia	n.a.	0.3	1.2	n.a.	n.a.	0.3	0.9	n.a.	2.4	0.3	1.3	3.7
South Africa	2.2	0.9	3.3	5.5	-0.3	0.8	2.9	2.6	1.4	-1.2	-4.3	-2.9
Spain	5.6	0.7	2.4	8.0	2.7	0.3	1.2	3.9	2.2	0.3	1.1	3.3

Appendix Table 3. Contributions of GDP per Capita and Life Expectancy to Living Standards, 136 Countries, 1950–2006

	1950–1973				1973–1990				1990–2006			
	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards	GDP per capita	Life Expectancy	Life Expectancy	Living standards
	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)	(Rate of growth)	(Rate of growth)	(Contribution to growth in living standards)	(Rate of growth)
Sri Lanka	0.8	0.6	2.2	3.0	2.9	0.4	1.5	4.4	3.8	0.3	1.1	4.9
Sudan	-0.2	0.8	2.9	2.6	-0.3	0.9	3.4	3.1	3.7	0.6	2.1	5.7
Swaziland	5.1	0.9	3.3	8.4	0.4	0.9	3.5	3.9	0.8	-1.9	-7.0	-6.2
Sweden	3.1	0.2	0.7	3.8	1.6	0.2	0.9	2.5	1.7	0.2	0.9	2.6
Switzerland	3.1	0.3	1.2	4.3	1.0	0.3	1.1	2.1	0.5	0.3	1.2	1.6
Syrian Arab Republic	2.2	1.1	4.1	6.4	2.1	1.0	3.8	5.8	2.2	0.5	1.7	3.9
Tajikistan	n.a.	0.7	2.5	n.a.	-1.9	0.2	0.9	-0.9	-4.0	0.3	1.0	-2.9
Tanzania	1.4	0.7	2.7	4.1	-0.5	0.4	1.5	1.0	1.2	0.1	0.4	1.6
Thailand	3.7	0.9	3.2	6.9	5.5	0.6	2.1	7.6	3.6	0.3	1.0	4.6
Togo	2.7	1.3	4.7	7.4	-1.9	0.9	3.1	1.2	-1.6	0.1	0.2	-1.4
Trinidad and Tobago	3.8	0.5	2.0	5.8	0.4	0.3	1.2	1.6	5.8	0.0	-0.1	5.7
Tunisia	3.0	1.1	4.1	7.1	2.4	1.2	4.5	7.0	3.3	0.3	1.0	4.3
Turkey	3.4	1.4	5.0	8.3	2.7	0.7	2.7	5.4	2.5	0.5	1.7	4.2
Uganda	0.9	1.2	4.5	5.4	-2.0	-0.1	-0.4	-2.4	2.7	0.1	0.3	3.1
Ukraine	n.a.	0.3	1.1	n.a.	1.2	-0.1	-0.2	1.0	-1.9	-0.2	-0.7	-2.5
United Kingdom	2.4	0.2	0.7	3.2	1.9	0.3	1.1	2.9	2.0	0.2	0.9	2.9
United States	2.5	0.2	0.7	3.1	2.0	0.3	1.0	3.0	1.7	0.2	0.7	2.5
Uruguay	0.3	0.2	0.7	1.0	1.6	0.3	1.1	2.7	1.9	0.2	0.9	2.8
Uzbekistan	n.a.	0.7	2.4	n.a.	-1.1	0.3	1.0	0.0	0.3	-0.1	-0.5	-0.3
Venezuela, Rep. Bol.	1.5	0.9	3.3	4.8	-1.4	0.4	1.6	0.1	0.8	0.3	0.9	1.7
Vietnam	1.0	1.1	4.0	5.1	1.3	1.5	5.7	7.0	5.7	0.5	1.9	7.7
Zambia	2.1	0.9	3.2	5.3	-1.5	-0.2	-0.7	-2.3	-0.1	-0.8	-3.1	-3.2

Source: Author's calculations, based on World Bank (2008), United Nations Population Division (2007b), and Maddison (2004).

IV.1. MACROECONOMIC IMPACT OF ICT-RELATED CAPITAL DEEPENING – LITERATURE SURVEY

A. Introduction

The present chapter reviews the available literature on the impact of ICT-related capital deepening on productivity and economic growth. Regarding our objective, the analysis of the economic role of ICT-related capital deepening in developing countries, the purpose of the present chapter is to provide some methodological context for our own analysis. However, most of the available studies on the economic impact of ICT-related capital deepening deal with the United States or other OECD countries,[140] reflecting the weight of these countries in the world economy or the global markets for ICT equipment, but also limited availability of data which complicate an analysis of ICT-related capital deepening in developing countries.[141]

The literature on the economic impacts of technological advances in ICTs on productivity or growth broadly distinguishes three channels through which such technological progress affects economic growth:

Productivity gains in the production of ICT equipment. In most countries, the share of the ICT-producing sector in GDP is small.[142] However, with very high rates of productivity growth in the ICT-producing sector, the sector can account for a disproportionate share of overall productivity growth.

[140] Baily (2001) provides a good introduction to many of the issues discussed below.

[141] Chapter IV.2 provides an extensive discussion of issues regarding the measurement of ICT-related capital deepening in developing countries, and documents construction of our dataset, largely from trade data.

[142] In 2001–05, production of "office, accounting, and computing machinery" (ISIC Rev. 3 category 3000), which is dominated by IT equipment, exceeded 1 percent of GDP for only 9 countries globally, including, with Japan, only one G7 economy (source: author's calculations, based on UNIDO (2007) and IMF (2008).

Capital deepening associated with falling prices of ICT equipment. The relative prices of ICT-related equipment decline as technological progress in the ICT sector translates into lower prices of ICT equipment (or improved capabilities of such equipment at a given price), resulting in an increase in the capital-labor ratio (at constant prices) and therefore an increase in labor productivity and growth.

Broader productivity gains owing to transformations in the economy enabled by improvements in ICTs, through advances in production processes or transformations in the global pattern of production enabled by ICTs.

Most of the literature on the economic impacts of ICTs focuses on the first two effects, because they can be captured, at least conceptually, in national accounts data. The third channel, which relates to the character of ICTs as "general purpose technologies," is more difficult to capture as it relates to "complementary advances" which may not directly be related to the intensity of ICT adoption. Furthermore, there may be lags between the "time to sow" and the "time to reap" which conventional growth accounting exercises would not capture.[143]

Against this background, this chapter is organized as follows:

In Section II, our discussion of the literature on the macroeconomic impacts of ICTs sets out with a discussion of the body of work focusing on the recent growth experience in the United States, the country for which the impacts of ICTs have been studied most extensively, and which has been a starting point or point of reference for much of the literature on the economic impacts of ICTs in Europe or the OECD.

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[143] The terminology in the present paragraph draws from Helpman and Trajtenberg, 1998. Some of the early work on the economic repercussions of "general purpose technologies" was motivated by technological advances in semiconductors (Bresnahan and Trajtenberg, 1995); and some of the early contributions on the economic impacts of ICTs emphasized their capabilities to generate efficiency gains across the economy and transform production processes (e.g., David (1990) on computers (and electricity), and Litan and Rivlin (2001) on the internet). More recently. Jovanovic and Rousseau (2005) provide a thorough comparative discussion of electricity and IT as general purpose technologies.

Section III discusses the available literature on the macroeconomic impacts of ICTs across countries (most of which focuses on OECD or European countries). Apart from expanding the geographical coverage of our discussion, this literature adds two dimensions to the study of the macroeconomic impacts of ICTs. It provides an opportunity to analyze differences in the adoption or the impact of ICTs across countries, and potential factors that may cause such differences. Also, it is necessary to address the implications of differences in national statistical systems for a cross-country analysis. The section concludes with a discussion of the few studies on the growth impacts of ICTs with a coverage that substantially extends beyond the OECD.

Although, owing to lack of data, this is an issue that is not immediately relevant for our analysis, Section IV discusses the additional insights that can be gained from an analysis of the impacts of ICTs on the industry or company level. The variations in the adoption of ICTs across sectors also enable a more refined econometric analysis of the economic impacts of ICTs, which also contributes to refining the understanding of trends in aggregate productivity indicators.

Section V concludes and discusses the relevance of the literature focusing on the United States and other OECD countries for the study of ICT-related capital deepening in developing countries.

B. Literature on ICTs and Economic Growth in the United States

One remarkable feature of the literature on the links between ICTs and growth in the United States is that it is dominated by two groups of authors, one being Oliner and Sichel, and the other Jorgenson, Ho, and Stiroh. Both of these groups (sometimes with additional co-authors, including the occasional overlap) have authored numerous papers, although some of these papers simply update the authors' earlier estimates.

Oliner and Sichel (1994), compared with their later work, provides a more informal discussion of the contributions of computers, or of broader measures of ICT inputs including communications equipment and software, to output growth. From today's perspective, an interesting feature is the discussion of measurement issues, which is more explicit than in the authors' later work. Oliner and Sichel (2000) presents the authors' fully developed framework, attributing changes in labor productivity in nonfarm business to IT-related capital deepening (as relative prices of hardware, software, and communications equipment fall), the contribution of other capital, increases in labor hours and quality, and MFP, and attributing part of MFP growth to the production of computers and semiconductors. They find that IT-related capital deepening accounted for about half of the acceleration of labor productivity growth between 1974–90 and 1996–99, and for more than half of the increase in MFP. Oliner and Sichel (2003), apart from updating their earlier estimates, provide a growth-accounting model that is used to conduct a forward-looking calibration of growth and its determinants along a steady-state growth path.

Two contributions by Gordon (2000, 2003) draw on the estimates by Oliner and Sichel. The earlier paper, using estimates from Oliner and Sichel (2000), focuses on the acceleration in MFP observed in the second half of the 1990s. Making an adjustment for changes in MFP owing to cyclical factors, he argues that the magnitude of the *structural* acceleration in MFP outside the IT-producing sector between 1995 an 1999 has been negligible. The later paper was written in the context of the experience of the early 2000s, when IT investment declined but productivity increased. In this regard, Gordon discusses the role of "intangible capital that is complementary to computer hardware and software," and provides some illustrative rough estimates of the implications of accounting for intangible capital for estimates of the impacts of ICT-related capital deepening on productivity. The key point is that investments in organizational changes and restructured production processes not captured in the national accounts slow down recorded productivity at the time IT investments occur, but result in an increase in recorded productivity reflecting the returns to this intangible capital.

To illustrate the lessons from the work of Oliner and Sichel, Table 1 reproduces (in a slightly modified form) their latest estimates, included in Oliner, Sichel, and Stiroh (2007). Table 1 shows an acceleration in labor productivity of about one percent between 1973–95 and 1995–2000, associated with an increasing role of ICT-related capital deepening and productivity growth in the ICT-producing sector (other capital deepening and MFP growth in non-ICT sectors roughly cancel out). The picture changes for the 2000–06 period, as labor productivity growth accelerates further, while the role of ICT capital and ICT production decline.

Table 1. Contributions to Growth in U.S. Labor Productivity, 1973–2006

	1973-1995	1995-2000	2000-2006
Growth of labor productivity in the nonfarm business sector (percent a year)	1.47	2.51	2.86
Contributions from (percentage points)			
Capital deepening	0.76	1.11	0.85
IT capital	0.46	1.09	0.61
Computer hardware	0.25	0.60	0.28
Software	0.13	0.34	0.20
Communications equipment	0.07	0.15	0.14
Other tangible capital	0.30	0.02	0.24
Improvements in labor quality	0.27	0.26	0.34
Growth of MFP	0.44	1.14	1.67
Of which: IT-producing sectors	0.28	0.75	0.51
Semiconductors	0.09	0.45	0.23
Computer hardware	0.12	0.19	0.10
Software	0.04	0.08	0.13
Communications equipment	0.04	0.04	0.05

Source: Adapted from Oliner, Sichel, and Stiroh, 2007.

Similar to Gordon (2003), Oliner, Sichel, and Stiroh (2007) point at the role of intangible capital. Drawing on empirical work on the impacts of ICTs on the sectoral or establishment level (discussed further below), and recent work on measuring intangible capital (e.g., Corrado, Hulten, and Sichel, 2006), Oliner, Sichel, and Stiroh extend the analysis for the effects of such intangible capital, which also requires some modifications to their framework, e.g., by adjusting factor shares. They find that inclusion of intangible capital does not change the basic lessons regarding the central role of ICTs in the acceleration of productivity after 1995. However, inclusion of intangibles implies that "the fastest gains in labor productivity occurred during 1995–2000, with some step-down after 2000," correspondingly, the increase in MFP growth after 2000 (as shown in Table 1) is mitigated.

The work by Jorgenson and others extend the framework for analyzing productivity changes that goes back to Jorgenson and Griliches to study the impact of ICTs on growth.[144,145] A key aspect of ICT equipment in this context is the rapid rate of price declines

[144] For early expositions of the underlying analytical framework, see Griliches and Jorgenson (1966, 1967).

observed for such assets, which has two consequences. (1) In comparing old and new equipment (e.g., to measure aggregate capital stocks), it is important to take into account the differences in the purchasing prices of equipment over time. (2) The user costs of ICT equipment, a proxy for the marginal product, importantly include the rate of decline in the price of ICT equipment, in addition to rate of return to capital and the rate of physical depreciation.[146]

A key features that distinguishes the work by Jorgenson and others from the work by Oliner and Sichel is the coverage of output and inputs. Jorgenson and others include services from durable consumption goods in output, treating spending on such products in a way that is "exactly parallel to that of capital goods" (Jorgenson and Stiroh, 1999). The measure of output thus is wider than the one applied by Oliner and Sichel (nonfarm business sector), probably as Jorgenson's work is geared towards identifying the contributions of ICTs to growth, while Oliner and Sichel focus more on productivity. One corollary from the wider measure of output covered by Jorgenson and others is the inclusion of ICT-related durable goods among inputs, similar to capital services.

The first contribution by Jorgenson and Stiroh (1999) in a general-interest economics journal provides a concise outline of the methodology and estimates of the impact of computer outputs and inputs to economic growth through 1996.[147] Jorgenson and Stiroh provide a more substantial analysis, extending the analysis to communications equipment and software, and documenting in some detail the construction of the estimated series for capital stocks and capital services. The focus of Jorgenson (2001) is wider, dealing with the role of information technology in the U.S. economy. While the discussion of the growth impacts of ICTs is similar to previous work by Jorgenson and Stiroh, Jorgenson (2001) places more

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[145] Oliner and Sichel also draw on this framework. As the studies by Jorgenson and others includes more explicit discussions and references, we discuss these methodological aspects of the literature on ICTs and growth here.

[146] These points are discussed in more detail in Jorgenson (1996).

[147] This follows the first publication by Jorgenson and Stiroh (1996) on "Computers and Growth" in *Economics of Innovation and New Technology*.

weight on stocktaking of developments in the ICT sector (including a review of issues regarding measuring price changes of ICT products) since the late 1950, and discussing implications for economic research. Jorgenson, Ho, and Stiroh (2003) update the earlier estimates, and provide a more accessible presentation of "capital quality," i.e., capital services derived from a given capital stock. Jorgenson (2005a) and, similarly, Jorgenson, Ho, and Stiroh (2005),[148] represent a fuller development of the approach by Jorgenson (2001) towards addressing the economic role of ICTs, and also include a discussion of the growth impacts of ICTs in the G7 economies.

Table 2 illustrates the latest estimates by Jorgenson, Ho, and Stiroh (2008).[149] The presentation is similar to the one in Oliner, Sichel, and Stiroh (2007, see Table 1), which facilitates comparisons. Unlike Oliner, Sichel, and Stiroh (which focus on the nonfarm business sector), Jorgenson, Ho, and Stiroh (2008) find that the growth rate of labor productivity has peaked in 1995–2000. However, the key reasons behind these differences are not related to ICTs, our primary areas of interest, the contributions of which are similar between the studies. Most significantly, Jorgenson, Ho, and Stiroh show a smoother trajectory of other tangible capital, and a more moderate acceleration of total factor productivity in the non-IT sector.

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[148] Much of the emphasis of Jorgenson, Ho, and Stiroh (2005) is on industry-level developments. These aspects will be discussed below.

[149] The title of the paper ("A Retrospective Look at the U.S. Productivity Growth Resurgence") is somewhat of a misnomer, as the bulk of the paper is concerned with growth *projections*, which we do not discuss here.

Table 2. Sources of U.S. Output and Productivity Growth, 1973–2006

	1973–1995	1995–2000	2000–2006
Average labor productivity (percent a year)	1.49	2.70	2.50
Contributions from (percentage points):			
Capital deepening	0.85	1.51	1.26
Information technology	0.40	1.01	0.58
Non-information technology	0.45	0.49	0.69
Labor quality	0.25	0.19	0.31
Total factor productivity	0.39	1.00	0.92
Information technology	0.25	0.58	0.38
Non-information technology	0.14	0.42	0.54

Source: Adapted from Jorgenson, Ho, and Stiroh, 2008.

One notable addition to the literature is provided by Nordhaus (2002). Among other points he makes, he provides an analysis of the impact of ICTs on "well-measured" output, which does not produce substantially different results, and augments the analysis by allowing for productivity effects of shifts in the composition of output.

C. Lessons from Cross-Country Studies

The study of the impacts of ICTs across countries adds additional challenges to the analysis, related to differences in national statistics, such as the availability of data on ICT-related production of expenditures, or differences in price indices applied to ICT-related categories. Additionally, variations in ICT penetration or the estimated impact of ICTs across countries motivate analyses of potential determinants of these cross-country differences.

Regarding ICT-related data in national accounts, Colecchia and Schreyer (2002) provide a snapshot of the availability of data across countries. For nine OECD countries, they document differences in the coverage of current-price investment series, which sometimes have to be augmented by OECD estimates to allow for cross-country comparisons. The lack of sufficiently detailed national accounts data, beyond key OECD economies, is also one of the reasons why most studies focus on a relatively small set of countries. One alternative source of data that is sometimes used is industry data on sales of ICT products, such as

WITSA's *Digital Planet* database or Global Insight's *Global IT Navigator* database, covering 70 countries.[150]

Probably the more significant issue regarding cross-country comparisons are differences in price series, a crucial item as the rate of technological progress in the ICT sector is usually measured by the rate of price decline of the respective goods. The internationally recognized best practice for measuring prices of ICT goods are hedonic indices that account for changes in the quality of ICT products.[151] However, the methods applied in generating price indices for ICT products across countries differ widely (Colecchia and Schreyer, 2002). The most common approaches to address this problem for cross-country studies is the use of a "harmonized" indices (Schreyer, 2002), which are based on the difference in U.S. data between the price index of IT equipment and the overall price index for equipment, assuming that the difference between prices of IT equipment and equipment overall evolves in the same fashion across countries. The alternative that is sometimes used involves adjusting U.S. price indices for exchange rate changes.[152]

A substantial share of the work on the growth impacts of ICTs in the G7 countries, Europe, or the OECD has been conducted at or commissioned by the OECD. Van Ark (2001), distinguishes between ICT-producing manufacturing and service industries, intensive ICT-using manufacturing and service industries, and other sectors. He finds that productivity growth differentials between the United States and most European countries are partly explained by a larger and more productive ICT-producing sector in the United States, but also by bigger productivity contributions from ICT-using industries and services in the United States. Pilat and Wölfl (2004) cover a wider set of countries, focusing on ICT-producing manufacturing and services, as well as ICT-using services. They find that the

[150] The WITSA database now is produced by Global Insight; the latest version (*Digital Planet 2008*) now covers 80 countries.

[151] See Schreyer (2002), Working Party on Indicators for the Information Society (2005), and Grimm and others (2005).

[152] For a discussion of the use of "harmonized" indices vs. the use of U.S. indices adjusted for exchange rates, see also van Ark (2002).

contributions of the ICT-manufacturing sector are modest for most OECD countries (exceptions are Finland, Ireland, and Korea), and point at a strong pick-up in productivity growth in ICT-using services in the United States and Australia in the second half of the 1990s. Ahmad, Schreyer, and Wölfl (2004), a companion paper to Pilat and Wölfl (2004), concentrate on the role of ICT-related capital deepening, estimating that the impact on growth roughly doubled between 1990–95 and 1995–2001 (with some variation between countries), and that it amounted to between 0.3 percentage points for France and 0.8 percentage points for the United States in the latter period. However, the authors stress that the measurement issues described above continue to make cross-country comparisons difficult.

Bassanini and Scarpetta (2002) – also of the OECD, but in an academic journal – document the contribution of ICT to capital input across countries. Their discussion of the contribution of ICTs to productivity growth is less formal, relying largely on a comparison of increases in MFP growth across countries. Salvatore (2003) also assumes that "growth of multifactor productivity (mfp) can be used as a rough measure of the contribution of the New Economy to the growth of the nation," but does not provide a more explicit analysis of the links between ICT adoption and MFP growth. The study by Inklaar, Timmer, and van Ark (2007) is based on input and output data on the industry level, distinguishing 26 industries and covering 7 advanced economies. They find that "differential growth performance is most strongly related to differences in TFP growth," whereas the pattern regarding ICT capital deepening was similar across countries, accelerating between 1995 and 2000, but slowing down subsequently. An industry decomposition points at slower productivity growth in business services in continental Europe as a reason for differences in productivity growth across countries.[153]

Jorgenson (2003, 2005b, also adapted in Jorgenson (2005a) and Jorgenson, Ho, and Stiroh (2005)) extends the framework developed for the United States by himself and his collaborators to the G7 economies. As the various published versions are virtually identical,

[153] Additionally, Inklaar, Timmer, and van Ark (2007) provide a discussion of differences in productivity *levels* across countries.

our discussion is based on Jorgenson (2005a) only. One point Jorgenson stresses is the distinction between capital stocks and capital quality, i.e. the flow of services obtained from a unit of capital (also discussed above). The growth contribution of ICT capital in the United States between 1980 and 2006 increased more than twice as fast as the stock of capital, as the increase was concentrated in IT hardware and software, commodities characterized by high marginal products (i.e., high rates of price decline and, in case of IT hardware, physical depreciation). The UK enjoy the highest rates of IT-related productivity growth over the 1995–2001 period (1.5 percentage points per year), more than half of which occurs in IT production. The productivity gains for the US and Japan are somewhat lower overall (1.4 and 1.3 percentage points per year), two-thirds of which are accounted for by IT capital deepening. Canada shows relatively low IT-related productivity gains (1.0 percent annually) – while the impact of IT-related capital deepening is among the highest, it features very little IT production.

Oulton (2002) focuses on differences in productivity growth between the UK and the United States and the role of ICTs. He finds that the role of ICT-related capital deepening increased gradually between 1989–94 and 1994–98, but attained a level of only about half of the estimates presented by Oliner and Sichel (2000) for the U.S. economy.[154] However, TFP declined in the UK, while it increased in the United States.

Timmer and van Ark (2005) and – most recently – van Ark, O'Mahoney, and Timmer (2008) discuss productivity differentials between the European Union (actually, 10 EU countries) and the United States.[155] The latter paper identifies 4 determinants of labor productivity – (a) labor composition, (b) ICT capital, (c) non-ICT capital, and (d) MFP –, defining the impact of the knowledge economy as the sum of items (a), (b), and (d). Overall, van Ark, O'Mahoney, and Timmer (2008) find that labor productivity growth has declined

[154] The point estimates are 0.24 percentage points per year for the UK, and 0.45 percentage points per year for the US. The time periods in Oliner and Sichel (2000) are one year later than those in Oulton (2002), which may affect the observed differences.

[155] The latter paper updates the analysis of contributors to labor productivity through 2004 (from 2001) and augments the analysis by accounting for changes in the composition of labor.

by 0.9 percentage points in the European Union between 1980–1995 and 1995–2004, whereas it has increased by 1.5 percentage points in the United States over the same periods (Table 3). In their analysis, the contribution of ICT capital has been lower and accelerated more slowly. However, the biggest factor underlying the divergent trends in labor productivity are the trends in MFP growth, which declined in Europe but increased in the United States. The analysis summarized in Table 1 is complemented by a discussion of contributions to growth in labor productivity (but not MFP) by sector; while a larger share of ICT production in the United States plays the role, most of the difference in labor productivity growth between the European Union and the United States arises from slower growth in the service sector.

Table 3. Growth of Labor Productivity in the Market Economy, EU and U.S., 1980–2004

	European Union		United States	
	1980–1995	1995–2004	1980–1995	1995–2004
Labor productivity growth (percent a year)	2.4	1.5	1.5	3.0
Contributions from (percentage points):				
Labor composition	0.3	0.2	0.2	0.3
Capital services per hour	1.2	1.0	0.8	1.3
ICT capital	0.4	0.5	0.5	0.8
Non-ICT capital	0.8	0.5	0.2	0.4
Multifactor productivity	0.9	0.3	0.5	1.4

Source: Adapted from van Ark, O'Mahoney, and Timmer, 2008.

Daveri (2002) takes a somewhat different approach than the studies discussed so far. Rater than using national accounts data, his estimates are based on WITSA's *Digital Planet* database. As a consequence, his paper covers some EU countries frequently left out because of issues with national accounts data. Second, he appears to use U.S. price indices adjusted for exchange rates rather than harmonized indices. He suggests that the pattern of ICT adoption in Europe has been uneven in 1998–2001, with a group of countries partially catching up with the United States, and a group of "slow adopters" continuing to lag behind. However, he does not find a strong impact of ICT adoption on labor productivity overall.

While most studies – owing to limited availability of sufficiently disaggregated national accounts data – focus on a limited number of advanced economies, a few studies have attempted to make full use of available cross-country databases. One of the first of these studies, Bayoumi and Haacker (2002),[156] assess the impacts of ICT production on GDP growth using a dataset comprising 32 countries, including some developing countries, from Reed Electronics Research (2001), as well as data from WITSA's *Digital Planet* database. They find that the growth effects from IT production are substantial for a few countries (exceeding 1 percentage points for 5 countries), but they only account for 0.1 percentage points or less in more than half of the countries covered. The analysis is complemented by an analysis of the impact of falling prices of ICT products on real domestic demand. Here the gains are much more even, and some of the countries with the highest gains barely produce ICT products (e.g., Australia, South Africa). Bayoumi and Haacker therefore find that productivity gains in ICT production are wiped out by deteriorating terms of trade for ICT products (as their prices decline), and the principal determinant of macroeconomic benefits from ICT production is absorption of ICT products.

Jorgenson and Vu (2005a, 2005b, 2007) build on earlier work by Jorgenson (2003, 2005b) on the G7 (discussed above), analyzing the contribution of ICT-related capital deepening to growth in the 110 countries covered by the Penn World Tables (Version 6.1). To this end, they use data for 70 countries from WITSA's *Digital Planet* database. For the 40 countries not covered by the WITSA database, they construct proxies drawing on data from various sources, including the World Bank and the International Telecommunications Union (as documented in Jorgenson and Vu, 2005b). For 2000–04, Jorgenson and Vu (2007) attribute, out of global growth of 3.75 percent annually, 0.42 percentage points to ICT-related capital deepening. Across major regions, the contributions of ICT-related capital deepening range from 0.27 percentage points (28 countries in sub-Saharan Africa) to 0.47 percentage points for the G7 economies. Notably, the impact of ICT-related capital deepening increased in all regions relative to the G7, doubling (for the non-G7) from 0.14 percentage points in 1989–95 to 0.27 percentage points in 2000–04 (while it increased from 0.39 percentage points to 0.47 percentage points in the G7, over the same periods).

[156] Pohjola (2002) also draws on the WITSA dataset, providing an informal discussion of the role of ICTs in development, as well as an econometric analysis of the impacts of ICT-related capital-deepening on growth, based on data for 40 countries, which yields inconclusive results.

Haacker (2008) offers the widest coverage of developing countries so far. Unlike the studies by Bayoumi and Haacker (2002) and Jorgenson and Vu (2005a, 2005b, 2007), he builds a database using trade data from the Commodity Trade Statistics Database maintained by the United Nations Statistics Division. One drawback of the analysis is that it cannot capture absorption of domestically produced ICT equipment; for this reason, Haacker concentrates on countries with low ICT-related exports, which presumably do not produce ICT equipment (most low- and low-middle-income countries, but few high-middle and high-income countries). Overall, he estimates the growth impact of IT-related capital deepening at 0.20 percentage points in 32 low-income countries, and 0.32 percentage points in 31 low-middle-income countries.

D. Additional Insights from Firm- or Industry-Level Studies

Although our discussion focuses on the macroeconomic impacts of ICTs, the literature on the impacts of ICTs on the industry or firm level is relevant for our purposes, because it adds insights regarding the form the macroeconomic impacts of ICTs take (this aspect already played a role in some of our preceding discussion, especially regarding the impacts of ICTs in Europe), and because industry data – owing to variations in ICT adoption across industries – enable more refined economic analyses of the impacts of ICTs, "casting a brighter light on the black box of production in the increasingly information technology-based economy" (Brynjolfsson and Hitt, 2000).

Early important contributions to the study of the impacts of ICTs on productivity on the firm level are those by Brynjolfsson and Hitt (2000, 2003) and Bresnahan, Brynjolfsson, and Hitt (2002), motivated by work on "general purpose technologies" (e.g., Bresnahan and Trajtenberg, 1995). Brynjolfsson and Hitt (2000) takes stock of the evidence and evolving literature, pointing at links between productivity and the information technology stock across firms, and between IT adoption and organizational change at the firm level. Among the key challenges to identifying the impacts of ICTs are the timing of the impacts (evolving over time and larger when measured over longer time periods; see Brynjolfsson and Hitt, 2003) and the complementarities of ICTs with investments in intangible capital which are difficult to measure. Bresnahan, Brynjolfsson, and Hitt (2002) point at complementarities between

ICTs, skilled labor, and two measures of innovation (organizational change, and new products and services).

Another important contribution to the literature is the body of work by Stiroh (and collaborators).[157] Stiroh (2002b) observes that ICT capital is correlated with an acceleration of labor productivity growth, but not of TFP growth. He also points at substantially different impacts of IT and communications equipment, and advises caution when using aggregate measures of ICT equipment. Stiroh (2002a) focuses on the timing of productivity gains, suggesting that industries investing heavily in ICT equipment in the 1980s and early 1990s experienced higher productivity growth after 1995. Jorgenson, Ho, Samuels, and Stiroh (2007), updating the more comprehensive study included in Jorgenson, Ho, and Stiroh (2005), find that productivity accelerated across industries after 1995, and that "the TFP boom of 1995–2000 was generated by the IT-producing industries, while IT-using industries, many of them in services, came to the fore in the aftermath of the dot-com crash of 2000." However, in a recent empirical study, Stiroh and Botsch (2007), suggest that the link between IT-intensity and labor productivity has weakened after 2000. In this regard, Oliner, Sichel, and Stiroh (2007) propose that productivity increased in industries under pressure to restructure, while the impact of ICTs was less clear.

Basu and Fernald (2008) focus on the role of ICTs as general-purpose technologies, pointing out that the acceleration in TFP growth after the mid-1990s (through 2004) was located primarily in ICT-using industries, and that TFP accelerations in the 2000s were positively correlated with previous ICT investments, which would be consistent with productivity gains, e.g. through organizational change, enabled by previous ICT investments. Earlier attempts by Basu, Fernald, Oulton, and Srinivasan (2003) to explain U.S.-UK differences in productivity growth using a similar approach were less successful, although it is important to note that much of the mileage of the later paper comes from post-2000 data not available in the earlier study.

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[157] See Stiroh (2002a, 2002b), Jorgenson, Ho, and Stiroh (2005), Jorgenson, Ho, Samuels, and Stiroh (2007), Stiroh and Botsch (2007), and Oliner, Sichel, and Stiroh (2007).

E. Lessons for Studying the Impacts of ICTs in Developing Countries

Much of the literature discussed in this chapter, focusing on the United States and other ECD countries, cannot easily be adapted to the analysis of the contributions of ICT-related capital deepening to productivity and economic growth, owing to data limitations. This applies, in particular, to the study of the impacts of ICT-related capital deepening on the industry level, most notably the econometric studies discussed in Section IV which have refined the understanding of the role of ICTs in economic growth in industrialized countries. Similarly, many of the studies prepared for the OECD discussed in Section III require data which are barely available beyond (a subset of) OECD countries, and cannot serve as a template for studying the impacts of ICT-related capital deepening in developing countries.

On the other hand, the basic approach, summarized in Section II and parts of Section III, provides a framework that could be applied to the study of macroeconomic impacts of ICT-related capital deepening in developing countries, as it can be applied bottom-up, i.e., it requires, at the minimum, sufficient data to identify the contributions of falling prices of ICTs to capital deepening, and – suitably weighted – to economic growth, but it does not require a comprehensive set of macroeconomic data. In Chapter IV.2 we therefore discuss the data situation in developing countries, with the objective of constructing a dataset covering as many countries as possible which could be used for an analysis of the macroeconomic role of ICTs in these countries.

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IV.2. MEASURING ACCESS TO ICTS IN DEVELOPING COUNTRIES

A. Introduction

Even for the most advanced industrialized countries, the study of the economic impact of or determinants of access to ICTs is complicated by differences in statistical systems across countries.[158] For studies focusing on developing countries, the issues are, in many regards, more complex. First, national accounts data, on a level of disaggregation that would allow for identification of ICT-related spending, is generally not available. Second, in many developing countries, national data series are available for limited periods only, and the series may not be complete. Third, the quality of statistical data in developing countries is more diverse than among G7 or OECD countries.

As a first step towards an analysis of the contributions of ICTs to economic growth in developing ocuntries, notably through the production of ICT equipment and through ICT-related capital deepening, the present chapter discusses the available data and documents the construction of a comprehensive dataset on the production of and spending on ICT equipment in low- and middle-income countries.

Regarding the production of ICT equipment (Section 2), the most important source of data is the Industrial Statistics Database assembled by the United Nations Industrial Development Organization (UNIDO).[159] In some cases, however, the UNIDO data appear to be incomplete, and had to be complemented by data obtained from other sources.

Sections 3 and 4 address the measurement of spending on ICT equipment. In the absence of sufficiently disaggregated national accounts data, trade data are the most important source of information on spending on ICT equipment. Section 3 discusses the construction of a comprehensive trade dataset, covering most low- and middle-income countries, based on the ComTrade database prepared by the United Nations Statistics Division (2008). The most

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[158] See, for example, van Ark (2002), or Schreyer (2000, 2002).

[159] See UNIDO (2007, 2008).

significant challenge to this arises from the fact that for many developing countries, there are no complete trade data series. In these cases, trade data need to be proxied from partner country data, which introduced a source of bias (associated wit trade between countries for which data are not reported through the ComTrade database), and Section 3 also documents how this problem has been addressed.

Section 4 discusses the construction of a dataset on spending on ICT equipment, largely based on the trade database described in Section 3. There are two main issues that need to be addressed here. First, for countries that do not produce ICT equipment, net imports of ICT equipment can be regarded as a good measure of the domestic absorption of such commodities. However, trade data do not directly translate into spending data in the national accounts, as it is necessary to account for items such as transportation costs, indirect taxes, or retail mark-ups which are included in final expenditure data, such as investment, but not in international trade data. Second, for producers of ICT equipment, it is necessary to account for domestic production of ICT equipment, in addition to net imports (or exports) in order to estimate domestic spending on ICT equipment.

A crucial issue for the measurement of the impact of ICT production and ICT-related investment on economic growth is the measurement of changes in the prices of ICT equipment (Section 5), as the rate of price decline of such equipment serves as a measure of the rate of productivity gains in the sector. As in most studies of the economic impacts of ICTs across countries, our price series are based on national accounts data from the United States, although we take into account some recent literature refining the price indices applied to communications equipment.

Finally, Section 6 discusses any issues regarding the sources of or the construction of any other dataset used in this study.

B. Production of ICT Equipment

Data on the production of ICT equipment are important for an assessment of the economic impacts of ICTs in developing countries. First, the literature on the impacts of ICTs in the United States, Europe, or the OECD identifies productivity gains in the production of ICT equipment as one of the primary channels through which advances in ICTs affect growth. Second, as data on spending of ICT equipment are not directly available for most low- and lower-middle-income countries, our data on spending on ICT are based on commodity trade data, and – in order to draw inferences from net imports regarding domestic spending – it is necessary to account for domestic production.

The UNIDO *Industrial Statistics Database* (UNIDO, 2007) provides data on industrial output and value added by ISIC category.[160] The categories of interest are ISIC 3 (i.e., ISIC, Rev. 3) category 3000 ("manufacture of office, accounting, and computing machinery") and the earlier ISIC 2 (i.e., ISIC, Rev. 2) category 3825 (with the same label) for IT equipment, and ISIC 3 category 30 ("manufacturing of radio, television, and communication equipment and apparatus").[161] For some countries, the data are available in ISIC 3 classification from the early 1990s; for most low- and middle-income countries the transition occurred in the late 1990s. While the categories coincide by title, merging ISIC2 and ISIC 3 series is not a trivial exercise – for countries where the series overlap, wide discrepancies may occur between the "matching" categories. While country coverage is wider than for Reed Electronics Research (2008), with 105 countries included in UNIDO (2007), including 4 low-income countries, there are no complete series for many of these countries. Also, the publication lag is relatively long (the median for the most current year for which data are available in the 2007

[160] Another important source of production data on the production of ICT equipment is the *Yearbook of Electronics Data* by Reed Electronics Research (2008). One of the advantages of this source is that it provides breakdowns of ICT spending fairly well delineated with commodity categories of interest (e.g., it differentiates computers from office equipment). Bayoumi and Haacker (2002) make good use of this resource to estimate the growth contribution of the ICT-producing sector. However, for the present purposes, with a focus on developing countries, the country coverage is insufficient, with data as for only 2 low-income countries (India and Vietnam) and 6 low-middle-income countries (China, Egypt, Indonesia, Philippines, Thailand, Ukraine), out of a total of 54 countries.

[161] ISIC 3 category 30 breaks down into 3 components on the 4-digit level, namely category 3210 (manufacture of electronic valves and tubes and other electronic components), 3220 (manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy), and 3230 (manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods).

edition is 2002), limiting the value for most of our analysis, which places a premium on the availability of recent data.

One drawback of the data included in UNIDO (2008) is the fact that a key commodity of interest, IT equipment, is available only included in the wider category "office, accounting, and computing machinery" (ISIC, Rev. 3, category 3000).[162] To assess the magnitude of potential errors that can arise when drawing inferences regarding the role of production of IT equipment from the wider ISIC Rev. 3 category 3000, it is useful to look at trade data (discussed in more detail below), which are available on a more disaggregated level. We find that the share of IT equipment in global exports of "office machines and automatic data processing equipment" (SITC category 75) has risen fairly steadily from 72 percent in 1980 to about 94 percent in 2003, and has remained at that level through 2006.[163] For recent data, the wider category thus appears to be a reasonable approximation for IT equipment, but the discrepancies are substantial for earlier years, and comparisons over time would have to take into account the changing composition of "office, accounting, and computing machinery."

While the UNIDO *Industrial Statistics Database* may include the major producers of ICT equipment, the limited coverage of low-income countries (and, to a lesser extent, lower-middle-income countries) is problematic, as an output in some country that is very small as a percentage of the global market may represent as substantial proportion of GDP of a small low-income country. For this reason, we analyze trade data (from United Nations Statistics Division, 2008) in order to identify additional countries which may produce ICT equipment. In a first round, all countries where exports of IT equipment, communications, or integrated circuits exceeded 0.1 percent of GDP were identified. For most of the countries identified in the round, exports were much lower than imports in the respective category, or the level of exports was so low in absolute numbers to make it implausible that the country was a producer. In the end, the analysis of trade data pointed to three countries not covered by UNIDO (2007) that could be producers – China, Thailand, and Tunisia. Additionally, trade

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[162] A point also made by Caselli and Coleman, 2001.

[163] Based on data from United Nations Statistics Division, 2008. IT equipment is defined as SITC 2 categories 752 and 7599, as explained in our discussion of data on IT equipment trade.

data suggest that Indonesia has become a net exporter of IT equipment since 1994, even though UNIDO (2007) shows trivial quantities of production of IT equipment. As two independent sources of data (trade data reported by Indonesia, and data reported by partner countries) contradict the UNIDO (2007) data, we also construct production data from trade data for Indonesia.

For these three countries, we construct an estimate for production of IT equipment using trade data and data on domestic spending on IT equipment (the three countries happen to be covered by Global Insight, 2006). To this end, it is necessary to take account of some differences in the definitions and the coverage of the data between the trade and spending data. First, trade data do not include various costs to importers that would need to be applied to imports (cif, tariffs and taxes), and domestic spending in the national accounts would also include some retail and distribution margins. At the same time, the production data also include a share of office equipment and do not identify intermediate inputs of ICT equipment that may be included in the trade data.[164]

Probably for these reasons (even though the various effects do not work in the same direction), domestic spending on IT goods is normally higher than the sum of production and net imports for countries where the different types of data (spending, production, trade) are all available.[165] In line with data for these countries, we apply a discount of 28 percent to spending data when estimating production data based on domestic spending and net imports. For communications equipment, it is not possible to estimate domestic production based on data on domestic spending, as Global Insight (2006) does not distinguish between communication equipment and related services.

Table 1 summarizes our data on production of ICT equipment (and related commodity flows) in low- and lower-middle-income countries for the period 2001–2004, including all

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[164] The role of intermediate inputs is discussed in some more detail in our discussion of ICT-related spending.

[165] Egypt, India, Iran, Morocco, Philippines, Sri Lanka, and Ukraine. As net exports are much higher than domestic spending for China, Indonesia, and Thailand, the discount factor applied to domestic spending does not play a large role in our estimates.

countries for which UNIDO (2007) data are available, plus the three countries for which we have constructed estimates of production of IT equipment (in case of Tunisia, the estimated amount is trivial). Production of IT equipment plays a significant role in only one low-income country (Vietnam), and in four lower-middle-income countries (China, Philippines, and Thailand, plus Macedonia where our data are inconsistent, showing significant production, but essentially zero exports). Similarly, there is only one low-income country (India) where production of communications equipment plays a significant role, and at least one lower-middle-income country (Indonesia). Especially China, a net exporter of communications equipment, would also fall in this category, but owing to lack of domestic spending data we cannot construct an estimate of domestic production. One point worth noting is the role of intermediate inputs, which is covered in Table 1 by net exports of integrated circuits. For two producers of IT equipment (Vietnam, China), our data show substantial net imports of integrated circuits, suggesting that production of IT equipment in these two countries may primarily take the form of assembly of imported components. Conversely, Philippines – which is the country with the highest share of production of IT and office equipment in GDP in our sample – is primarily a major exporter of integrated circuits.

Table 1. Production of ICT Equipment in Low- and Lower-Middle Income Countries, 2001–2004 (Percent of GDP)

Country	Production of IT and office equipment	Production of Communications Equipment	Spending on IT Equipment	Net Exports: IT Equipment	Net Exports: Communi-cations Equ.	Net Exports: Integrated Circuits
Low-income countries						
India	0.2	1.0	0.8	-0.3	-0.4	-0.1
Kyrgyz Republic	0.1	0.2	n.a.	-0.3	-0.6	0.0
Vietnam	0.9	0.0	n.a.	0.3	-0.7	-0.6
Lower-middle-income countries						
Albania	0.3	0.0	n.a.	-0.3	-0.9	-0.1
China,P.R.: Mainland[1]	*3.0*	n.a.	1.6	1.7	0.6	-1.8
Egypt	0.0	0.2	0.2	-0.2	-0.3	0.0
Indonesia	*1.2*	1.8	0.4	0.9	0.4	0.1
Iran, I.R. of	0.1	0.8	0.2	-0.2	-0.3	0.0
Macedonia, FYR[2]	1.8	0.0	n.a.	-0.7	-1.1	-0.1
Moldova	0.1	0.0	n.a.	-0.7	-1.1	-0.1
Morocco	0.0	0.2	0.4	-0.4	-0.7	0.0
Philippines	4.2	0.0	0.8	4.1	-0.7	13.2
Sri Lanka	0.3	0.1	0.7	-0.1	-0.5	0.0
Thailand[1]	*3.5*	n.a.	0.7	2.9	-0.1	0.5
Tunisia[1]	*0.0*	n.a.	0.5	-0.6	-0.8	0.0
Ukraine	0.2	0.6	1.1	-0.2	-0.4	0.0

Source: Author's calculations. If not stated otherwise, production data are obtained from UNIDO (2007), data on spending on IT equipment are from Global Insight (2006), and data on net exports of ICT-related commodities from United Nations Statistics Division (2008).

[1] Data on production of IT equipment (in italics) for China, Indonesia, Thailand, and Tunisia are estimates based on data on IT spending and net exports, as explained in text.

[2] The estimate of the magnitude of IT production for Macedonia from UNIDO (2007) of 1.8 percent of GDP seems implausible, as the country does not export any appreciable quantities of IT equipment (gross exports were 0.03 percent of GDP in 2001–2004), and as estimated production minus net exports suggest an unusually high amount of domestic spending on IT equipment.

Tables 2 and 3, which provide annual data for the production of IT equipment and communications equipment, complement the "snapshot" across ICT products in Table 1. In only few cases were complete production data available from UNIDO (2007), and data which have been estimated by intrapolation or extrapolation are shown in italics. Countries were included in Tables 2 and 3 if production of IT equipment or of communications equipment attained at least 0.1 percent of GDP in consecutive years.

Similar to Table 1, estimates for two countries (China, Thailand) for which production data were not available from UNIDO (2007) were constructed based on data on net exports and domestic spending. To extend the available data for spending on IT equipment back to 1992, Global Insight (2006) data were supplemented with WITSA (2001) data. Unfortunately, our data do not allow us to construct similar estimates for China and Thailand for production of communications equipment, as the spending figures only identify total communications spending, and not the share of communications equipment.

For all other countries, the data are based production data from UNIDO (2007). As the UNIDO data also include non-IT office equipment, an adjustment needed to be made to obtain estimates of production of IT equipment only. To this end, the shares of IT equipment (SITC 2 categories 752 and 7599) in gross exports of IT and office equipment (SITC 2 category 75) for each country were applied to scale the production figures.

As noted before, production data for Macedonia were inconsistent with trade data (both data reported by Macedonia and by partner countries), this finding also applies to the time series from 1990–2005. While production of IT and office equipment attained a level of about 4 percent of GDP in 1997–2000 according to UNIDO (2007), subsequently tapering off to a still substantial 1 percent of GDP, gross exports of these products did not exceed 0.02 percent of GDP in any of these years according to United Nations Statistics Division (2008). For our estimates of the contributions of the production of IT equipment and ICT-related capital deepening to economic growth, we follow the trade data and assume that the level of production of IT equipment in Macedonia is zero.

Production of IT equipment did play a marginal role in low- or lower-middle income countries in 1990, but started to take off in three countries (China, Philippines, and Thailand) in the mid-1990s, rising to between 3.7 percent and 4.9 percent of GDP by 2005 (on a gross basis – the contribution to GDP would be smaller on a value-added basis). Other notable countries include India (production around ¼ percent of GDP throughout the 1990–2005) period and Sri Lanka where production peaked at 0.9 percent of GDP 1999.

For communications equipment, production plays the most important role in Indonesia and India (our data exclude China) and, to a lesser extent, in Egypt, Iran, and Ukraine. On peculiar feature of the data is the fact that Philippines and Thailand, the two significant IT producers for which we have data on the production of communications equipment, started out with a large production of communications equipment, which tapered off as the IT-producing sector took off.

Table 2. Production of IT Equipment in Low- and Lower-Middle Income Countries, 1990–2005 (Percent of GDP)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Low-income countries																
India	0.20	0.28	0.30	0.17	0.31	0.29	0.27	0.29	0.12	0.14	0.22	0.23	0.20	0.24	*0.24*	*0.24*
Kyrgyz Republic	0.06	0.05	0.14	0.17	0.02	0.04	0.03	0.04	0.03	0.02	0.11	0.09	0.07	0.02	0.02	*0.02*
Vietnam	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.14	*1.37*	1.60	0.53	0.66	0.99	1.04	*1.04*
Zimbabwe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Lower-middle-income countries																
Albania	*0.00*	*0.00*	*0.00*	0.00	0.00	0.00	0.00	0.00	0.19	0.16	0.13	0.73	0.10	0.12	0.17	*0.17*
China,P.R.: Mainland	*0.26*	*0.26*	*0.32*	*0.20*	*0.41*	*0.52*	*0.64*	*0.83*	*0.96*	*0.98*	*1.31*	*1.62*	*2.20*	*3.39*	*4.33*	*4.70*
Egypt	0.00	0.02	0.00	0.02	0.02	0.01	*0.03*	0.06	0.05	*0.04*	*0.03*	*0.02*	0.01	*0.01*	*0.01*	*0.01*
Indonesia	*0.03*	*0.08*	*0.15*	*0.14*	*0.23*	*0.32*	*0.42*	*0.46*	*0.70*	*0.83*	*1.95*	*1.42*	*1.29*	*0.92*	*1.14*	*1.01*
Iran, I.R. of	*0.00*	0.00	0.01	0.01	0.06	0.03	0.05	0.08	0.08	0.08	0.10	0.08	0.05	0.03	*0.03*	*0.03*
Macedonia, FYR[1]	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Moldova	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.05	0.10	0.05	0.09	0.04	0.04	0.08	0.12	0.07	*0.07*
Morocco	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.19	0.17	0.10	0.12	0.00	0.00	0.00	0.00	0.01	*0.01*
Peru	0.04	0.09	0.02	*0.02*	0.03	0.00	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Philippines	0.02	0.04	0.06	0.40	0.47	0.80	0.92	1.18	3.77	4.21	*4.37*	4.53	*4.10*	3.66	*3.66*	*3.66*
Sri Lanka	0.01	0.00	0.00	0.12	0.14	0.29	0.00	0.54	0.52	0.94	0.53	0.31	*0.31*	*0.31*	*0.31*	*0.31*
Thailand	0.00	0.07	*0.08*	0.09	0.01	*1.37*	2.73	*1.99*	1.25	*2.26*	3.28	*3.89*	*3.31*	*3.21*	*3.20*	*3.90*
Ukraine	*0.00*	*0.00*	0.77	0.21	0.16	0.10	0.05	0.13	0.07	0.11	0.23	0.18	0.21	0.18	0.28	*0.28*
Memorandum items:																
Share of IT production in ISIC Rev. 3 category 3000[2]	78.6	77.9	75.2	82.5	77.0	85.4	85.4	86.2	87.2	86.4	88.5	86.4	89.5	90.2	89.9	89.8
Macedonia, FYR: Production of IT and office equipment (UNIDO, 2007)						0.00		4.03	4.28	4.00	3.89	3.59	1.57	1.13	0.99	
Macedonia, FYR: Exports of IT Equipment				0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.01

Source: Author's calculations, based on data from UNIDO (2007), UN Statistics Division (2008), and IMF (2008), except for China (1990–2005) and Thailand (2001–2005), which are not covered by UNIDO (2007). For these two countries, estimates have been constructed based on data on net exports from UN Statistics Division (2008), and spending data from Global Insight (2006) and WITSA (2001).

[1] For Macedonia, trade data (both reported by Macedonia and corresponding data from partner countries were inconsistent with production data in UNIDO 2007). Our estimates follow the trade data, assuming that the level of production is equal to zero. Source data for production and trade are shown under memorandum items.

[2] The assumed share of IT equipment in production in ISIC Rev. 3 category 3000 (IT and office equipment) for each country is based on the share of IT equipment (SITC2 categories 752 and 7599) in gross exports in SITC category 75 (office machines and automatic data processing equipment) for that country. For orientation purposes, we show the unweighted average of these shares (which was also used to scale the estimates for Peru, as no trade data were available for that country).

Table 3. Production of Communications Equipment in Low- and Lower-Middle Income Countries, 1990–2005 (Percent of GDP)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Low-income countries																
India	0.80	0.84	0.99	0.83	1.05	1.02	0.90	1.11	1.04	1.00	0.98	0.82	1.18	1.06	1.06	1.06
Kyrgyz Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.15	0.15	0.17	0.19	0.10	0.18	0.18
Vietnam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	1.58	1.63	0.00	0.00	0.00	0.00	0.00
Zimbabwe	0.21	0.22	0.20	0.16	0.19	0.20	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lower-middle-income countries																
Albania	0.00	0.00	0.00	0.11	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
China,P.R.: Mainland[1]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.16	0.24	0.34	0.31	0.28	0.41	0.35	0.29	0.36	0.33	0.30	0.28	0.25	0.25	0.25	0.25
Indonesia	0.49	0.43	0.86	0.81	1.06	1.41	1.65	2.16	2.35	2.16	3.11	1.59	1.72	1.96	1.96	1.96
Iran, I.R. of	0.34	0.34	0.34	0.35	0.40	0.23	0.39	0.65	0.89	1.26	1.65	1.47	0.47	0.39	0.39	0.39
Macedonia, FYR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moldova	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15
Morocco	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.21	0.20	0.02	0.40	0.23	0.23	0.25	0.28	0.28
Peru	0.31	0.28	0.42	0.24	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Philippines	3.07	3.92	4.08	3.78	4.15	4.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sri Lanka	0.07	0.13	0.07	0.03	0.10	0.10	0.10	0.08	0.10	0.13	0.11	0.09	0.09	0.09	0.09	0.09
Thailand	3.51	6.62	5.87	5.13	2.62	3.51	4.41	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.54	0.49	0.51	0.66	0.66

Source: Author's calculations, based on data from UNIDO (2007) and IMF (2008).

C. Data on Trade in ICT Equipment

In the absence of national accounts data on ICT-related spending, and the limited coverage of other databases on ICT-related spending across developing countries, trade data are the principal source of data for constructing a dataset on absorption of ICT-related equipment in low- and lower-middle-income countries. In particular, as we argue above, most low- and lower-middle-income countries do not produce ICT-related equipment, which means that net imports of such equipment could be good measures of domestic spending. However, the availability of trade data from low-income countries is also limited, and time series of trade data often exhibit missing years. One approach that is some times used in the literature to address such missing values (or entire missing series) involves use of partner country trade data as proxies for data from countries for which no official statistics are available.

ICT-related commodities in trade statistics

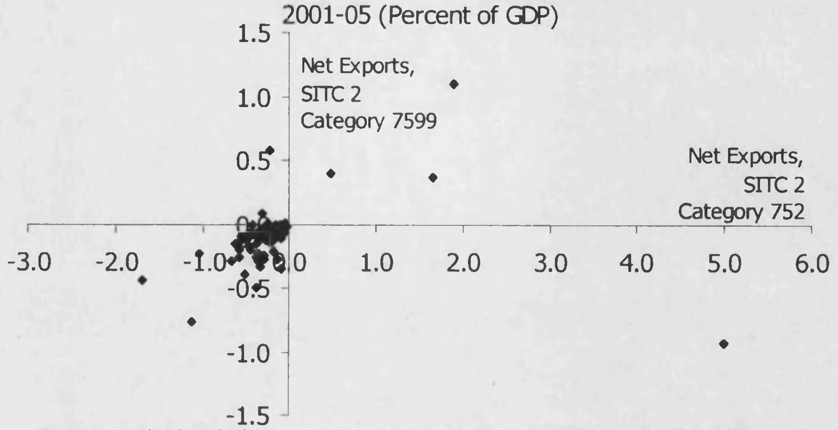
A key choice we need to make at the outset is the classification of trade data on which our dataset is to be based. The classifications used in trade statistics are revised in irregular intervals, and most countries now report data in "HS 2002" or "HS 1998" format. We adopt the older "SITC 2" classification, because it captures the categories of IT equipment we are interested in fairly well, and allows us to construct a dataset that extends back to 1980. Adopting "SITC 2 does not involve loss of access to more current data (at least on the level of aggregation we use) – more current classifications tend to be more refined than the predecessor, and can be (and routinely are in the UN COMTRADE database) mapped into older categories (while older categories are not generally upward-compatible).

Specifically, as measures of IT equipment, we focus on SITC 2 categories 752 (automatic data processing equipment) and 7599 (parts and accessories pertaining equipment in category 752), corresponding to HS 2002 categories 8471 and 847330. For some purposes (the discussion of gains in the production of ICT-related equipment), we also look at SITC 2 category 7764 (electronic microcircuits). The measure of communications equipment we adopt is SITC 2 category 764 (telecommunication equipment, parts and accessories).

The inclusion of SITC 2 category 7599 among IT equipment requires some further elaboration, as analysts sometimes focus on SITC 2 category 752 only (see, for example, Caselli and Coleman, 2001a, 2001b). For our purposes, we seek a measure of IT-related equipment that matches the data from other sources on IT-related production and spending. However, if commodities in SITC 2 category 7599 are largely intermediate products, they should not be counted towards spending on IT equipment directly, as their value would be embodied in domestic production of IT equipment.

To gain some more insights regarding the relation between commodities in SITC categories 752 and 7599, Figure 1 illustrates the pattern of net exports of IT equipment in these categories across countries. For the vast majority of the countries in our sample, which do not produce IT equipment (or produce trivial quantities only), imports in SITC 2 category 7599 clearly complement imports in SITC 2 category 752, and represent a significant share of IT-related expenditure. However, the breakdown between SITC 2 categories 752 and 7599 differs considerably across countries. These differences cannot easily be explained by differences in the demand for IT equipment (computers, their constituent parts, and peripheral equipment are more or less used in fixed proportions). Alternative explanations are differences in classifications applied across countries (the dividing line between SITC 2 categories 752 and 7599 is not exceedingly well-defined), or differences across countries on the retail level. If this reasoning is correct, then focusing on SITC 2 category 752 as measure of IT-related investment introduces a source of error and possibly bias.

Figure 1. Net Exports in SITC 2 Categories 752 and 7599, 2001-05 (Percent of GDP)



Source: Author's calculations, based on United Nations Statistics Division (2008) and International Monetary Fund (2008).

The second consideration regards the role of intermediate products. As production figures we use for some purposes do not identify IT-related inputs, it is difficult to draw inferences from data sets that combine production and trade data (e.g., in order to estimate domestic absorption). This may be an issue for SITC category 7599 in some countries (e.g., Philippines report net exports of IT equipment in SITC 2 category 752 of 5 percent of GDP over the 2001–05 period, but net imports of IT equipment in SITC 2 category 7599 of 1 percent of GDP. However, the Philippines are an outlier among IT producers (although a large one), and IT producers trade large quantities of IT equipment between themselves, both in SITC 2 category 752 and in category 7599.

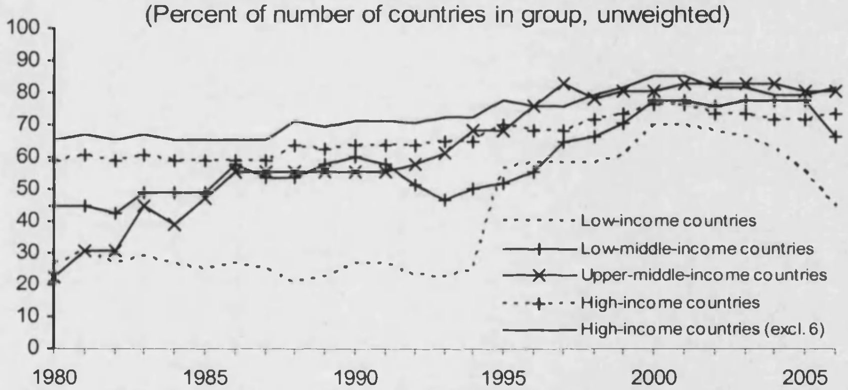
In light of the observed patterns in trade flows, focusing on SITC 2 categories 752 and 7599 as measure of trade in IT-related equipment therefore seems to be the right choice, in light of the noted similarities in trade flows in IT-related commodities in SITC 2 categories 752 and 7599. Notably, we find little evidence suggesting that "arts and accessories" should be primarily classified as intermediates.

Availability of trade data

The availability of detailed trade data has improved substantially in recent years, especially through the COMTRADE database maintained by the United Nations Statistics Division

(2008). Figure 2 illustrates the availability of trade data (SITC 2 classification[166]) from the COMTRADE database. It shows that data availability for low- and middle-income countries has improved substantially over the last decades. Most notably, the availability of data for low-income countries has increased dramatically around the mid-1990s (at least partly owing to improved access to ICTs in developing countries), from around 30 percent for which data are available to over 60 percent. However, data reporting for these countries appears to be subject to delays, as evident from the drop in the number of countries for which data are available in the later years.

Figure 2. Availability of Trade Data by Country Group, 1980-2006
(Percent of number of countries in group, unweighted)



Sources: Author's calculations, based on UN Comtrade database. "High-income countries (excl. 6)" excludes 6 small economies for which trade data are reported as part of the statistics of the surrounding economies. Countries are included in the denominator from the first full calendar year after independence.

An additional aspect of data quality is the availability of data over time, which is required to illustrate and analyze trends over time. However, the composition of countries for which data are available changes over time. Especially for low-income countries, data series are frequently incomplete. Thus, while data for at least some year are available for almost all low-income countries (see discussion of country classifications, below), focusing on countries for which complete data series are available would severely restrict the coverage for these countries.

One method researchers have attempted to get around breaks in trade data is the substitution of partner country data for missing country observations. For example, one

166 Our choice of SITC 2 as the basis for our empirical analysis is explained further below.

country's imports correspond to the exports of all partner countries to that country. This principle has been applied by Feenstra and others (2005) to construct a data set of bilateral trade flows for 1962–2000, using a country import data where available, and substituting another country's exports to that country if no data are reported from the former country.

However, the dataset constructed by Feenstra and others has several shortcomings regarding our purposes. Most substantially, it is based only on trade data from 72 countries accounting for 98 percent of overall world exports. For all other countries, it constructs trade flows based on the reported data from the 72 countries. For a study focusing on low- and lower-middle-income countries, it means that the bulk of the data are from partner countries, even if some data are available for the country of primary interest. Second, the data set constructed by Feenstra and others (2005) extend to 2000 only, whereas data are now available through 2006 for most countries (Figure 2). Third, we focus on a much narrower set of trade data than Feenstra and others, who are primarily concerned with consistency of broad aggregates of trade data, which gives us an opportunity to scrutinize the data of interest in more detail.

Constructing a comprehensive dataset on trade in ICT equipment

In terms of assembling a dataset for empirical analysis, there are essentially three options:

Using only observations from countries reporting trade data. This may work for cross-sectional analysis, but is awkward when comparing results for different years (as the coverage data sets would differ across years). Alternatively, the data may be used as an unbalanced panel, with all the problems this entails.

Using the observations from countries under consideration where available, and substituting the corresponding data from partner countries where data for a country under consideration are unavailable. However, inconsistencies in data across countries would translate into inconsistencies within the trade dataset generated in this way, and the quality of the data would be affected by any errors in the destination of exports in partner countries.

Using only partner country data. This approach, given the focus of the present study on low-income countries, would be similar to using the Feenstra (2005) dataset. Principal advantage of this approach are consistency across countries (other than for major exporters for IT equipment, which we are not concerned with here), and – similarly – the fact that it controls for idiosyncrasies in individual country's statistical systems. The principal drawback is that it increases the scope for errors arising from incorrect records regarding the destination of exports or source of imports in partner country trade data.

In order to adopt the second or third approach, two criteria would have to be satisfied. First, data from reporting countries would have to capture a large proportion of global trade in ICT equipment.[167] Second, trade data assembled from partner countries must be a good approximation for missing observations from non-reporting countries.

The issue of completeness cannot be addressed directly, as trade flows between non-reporting countries are, for our purposes, unobserved. However, it is possible to draw some indirect conclusions regarding the share of global trade in ICT equipment that we cannot observe, drawing on the extent to which reporters trade with reporters. To this end, Figure 3 illustrates the magnitude of recorded trade flows in SITC 2 categories 752 (IT equipment) and 7599 (parts and accessories relating to category 752). For IT equipment (Figure 3.1, we find that reporting countries import usually import more than they export (the annual gap averages 8.2 percent of imports). Much of the gap can be attributed to a trade deficit in SITC 2 category with non-reporting countries; if only trade between reporting countries is considered (Figure 3.2.2), imports still exceed exports, but the annual gap between imports and exports is reduced to 4.9 percent (which still represents a sizable error).

Figure 3.3 shows trade between reporting countries as a percentage of total trade in SITC 2 category 752. One trend that appears is an increase in the share of exports to countries also reporting trade data, which can largely be attributed to an increase in the number of countries reporting trade data (compare Figure 2). Economically more significant is the fact that a substantial share of imports, peaking at 9.8 percent in 2000, is from non-reporting countries. The most important contributor to imports from non-reporting countries (accounting for

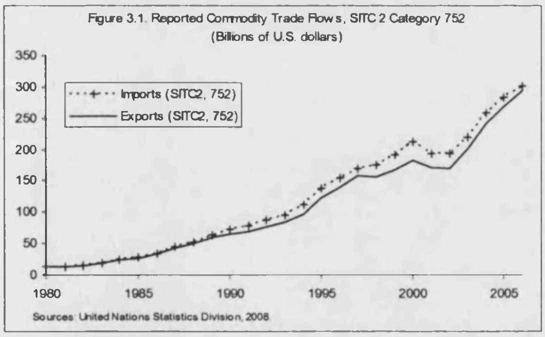
[167] Feenstra (2005) provides a discussion of this point regarding aggregate trade flows. As trade patterns for ICT equipment – our primary object of interest – could be very different from aggregate trade flows, findings for aggregate trade flows do not necessarily carry over to trade flows in specific commodity categories.

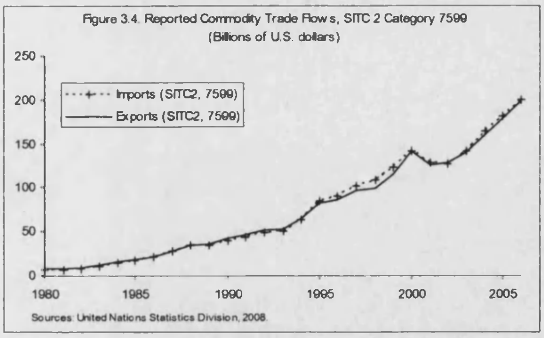
about half of the total) is the UN Comtrade region "Other Asia, nes," most probably reflecting that Taiwan Province of China is included in this region.[168]

In some regards, trade in SITC category 7599 (Parts of IT equipment) shows a similar picture, in particular regarding the role of trade with non-reporters, which accounts for up to 11.3 percent of all imports by reporting countries, and a smaller proportion of exports, suggesting that non-reporters are net exporters in this category (Figure 3.6). However, unlike for SITC 2 category 752, most of the discrepancies between reported exports and imports on the global level are not related to non-reporters, but to the fact that reporter report higher exports to each other than they report as imports from reporters (Figure 3.5), suggesting some inconsistencies between data across countries.

For communications equipment (Figure 3.7), the share of trade between reporters is lower than for IT-related equipment in the early 1980, notably for exports of IT equipment where reporters account for only about three-quarters of exports to reporters in 1980. However, the share of reporters increases to about 90 percent by the mid-1990s and to about 95 percent in the later years covered by Figure 3.

Figure 3. Global Trade Flows in SITC 2 Categories 752 and 7599





[168] For the early years covered by Figure 3, Brazil – then a non-reporter – also is an important source country for imports of IT equipment.

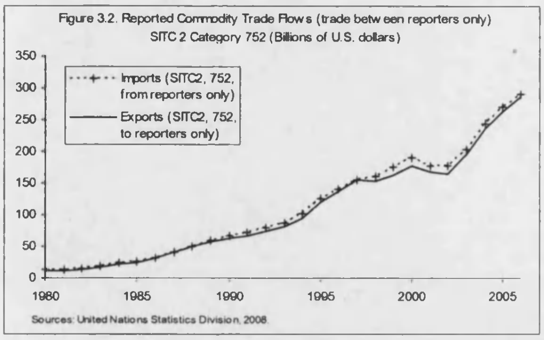


Figure 3.2. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 752 (Billions of U.S. dollars)

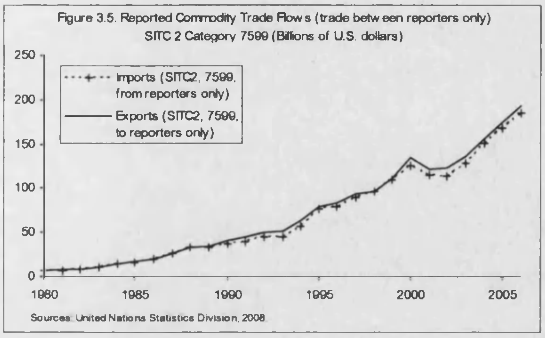


Figure 3.5. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 7599 (Billions of U.S. dollars)

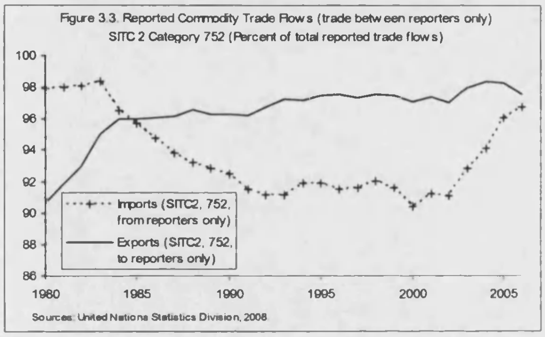


Figure 3.3. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 752 (Percent of total reported trade flows)

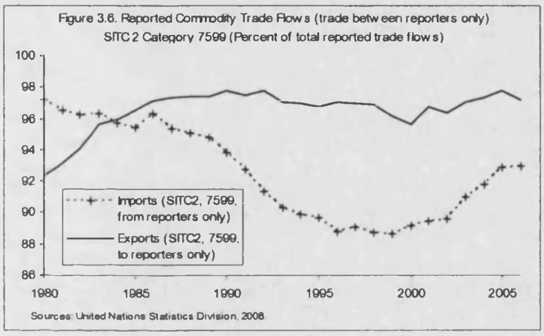


Figure 3.6. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 7599 (Percent of total reported trade flows)

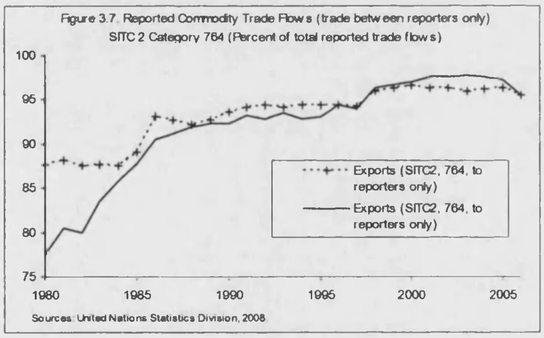


Figure 3.7. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 764 (Percent of total reported trade flows)

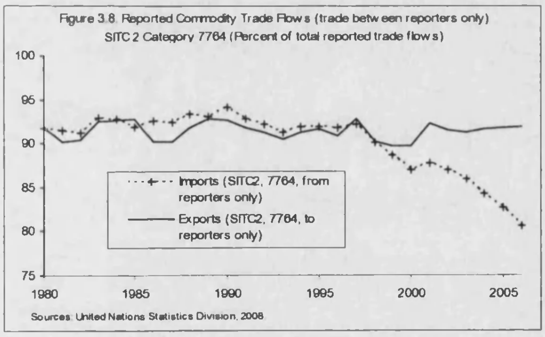


Figure 3.8. Reported Commodity Trade Flows (trade between reporters only) SITC 2 Category 7764 (Percent of total reported trade flows)

The share of trade between reporting countries for SITC 2 Category 7764 (integrated circuits), however, shows a different pattern than those observed for ICT equipment. For exports of ICT equipment, the coverage of the data appears to be somewhat lower than for IT equipment at the start of the period under consideration, and remains flat afterwards. For imports of ICT equipment, the share of trade between reports starts at 92 percent, but is has fallen steeply since 1997 to only 80 percent in 2006.

Overall, the data summarized in Figure 3 suggest that the coverage of our data appears fairly complete, either bilaterally between reporters or partially as one of the parties of a trade transaction is a reporter. Under fairly general assumptions, the trade between non-reporters accounts for a very small proportion of global trade in IT products. According to our data, the share of trade between non-reporters would attain a non-trivial proportion only if non-reporters highly disproportionally trade with each other.[169]

Nevertheless, the gaps in the data suggest several problems that may arise if partner country data are used to substitute for missing data from non-reporters. First, for non-reporting countries, trade data proxied by aggregating the corresponding bilateral trade flows from partner countries are biased, as the proxies do not capture all trade flows. Second, if data from reporting and (proxied data for) non-reporting are merged in a dataset, (proxied) trade for non-reporters (and for groups containing a disproportionate share of non-reporters) will appear lower than for reporting countries; if the extent to which data are reported is correlated across countries, this can introduce bias in econometric inference. Third, as the number of reporting countries increases over time (and thus the extent to which partner country data capture the trade of non-reporting countries), the declining measurement error introduces artificial trends in the data. We will get back to these points further below.

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[169] A simple numerical example may illustrate this. Suppose that non-reporters account for 10 percent of world exports and 4 percent of imports, import 10 percent of their imports from non-reporters, and that 4 percent of their exports go to non-reporters (roughly in line with actual numbers for SITC 2 category 952, assuming that the trade patterns of non-reporters, regarding the shares of non-reporters, is the same as for reporters. In this case, non-reported trade flows (where both partners are non-reporters) account for 0.4 percent (4 percent of 10 percent) of global trade flows.

In addition to the criterion of *completeness* of partner country data, which we just discussed, it is also necessary that there is a good *correspondence* between the corresponding bilateral trade flows across countries. This cannot be tested directly for the non-reporting countries (as we generally do not have the trade data for these countries). However, it is possible to analyze the extent to which data between reporting countries match. While a good match between reporting-country data is neither necessary nor sufficient for reporting-country data being a good proxy for the data of non-reporting countries, problems in matching data between reporting countries may signal problems in applying this approach to create proxies for non-reporting countries.

We therefore create proxies for imports and exports of commodities of interest (SITC 2 categories 752, 7599, 764) for all reporting countries covered by our sample, by aggregating the trade flows to and from any reporting country by reporting trade partners. This yields a total of 2862 observations over the years 1980–2005. We then assess the quality of these proxies by using them to "predict" the actual trade flows reported by country *i*. Specifically, using m_{ij} to note imports to country *i* from country *j* reported by country *i*, and x_{ij} exports to country *j*, reported by country *i*, we proxy country *i*'s imports $m_i \equiv \sum_{i,i \neq j} m_{ij}$ by partner country's exports $\tilde{m}_i = \sum_{j,j \neq i} x_{ji}$, and country *i*'s exports $x_i \equiv \sum_{i,i \neq j} x_{ij}$ by $\tilde{x}_i = \sum_{j,j \neq i} m_{ji}$. Below, we test the quality of $\tilde{m}_i$ or $\tilde{x}_i$ as a proxy for m_i or x_i by estimating the equation $log(m_i) = \alpha + \beta\, log(\tilde{m}_i) + e_i$ (or $log(x_i) = \alpha + \beta\, log(\tilde{x}_i) + e_i$), where we would like to see α to be close to zero, β to be close to 1, and the variance of the error term to be small.

Table 4. Relation Between Reported Trade Data and Data Predicted From Partner Country Data

Dependent variable	Constant	Predictor ($\tilde{m}_i$ or $\tilde{x}_i$)	R^2	F-test
m_i (SITC 952)	0.16*** (0.03)	0.67*** (0.09)	0.57	F(2,2862)=127.5***
x_i (SITC 952)	0.00 (0.01)	0.96*** (0.03)	0.91	F(2,2862)=3.7**
m_i (SITC 9599)	0.00*** (0.02)	0.95*** (0.09)	0.77	F(2,2862)=2.55*
x_i (SITC 9599)	0.04*** (0.01)	1.04*** (0.06)	0.78	F(2,2862)=29.5***
m_i (SITC 952+9599)	0.12** (0.05)	0.86*** (0.01)	0.74	F(2,2862)=31.6***
x_i (SITC 952+9599)	0.01 (0.01)	1.02*** (0.03)	0.92	F(2,2862)=3.6**
m_i (SITC 964)	0.08*** (0.08)	0.86*** (0.12)	0.65	F(2,2862)=6.4***
x_i (SITC 964)	0.05*** (0.01)	1.01*** (0.06)	0.69	F(2,2862)=27.0***

Based on import and export data from United Nations Statistics Division (2008), transformed in terms of percent of GDP using GDP data from IMF (2008). Heteroskedasticity-consistent standard errors in parentheses. The F-test relates to the joint hypothesis that $\alpha = 0$ and $\beta = 1$. 1,2, and 3 stars indicate coefficients significant at the 10-, 5-, and 1-percent level. For the F-tests, 1,2, and 3 stars indicates that the hypothesis is rejected at the 10-, 5-, and 1-percent level.

We find that there is a fairly good match between the reported data and the proxies created from trade data, with a median R^2 of 0.73 (excluding the regressions for the composite of SITC 2 categories 952 and 9599). Most of the estimated coefficients are in the vicinity of the desired values of α and β (but not the coefficients for imports in SITC category 952). Some of the inconsistencies observed earlier in the global data (see Figure 3.2 and 3.5) also appear in the regressions, as reported global imports in SITC 2 category 952 exceed exports, while exports exceed imports for SITC 2 category 9599 (which could result in estimates of β exceeding 1 for exports in SITC 2 category 7599 as dependent variable, and makes the estimated coefficients for imports in SITC 2 category 752 more puzzling). Overall, the estimated coefficients (positive estimates for α, and estimates of β that tend to be below 1) are suggestive of errors in variables. The R^2 of the regressions is consistently higher for exports. This may reflect that production is concentrated in few countries, and errors in export data for the producing countries may result in large errors in predicted imports for some importing countries, while imports are more diffuse and random errors would therefore average out.

We are now in a position to revisit the problem set at the outset of the present section, the choice between three approaches to constructing a trade dataset. The gold standard in terms of the quality of the underlying data, in light of the considerable errors that may occur when constructing proxies for non-reported trade flows from counterpart data, would involve using directly reported data only. This, however, is not feasible for a study focusing on low-and lower-middle-income countries as the availability of complete data series over longer periods of time is very limited, at least for low-income countries. According to Table 5, complete trade data series are available for between 0 and 7 low-income countries for the periods considered, and the number of countries with complete series corresponds to less than half of all lower-middle income countries for all but the most recent period (2000–05).

Table 5. Availability of Complete Trade Data Series by Income Group, Various Periods (Number of Countries)

Period	Low-Income Countries	Lower-middle Income Countries	Upper-Middle Income Countries	High-Income Countries
1980–2005	0	11	5	26
1980–2000	2	11	5	29
1980–1990	3	13	6	30
1990–2000	4	18	15	31
1990–2005	5	18	16	33
2000–2005	7	38	30	42

Source: Author's calculations, based on United Nations Statistics Division, 2008.

Regarding the choice between the second of the three options outlined at the outset, which substitutes estimates constructed from partner country data only where and when directly reported trade data is unavailable, and the third option, which uses partner country data consistently even if directly reported data are available, this essentially involves accepting either of two evils, namely (i) inconsistencies in the dataset that arise when directly reported data and generated data are mixed , and (ii) introducing additional errors that arise as through inconsistencies in recorded trade flows across countries.

We adopt the second of the three options, substituting estimates constructed from partner country data only where and when directly reported trade data is unavailable. There is no well-defined criterion underpinning this choice (none of the approaches is clearly superior). Instead, the choice reflects the considerable scope for errors that can arise when substituting partner country data for missing trade data for non-reporters (Table 4), and the fairly large number of low- and lower-middle-income countries for which reported trade data are available at least on an intermittent basis (Figure 2). Alternative arguments that would support the choice of the third option could point at the inconsistencies arising from mixing different types of data, and weaker statistical systems in low- and lower-middle-income countries which introduce another source of error that can be bypassed by using partner country data.

Specifically,

- We use data as reported by countries of interest (low- and lower-middle-income countries) where available; and

- For non-reporting countries, we use proxies created by adding up the corresponding trade flows from reporting countries, but scale them to account for the share of non-reporting countries in recorded trade flows (see Figures 3.2, 3.5, and 3.7).[170]

As the choice between the second and third approach was not based on unambiguous criteria, we also create an alternative dataset, using partner country data only, which will be used as a "sanity check" against our preferred approach on some regressions we conduct. As in our preferred dataset, we scale the proxies derived from partner country data in line with the share of non-reporting countries in recorded trade flows.

Scaling the proxies to account for the share of non-reporting countries removes trends in estimates constructed from partner country data that simply reflect an increase in the share of directly reported trade in global trade flows. However, our scaling method implies an assumption that for non-reporting countries the share of trade with reporters and non-reporters, respectively, is the same as the corresponding shares for reporting countries. If this assumption is not satisfied (either overall, e.g., if non-reporting countries disproportionally trade with each other, or for individual countries with specific trade patterns), then mixing data constructed from partner country data and data directly reported introduces inconsistencies between data for different countries or over time for countries not consistently reporting data (where partner country data have to be used to fill gaps in data series).

[170] A numerical example is helpful. In 2005, 96.1 percent of imports of reporting countries were from reporting countries. To construct estimates of imports of non-reporting countries, we add up reported exports to that country, and multiply this sum by a factor of 1.041 (=100/96.1). This adjustment is exact if the share of imports from reporters is the same for non-reporters as for reporters. However, the fact that reporters include most significant producers (except Taiwan Province of China, which is not included directly in the UN Commodity Trade Database), and that producers trade disproportionally with each other, may imply that the adjustment factor does not fully remove the bias.

It is worth noting that, while the errors-in-variable issues discussed earlier and our empirical analysis summarized in Table 4 suggest that there may be more efficient rules to derive estimates for trade flows from partner-country data, we do not adopt the empirical findings regarding the relation between trade data and data predicted from partner country data (summarized in Table 4) for deriving estimates of trade flows where directly reported data are available. This would be difficult and arbitrary, as by construction the dataset these findings are based on (trade between reporting countries) does not intersect with the set of countries (or specific periods for a country) for which no directly reported data are available. One way of improving on our estimates would involve exploiting the information from low- and lower-middle-income countries for which partial series are available. As this would be very complex, in light of the heterogeneity across countries in these groups in terms of the availability of data, it is beyond the scope of the current paper and we do not pursue this line of inquiry further.

Finally, a few words about differences between our dataset and those included or employed in other studies. An earlier dataset that has been used frequently in the literature is the one included by Feenstra and others (1997), drawing on the *World Trade Database* published by Statistics Canada (1995), covering over 150 countries. The approach taken by Statistics Canada (1995) that the relevant portion of Feenstra and others (1997) is based on is similar to the approach adopted in our paper, drawing on the UN COMTRADE Database using reporter country data where available and substituting partner country data otherwise, but making some adjustments to the data to reconcile published data on exports and imports. An important shortcoming for our purposes are the asymmetries between non-reporting and reporting countries regarding the coverage of trade in ICT-related equipment, which mean that imports of IT equipment for non-reporters are likely to be understated, introducing a source of bias in econometric inference as the fact that a country is a non-reporter is correlated with economic characteristics, and as the size of the bias evolves over time.[171] This

[171] The trade data summarized in Figure 3.2 suggests that the size of this bias increases from 2 percent in 1980 to about 8 percent in 1990.

can have some implications for econometric studies, especially those drawing on a large number of countries.[172]

Feenstra (2005) updates the earlier database, focusing (for 1984–2000) on data from 72 countries reporting trade data more or less regularly. Between reporters, bilateral trade flows are reconciled by focusing on reported imports, for countries outside the group of 72 preselected economies (or, presumably, missing observations within), partner country data are adopted. In addition to the bias introduced by the method adopted for merging directly reported data and data generated from (reporting) partner country data, the Feenstra (2005) has one considerable shortcoming that makes it difficult to use for our purposes. Bilateral trade flows on the SITC 2 4-digit level exclude any flows with a value of less than $100,000. As these omissions are more relevant for small and low-income countries, and therefore are correlated with economic characteristics of countries, they introduce a further source of bias to cross-country comparisons and econometric inference.

D. Spending on ICT Equipment

In light of the limited role of production of ICT-related equipment in low- and lower-middle-income countries, the most important direct impacts of technological advances in ICTs on economic growth occur through ICT-related capital deepening.[173] However, national accounts data on ICT-related spending are generally unavailable for low- and lower-middle income countries, and it is necessary to construct data from other sources. Conceptually, domestic spending can be captured as the sum of domestic production and net imports of the relevant commodities. In our context, as production of ICT equipment plays no role in most

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[172] For example, Caselli and Coleman (2001) analyze the global diffusion of computers (SITC 2 category 952). In their study, at least 41 percent of observations regarding Latin America, and 49 percent of observations for sub-Saharan Africa, are generated from partner country data. (These rates could be highly understated, as we identify reporting countries based on United Nations Statistics Division (2008) and do not capture trade data which are included in United Nations Statistics Division (2008) but had not been reported by 1995.)

[173] Compare our discussion in chapter 4.1 and chapter 4.3, which distinguishes between productivity gains, in IT-producing sectors, capital deepening associated with falling prices of ICT equipment, and gains in total factor productivity (which may or may not be associated with economic transformations associated with ICTs).

low- and lower-middle income countries, the most important data source on domestic spending on ICT equipment therefore is net imports of the relevant commodities; while adjustments would have to be made for the few countries producing such commodities.[174]

Non-Producers of ICT Equipment

For non-producers of ICT equipment, net exports of the relevant commodities (SITC 2 categories 952 and 9599 for IT equipment, and category 964 for communications equipment) capture the domestic absorption of ICT equipment, and would be an adequate measure of ICT spending for the purpose of cross-country analyses of access to such equipment. However, as we are also interested in the contribution of ICT-related capital deepening to economic growth, we need data on ICT-related spending which are compatible with national accounts data, notably with investment data as a component of GDP by expenditure category.

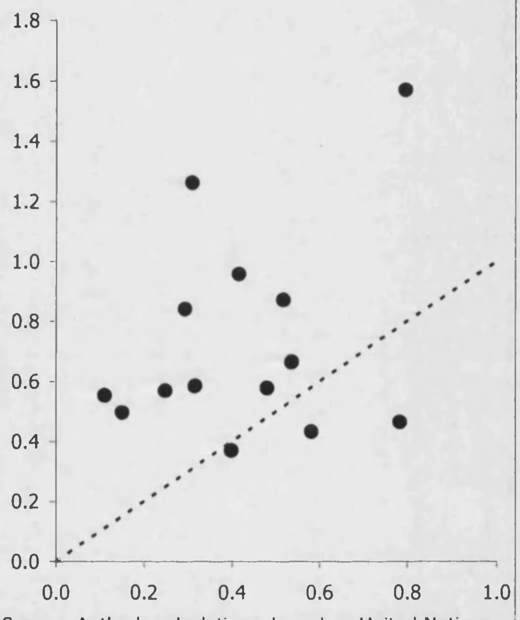
These final expenditure data include components which are not included in trade data. First, the trade data we use are available on a fob ("free on board") basis, and do not include insurance, freight, and related costs. Additionally, the importer bears the costs of customs clearance, and would be liable to pay import tariffs. Additionally, other indirect taxes may apply (value added tax, sales tax, and excise taxes), and final expenditure data would also include costs incurred on the retail level, in addition to any profit margins. For these reasons, expenditures on ICT-related equipment in the national accounts would be considerably higher that the costs of net imports.

In the absence of cross-country data on most of these costs (with the possible exception of import tariffs and taxes), one way of assessing the size of mark-ups involves comparing available expenditure data on ICT equipment for the countries of interest with the corresponding trade data. To this end, we consider data from the Global IT Navigator database (Global Insight, 2006), which provide expenditure data for 24 low- and lower-middle-income countries. Of these 24 countries, 10 countries had non-zero production of IT

[174] See Caselli and Coleman (2001) for a discussion of similar issues.

equipment.[175] For the remaining 14 countries,[176] Figure 4 shows average levels of spending on IT hardware and net imports of IT equipment for 1999–2005 (the years covered by Global Insight, 2006), confirming that spending generally is much higher than recorded net imports, with 11 of the 14 countries above the 45° line. On average, spending on IT hardware from Global Insight (2006) exceeds net imports of IT equipment by 72 percent.[177]

Figure 4. IT-Related Spending and Net Imports, 14 Countries, 1999-2005 (Percent of GDP)



Source: Author's calculations, based on United Nations Statistics Division (2008), Global Insight (2006), and International Monetary Fund (2008).

To construct a dataset on ICT spending, we will proceed in two steps.

[175] China, Egypt, India, Indonesia, Iran, Morocco, Philippines, Sri Lanka, Thailand, and Ukraine, all showing production of IT equipment of at least 0.01 percent of GDP in any year between 1999 and 2005 in Table 2.

[176] Bangladesh, Bolivia, Cameroon, Colombia, Ecuador, Honduras, Jamaica, Jordan, Kenya, Pakistan, Peru, Senegal, Tunisia, Zimbabwe.

[177] When a least-squares criterion is applied, the mark-up ranges from 39 percent (when IT hardware spending is used as dependent variable) to 102 percent (when net imports are used as dependent variable).

- We adopt data from Global Insight (2006) and WITSA (2001) on spending where available (note that this applies to producers of IT equipment only).

- For other countries, we generate estimates of spending on IT equipment by applying a markup of 72 percent to net imports in SITC categories 752 and 7599, based on the sample averages for the countries captured in Figure [x].

- For spending on communications equipment, where domestic spending figures are unavailable, we apply the same mark-up of 72 percent to imports in SITC 2 category 764.

Producers of ICT Equipment

For producers of IT equipment, estimating spending data from trade and production data is more complex, owing to the higher gross trade volumes for these countries (reflecting both re-export trade and trade in intermediates, which introduces an additional source of measurement error.[178] This is an issue especially for spending on communications equipment (where we do not have national spending figures), whereas we do have expenditure data for all countries which are large IT producers. Overall, we adopt the following approach(es) to estimating spending volumes for producers of ICT equipment:

- We adopt data from Global Insight (2006) and WITSA (2001) on spending on IT equipment where available.

[178] To illustrate this point, we abstract, for the moment, from any markups that would have to be applied to production, trade, or spending to draw inferences across these categories. Define, for simplicity, production as the sum of value added and importers of intermediates ($P = VA + I_P$), spending as the sum of production and imports of ICT equipment destined for spending ($S = P - E + I_S$), and net exports as exports minus imports of ICT products used as intermediates and for final sales $E_{NET} = E - I_S - I_P$. If the sum of spending and net exports is used as a proxy for spending, imports of intermediates create a downward bias, as $\tilde{P} = S + E_{NET} = P - I_P$, whereas using production minus net exports as a measure for spending results in an upward bias, as $\tilde{S} = P - E_{NET} = S + I_P$.

- For spending on communications equipment, or spending on IT equipment for the countries where spending data are unavailable,[179] we apply the same mark-up as for non-producers to net imports of IT equipment.

- We obtain estimates of ICT-related spending as the sum of the relevant net imports (plus markup) and of estimated production levels at face value. The zero markup applied to production data reflect two considerations. We apply a deduction of 20 percent of the production value to account for intermediates, and apply a markup of 20 percent to the production value to account for markups on any domestically produced ICT products absorbed domestically, and any markups that may apply to transform production values into fob export prices. The two markups go in different directions and happen to cancel out.

E. Prices of ICT Equipment

Adequately measuring prices of ICT equipment is a crucial issue in understanding the economic impacts of advances in ICTs, as the rate of technological progress embodied in ICTs (and, indirectly, the contribution of ICTs to economic growth) is generally measured by the rate at which prices of these commodities decline. Our discussion first covers issues regarding the measurement of prices of ICTs, focusing on data and literature from the United States. We then discuss issues regarding cross-country analyses of prices of ICT equipment, notably regarding the construction of price series which allow for an assessment of contributions of ICTs to growth across countries. Finally, we define and describe the price series for ICTs used elsewhere in this study, which are available from Table [x] at the end of this section.

Measuring Prices of ICT Equipment

In case of certain well-defined commodities, technological progress can be measured based on the ratio between outputs and inputs, or declines in prices of the respective products

[179] For 1999–2005, this applies to Albania, Kyrgyz Republic, and Vietnam. For 1990–1998, it applies to the same three countries, as well as Iran, Moldova, and Peru.

(controlling for input prices). For ICT products, this is complicated by the fact that the technical specifications of ICT equipment change rapidly, so that (a) products (e.g. computers) are not comparable over time (as typical specifications change), and (b) weights within categories change rapidly (as outdated models disappear from the market and new ones become introduced).

As we are dealing with aggregated data, we are primarily concerned with the first issue.[180] In the context of national accounts, the most common approaches for addressing changes in the quality of commodities are either the application of matched-model indices (which are based on the evolution of the price of specific models over time) or the construction of "hedonic indices," which "make use of a (...) relation between the prices of different varieties of a product, such as the various models of personal computers, and the quantities of characteristics in them" (Triplett, 2004).[181]

Hedonic price indices are widely regarded as the preferred method for constructing price indices for ICT products, owing to the rapid technological change in the sector and the evolving specifications of ICT products. Working Party on Indicators for the Information Society (2005) recommends the use of hedonic indices for ICT equipment, and U.S. National Income and Product Accounts and Producer Price Indices employ hedonic indices for key categories of IT equipment, although less so for communications equipment (see Grimm and others, 2005).

Figure 5 illustrates the declines in relative prices of key categories of production or spending for the United States. The series shown have been generated from the corresponding U.S. National Income and Product Accounts and producer price indices by dividing the series by the CPI, and then rescaling the series, setting the 1990 values equal to

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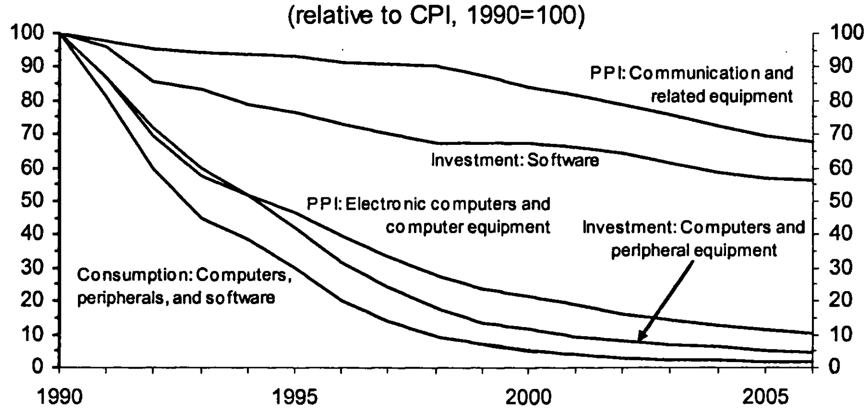
[180] To address the issue of rapidly shifting weights among the components of an index, "chain-weighting" provides some remedy. See Whelan (2002) for a discussion.

[181] The most comprehensive study discussing the application of hedonic indices and other price indices accounting for quality changes is Triplett (2004). Working Party on Indicators for the Information Society (2005) also provides a discussion of key features of hedonic indices, drawing on Triplett's study. Aizcorbe and others (2003) also provide a thorough discussion of differences between hedonic and matched-model indices.

100.[182] Figure 5 shows rapid declines for computers and related equipment, for investment, durable consumption goods, and producer prices, with an average rate of decline (relative to the CPI) averaging between 13 percent per year (PPI) and 23 percent a year (consumption spending on IT equipment and software). The declines of prices in software (3.6 percent per year) and communications equipment (2.4 percent per year) are much less pronounced, although these rates still translate into a substantial overall decline in relative prices of 44 percent and 33 percent, respectively, over the 1990–2006 period.

Figure 5. U.S. Price Indices for ICT Equipment (relative to CPI, 1990=100)



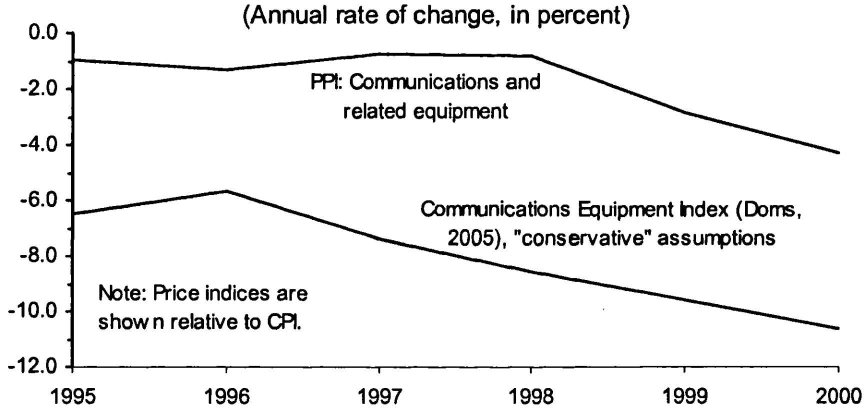
Sources: Author's calculations, based on data from U.S. Department of Commerce, Bureau of Economic Analysis (2008) for investment and consumption price indices (NIPA Tables 5.3.4 and 2.3.4, respectively), and from U.S. Department of Labor, Bureau of Labor Statistics (2008) for producer price indices.

The much lower rates of price declines for communications equipment are puzzling, considering that this sector has been characterized by very high rates of technological progress and a profound transformation. Doms (2005), in a study that has been recognized (e.g., by Jorgenson, 2005) as a major improvement in measuring changes in prices of communications equipment, attributes the relatively slow pace in research on prices of communications equipment to two factors – (1) communications equipment covers a more diverse set of products, and (2) large chunks of communications equipment are not sold on the retail level, and prices are not as widely published as for computer-related equipment.

[182] The PPI series for electronic computers and computer equipment goes back to 1991 only, and has been extended through 1990 using the rate of change of the deflator for investment in computers and peripheral equipment.

To address these shortcomings, Doms (2005) collects the available evidence on changing prices of communications equipment, constructing improved indices "bottom-up," i.e. by assembling evidence on changing prices of different types of communications equipment (accounting for quality changes), and aggregating. Figure 6 illustrates the differences between the U.S. producer price indices for communications equipment and the corresponding series constructed by Doms (2005) for 1994–2000, the years covered by his study. The adjusted series declines at a much faster rate than the series from the U.S. producer price indices, suggesting that the declines in producer price indices substantially understate technological gains embodied in communications equipment.

Figure 6. Price Indices for Communications Equipment
(Annual rate of change, in percent)



Sources: Author's calculations, based on Doms (2005), and data from U.S. Department of Commerce, Bureau of Economic Analysis (2008) the U.S. Department of Labor, Bureau of Labor Statistics (2008).

Issues regarding price measurement in cross-country studies

For international comparisons of the contribution of ICTs to growth, differences in statistical methods applied in national accounts to the measurement of prices of ICT equipment can blur the picture. The margin of error introduced by discrepancies in statistical methods has been illustrated by Schreyer (2002), and in a more extensive working paper version (2000). For example, he points at differences in the national price indices between the United States, where the price index for investment in office, accounting, and photocopying equipment declined by 22 percent annually in 1995–99, and Germany, where the rate of decline for the corresponding index was only 7 percent over this period. Gust and Marquez (2000) also provide a overview of statistical methods applied to computer prices in national accounts with a larger coverage of countries, although a less explicit analysis.

Adopting national price indices (resulting in the noted inconsistencies, but consistent with other national data) could make sense in some circumstances. However, for measuring the economic impacts of ICTs across countries, this seems hardly adequate. Therefore, cross-country studies normally use either of two approaches – constructing "harmonized indices," or applying U.S. indices adjusted for exchange rates.[183] Reflecting a consensus that U.S. price indices for ICT equipment represent the state of the art in measuring price developments for ICT equipment (in spite of noted problems in some areas, some of which are discussed above), the "harmonized index" is based on the smoothed difference between prices of respective categories of ICT equipment and of non-ICT investment goods for the United States. Based on the observation that most ICT equipment is highly tradable, some studies generate price indices for cross-country studies by applying an exchange-rate adjustment to the U.S. price indices (e.g., Daveri, 2002, also Bayoumi and Haacker (2002), although in a somewhat different context). While this measure may approximate price developments in a country of interest fairly well (depending on the extend and speed of pass-through), the drawback is that it could be dominated by exchange rate developments, rather than providing a measure of technical progress.

Construction of price series used in this study

Given the focus of our study on developing countries, applying "harmonized indices" is not feasible as meaningful price indices for investment (especially those differentiating between equipment and residential investment) are not available for many developing countries. As we mainly want to use price indices for ICT equipment for an assessment of the contribution of advances in ICTs to economic growth, using U.S. indices adjusted for exchange rates is also problematic, as these may be dominated by exchange rate changes for some countries in our wide sample, whereas we are primarily interested in the portion of ICT prices that can be attributed to technological progress in ICTs.

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[183] For examples of the first approach, see, among others, Bassanini and Scarpetta (2002), Colecchia and Schreyer (2002), Jorgenson (2005), or Schreyer (2002).

The measure of productivity gains embodied in ICT equipment that we are using in this study are therefore based on the respective U.S. indices relative to the U.S. consumer price index. We choose not to use the price index for non-ICT equipment as a benchmark, as the investment data for developing countries we use do not differentiate between equipment and residential investment, removing one advantage for using harmonized indices as described above. Also, the price index for non-ICT equipment investment may also reflect productivity gains in certain manufacturing sectors.

That said, using the CPI as a benchmark also carries some problems. First, the CPI includes some ICT-related components. In light of the low weight of ICT spending in consumer spending, we estimate that the impact of declining prices of ICTs on the consumer price index amounts to about 0.1 percentage points in 2006. We do not correct for the impact of declining prices of ICTs, this factor alone may result in a very small over-estimation of the impact of technological progress in ICTs.[184]

Second, the CPI itself is affected by changes in MFP (beyond the impacts of ICTs. This could result in an underestimation of the impact of technological progress in ICTs, if this estimate is based on a comparison with the CPI. The size of the bias could be of an order of magnitude of around 1 percentage point – possibly somewhat higher after 2000 – judging from estimates of MFP growth available for the United States (see, for example, Jorgenson, 2005, and our discussion in chapter [4.1]).

Overall, our measure of technological progress in ICTs, i.e. declining relative prices of ICTs, therefore suffers from a small downward bias (i.e., it is underestimating the rate of technological progress). As the size of the bias appears moderate, we do not correct for it. The benefit of this approach is that our price series are directly derived from published data.

Table 6 summarizes the relative price series used elsewhere in this study.

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[184] With prices of IT equipment declining at more than 10 percent per year (see our discussion of Figure [x]), an adjustment of 0.1 percentage points would account for less than 1 percent of the annual price change.

Table 6. Relative Prices of ICT Equipment, 1990–2006 (1990=100)

Year	NIPA: Investment: Computers and peripheral equipment	PPI: Communication and related equipment	Communication and related equipment (based on Doms, 2005)	PPI: Integrated microcircuits
1990	100.0	100.0	*100.0*	100.0
1991	86.7	97.7	*91.8*	85.3
1992	71.9	95.4	*84.3*	73.4
1993	59.7	94.3	*78.3*	70.1
1994	51.4	93.8	73.2	69.7
1995	42.1	92.9	68.4	61.1
1996	31.5	91.6	64.6	46.4
1997	23.9	90.9	59.8	34.4
1998	17.6	90.2	54.7	25.0
1999	13.4	87.6	49.5	22.7
2000	11.4	83.9	44.2	20.3
2001	9.2	81.4	*40.2*	16.1
2002	7.8	78.8	*36.6*	14.3
2003	6.8	75.8	*33.0*	13.6
2004	6.2	72.3	*29.5*	12.5
2005	5.3	69.7	*26.6*	11.5
2006	4.5	67.7	*24.3*	10.4

Source: Author's calculations, as described in text, based on data from U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005). Underlying indices have been divided by the CPI and scaled so that 1990 values = 100. Estimates from Doms (2005) were available for 1994-2000 only. For 1990-93 and 2001-06 (numbers shown in italics), the series were extrapolated, assuming that the price index for communication equipment declines at a rate that is 6 percent faster than in the PPI statistics.

F. Other Data

Data on **GDP** (in millions of U.S. dollars) and **GDP per capita** (in U.S. dollars) were obtained from the IMF's *World Economic Outlook* database (IMF, 2008).

Data on the **sectoral composition of GDP** (specifically the shares of agricultural value added and industrial value added in GDP) were obtained from the World Bank's *World Development Indicators 2007* (2007). For numerous countries, estimates on the shares of the respective sectors in GDP were not available for 2006 (to a lesser extent, this also applies to 2005 and 2004, and, for a few countries, earlier years). In these cases, the latest available estimates were used for the missing years. Similarly, some missing values for early years were approximated by the earliest available estimate, and in few cases, missing values were approximated by linear intrapolation.

Data on **tariff rates** were obtained from the IMF's Trade Policy Information Database (IMF, 2008), and are defined as the simple average of import tariffs for most-favored nations. The database covers the years 1997–2007.

Data on the volume of **oil production** (in thousands of barrels per day), were obtained from the *December 2007 International Petroleum Monthly*, published by the Energy Information Administration of the United States Department of Energy (2008).

Data series on the **value of oil production** were constructed based on production data and data on oil prices from the "Global Assumptions" database maintained at the IMF, defined as the simple average of three crude oil spot prices (Dated Brent, West Texas Intermediate, and Dubai Fateh), in US$ per barrel.

The definition of **country groupings** into low-, lower-middle-, upper-middle-, and high-income countries adopted in this study is based on the World Bank's country classification for 2007 (World Bank, 2007). In our discussion of availability of trade data, we refer to a group of high-income countries excluding six countries for which trade data are included in the trade statistics of another country (Isle of Man, Liechtenstein, Monaco, Puerto Rico, San Marino, and U.S. Virgin Islands). While our dataset on trade in and spending on ICT products includes all 49 countries currently classified as low-income countries and all 54 countries classified as low-middle-income countries, the analysis is largely confined to a group of 95 countries for which a minimum set of data are available from IMF (2008), and excludes Democratic People's Republic of Korea, Liberia, Somalia, Federated States of Micronesia, Iraq, Marshall Islands, West Bank and Gaza, and Timor-Leste.

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IV.3. ICT EQUIPMENT INVESTMENT AND GROWTH IN LOW- AND LOWER-MIDDLE-INCOME COUNTRIES

A. Introduction

The primary objective of the present chapter is an assessment of the macroeconomic impacts of advances in ICTs. In this regard, it builds on the fact that the the use of ICTs is tied to the availability of certain types of equipment, such as computers for information technology, or certain communication devices (phones, or computers, depending on the type of communication) as well as the existence of a telecommunications infrastructure for communication technologies.

In the present chapter, we develop and apply a framework that draws on the existing literature on growth impacts of ICTs (see our discussion in Chapter 4.1), which is adapted to take into account the lack of availability of national accounts or industry data on a level of detail that the most common approaches to assessing the macroeconomic impact of ICTs – focusing on high-income countries – draw from (compare our discussion in Chapter IV.2).

Specifically, our study focuses on the macroeconomic impacts of ICT-related capital deepening. In the absence of disaggregated investment data, this involves drawing inferences from the observed patterns of trade and – where available – production data regarding the levels of ICT-related investment. Using a set of commonly available macroeconomic variables (e.g., investment rates, underlying growth rates), international data on relative prices of ICT equipment, and a growth-accounting framework inspired by the literature on sources of growth in high-income countries, we estimate the implications of technological advances in ICTs (i.e., falling prices of ICT equipment)[185] for the accumulation of capital and economic growth.

While the production of ICT equipment plays no role or a minor role only in most low- and lower-middle-income countries, it is a significant contributor to economic growth in a

[185] For a discussion of the "price or 'dual' approach to productivity measurement" (as Jorgenson, 2005, describes it), also see Chapter 4.5).

few countries. While the focus of the chapter is on ICT-related capital deepening, our analytical framework can also easily be applied to the study of the growth contribution of the production of ICT equipment. The main challenge here is the weakness of the data, as our production data do not identify the role of ICT-related inputs.

A third channel, which we will not attempt to quantify in this study, owing to data constraints, are generalized productivity gains associated with structural changes in the economy enabled by the usage of ICTs. Even for the U.S., the empirical evidence for such broad-based productivity gains is weak.[186] As we are dealing with countries with generally weaker statistical systems, and a less prominent role of ICT equipment, we are in no position to estimate such generalized productivity effects.

Our discussion is broadly structured in 4 parts. Section II relates our study to the existing literature on sources of growth, especially to those studies analyzing the impacts of advances in ICTs across countries. Against this background, it motivates the approach taken in the present study, which aims for (near) complete coverage of low- and lower-middle-income countries. Section III describes the analytical framework, adopting a simple growth-accounting framework with two types of capital (non-ICT-related and ICT-related) in which technological advances in ICTs are identified as falling relative prices of ICT capital. Section IV applies the framework to assessing the growth impacts of ICT-related capital-deepening, offering an analysis for a cross-section of low- and lower-middle-income countries (using 2001–06 averages of key variables), drawing on steady-state properties of the model, and an analysis covering the years 1990–2006, which distinguishes the immediate impacts of falling relative prices of ICT equipment on growth and the "multiplier effects" that arise if a shock to growth results result in changes in the rate of accumulation of capital in subsequent periods. Section V complements our analysis of the growth effects of ICT-related capital deepening with an assessment of the contribution of the ICT-producing sector to economic growth, for the limited number of developing countries where this is relevant. Section VI concludes.

[186] See, for example, discussions included in Gordon (2000) and Oliner and Sichel (2000).

B. Background

The analysis of the impact of advances in ICTs in low- and lower-middle-income countries can draw on a longstanding economic literature analyzing the sources of economic growth in advanced economies (summarized in Chapter IV.1), notably the work in the tradition established by Griliches and Jorgenson (1966, 1967). In recent years, particularly in the context of the acceleration in economic growth experienced by the U.S. economy in the latter half of the 1990s, a number of studies addressed the role of ICTs in the "growth resurgence," and identified technological advances in the production of ICTs, as well as capital deepening associated with falling prices of ICT-related equipment, as key factors behind the acceleration in economic growth.[187]

Relatedly, numerous studies have addressed the impacts of ICTs across countries, for example for the G7 economies (Jorgenson, (2003, 2005b), the OECD (see Ahmad, Schreyer, and Wölfl (2004), Colecchia and Schreyer (2002), or Pilat and Wölfl (2004)), or the European Union (see Daveri (2002) or van Ark, O'Mahoney, and Timmer, (2008)). A few studies have analyzed the impacts of ICTs across a larger number of countries, notably Bayoumi and Haacker (2002), for a group of 49 countries, and Jorgenson and Vu (2005a, 2005b, and 2007), who cover 110 countries.[188]

The key challenges regarding the study of the economic impact of ICTs across countries are inconsistencies in national accounts data across countries, and – especially for a study focusing on low- and lower-middle-income countries – lack of any disaggregated national accounts data that would identify the production of or investment in ICT equipment in the countries of interest.

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[187] See, for example, Gordon (2000), Jorgenson (2001, 2005a), Jorgenson, Ho, and Stiroh (2005), Oliner and Sichel (2000), Oliner, Sichel, and Stiroh (2007)

[188] See Chapter 4.1 for a more comprehensive discussion of the literature, which also covers studies focusing on the evidence on impacts of ICTs on the industry level. Owing to the absence of industry-level data for the vast majority of countries we focus on in the present chapter, the sample from the economic literature referred to here focuses on the aggregate impacts of advances in ICTs.

Regarding price indices for ICT equipment (crucial as the rate of price decline of a commodity can be interpreted as a measure of the pace of productivity gains in the production of that commodity), most studies referred to above resolve the issue of consistency across countries by constructing "harmonized" price indices, following Schreyer (2000, 2002), based on the difference between prices of ICT equipment and non-ICT equipment in U.S. national accounts.

The more significant constraint for our purposes is the absence of production and spending data from national accounts. Some studies aiming for a wider country coverage have adopted data on ICT-related spending from industry sources (Daveri (2002), Bayoumi and Haacker (2002), and Jorgenson and Vu (2005a, 2005b, and 2007)). The most significant effort so far in developing a global perspective on the macroeconomic impacts of ICTs are the studies by Jorgenson and Vu, using sales data published by the "World Information Technology and Services Alliance,"[189] which are available for 70 countries, and extrapolating spending data based on several secondary data sources for another 40 countries for which complete national accounts data are available from the Penn World Table Version 6.1 (Heston, Summers, and Aten, 2002) for their period of interest (1989–2003).

As a key objective of the present study is a comprehensive assessment of the growth impact of ICTs in low- and low-middle income countries, the coverage of which is limited even in the Jorgenson and Vu dataset (although it is the study with the largest coverage of countries so far, it covers only 50 of 103 countries classified as low- or low-middle-income countries by World Bank, 2007), we follow a different track.

First, we construct a database of spending on ICT equipment based on trade data (with some modifications for countries producing ICT equipment), using data reported by countries of interest where available, augmented by data from trade partners where necessary (see our discussions in Chapters 4.2 and 4.5). This yields a dataset of spending on ICT equipment with a complete coverage of all 103 low- and low-middle-income countries, going back to

[189] Version of the same database have also been used by Daveri (2002) and Bayoumi and Haacker (2002). In recent years, the WITSA database has been produced by Global Insight, and presents a subset of Global Insight's *Global IT Navigator* database used in the present study (see Global Insight, 2006).

1980 (as some countries became independent only after 1980, the number of countries covered is lower for the earlier years).

Second, rather than attempting a complete growth accounting exercise (attributing growth to inputs of labor, different types of capital, and multifactor productivity), we focus on the contributions of the production of ICT equipment and of ICT-related capital deepening to economic growth. As our accounting for the impacts of ICTs relies on the availability of data on investment and, in its crudest form, GDP, our analysis captures between 89 and 97 countries towards the end of the sample period (our analysis of the growth impacts of ICTs covers the years 1990–2006), and 80 countries at the beginning.[190] Notably, our approach does not require an estimation of the contribution to growth of changes in the supply of labor, which is a problematic area for low-income countries as frequently estimates are based on crude demographic models, and findings are difficult to interpret for the purposes of growth accounting if the economy features a large informal sector.

C. Analytical Framework

The purpose of the present section is two-fold: developing a model that will be used to assess the growth impacts of advances in ICTs, and making use of the model to calibrate some key parameters of interest regarding the impacts of ICTs, in addition to those that can be directly obtained from available data or be adapted from other studies. After introducing the key components of the model, we first derive the links between advances in ICTs and growth in the steady state.

However, as some of the impacts of falling prices of ICTs on economic growth unfold only over time, and the rates of technological advances in ICTs fluctuates, an analysis focusing on the steady-state properties of the model may yield exaggerated estimates of the (immediate) impact of ICTs on growth. We therefore adapt the model in order to track the growth impacts of advances in ICTs over time, interpreting fluctuations in the rate of change of relative prices of ICT equipment as perturbations along the steady-state growth path.

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[190] The lower coverage at the beginning of the period under consideration primarily reflects the fact that some countries became independent only after 1980, rather than data constraints.

In light of the previous discussion (in the introduction to the present chapter, and in Chapter 4.1), we focus on

the growth impacts of rising productivity in the production of ICT equipment, and

- the contribution of ICT-related capital deepening, fueled by declining relative prices of ICT equipment.

Many of the issues regarding the contribution of ICTs to growth can be captured in a straightforward growth accounting framework, differentiating between ICT products (indicated by subscript 2) and any other products (subscript 1). We assume that ICT equipment is used as an investment good only,[191] while the other good is used both as consumption goods and as investment good. Without loss of generality, we will choose good 1 as the numeraire, so that p_1 is identically equal to 1 (and will be suppressed below), and p_2 represents the relative price of ICT products. Specifically, we assume that the world is populated by economies characterized by an equation that describes output (in terms of the numeraire) as the sum of production of good 1 and 2, with

$$Y = Y_1 + Y_2 = p_1 A_1 F_1(K_{1,1}, K_{1,2}, L_1) + p_2 A_2 F_2(K_{2,1}, K_{2,2}, L_2), \qquad (1)$$

where p_i stands for the price of good i, A_i represents total factor productivity in sector i, $K_{i,j}$ stands for capital of type j used in the production of good i, and L_i is the amount of labor occupied in sector i. We assume that $F_1(\cdot)$ and $F_2(\cdot)$ are exhibiting constant returns to scale. Both good 1 and good 2 are traded, so that the use of any commodity does not need to equal production in any economy. We do not impose a global market-clearing condition on either

[191] Our approach, attributing all spending on ICT equipment to investment, differs somewhat from approaches adopted in key contributions to the literature. It is closest to the framework adopted by Jorgenson and collaborators, who also incorporate all spending on ICT equipment in the analysis. However, they use data that differentiates between investment and spending on durable consumption goods (which include ICT equipment), and adjust GDP figures for the services obtained from durable consumption goods. Other studies, including several studies by Oliner and Sichel, focus on non-farm agricultural output, and correspondingly consider ICT-related investment in those sectors only.

commodity, as we focus on a subset of countries only, and market-clearing is implicit in our dataset (as trade flows – aside from measurement errors – would have to balance out).

Concretely, we adopt a Cobb-Douglas production function, with

$$Y = A_1 K_{1,1}^{\alpha_{11}} K_{1,2}^{\alpha_{12}} L^{1-\alpha_{11}-\alpha_{12}} + A_2 p_2 K_{2,1}^{\alpha_{21}} K_{2,2}^{\alpha_{22}} L^{1-\alpha_{21}-\alpha_{22}}, \tag{2}$$

In this framework, the direct growth contribution of productivity gains in the ICT sector (an increase in A_2) can simply be obtained as the rate of growth of A_2, weighted by the share of the ICT-producing sector 2 in output, i.e.

$$dg_Y = d\left[\frac{\dot{A}_2}{A_2}\right]\frac{Y_2}{Y} \tag{3}$$

However, for the large majority of countries considered in the present study, the primary impacts of advances in ICTs arise from ICT-related capital deepening. To capture those in the present framework, we first make two related (in fact, one can argue, equivalent) assumptions:

(1) We assume that the any productivity gains in the production of ICT equipment (an increase in A_2) beyond the productivity gains in the production of non-ICT products result in a equiproportionate decline in the price of ICT equipment, i.e.,

$$x_2 \equiv \frac{\dot{A}_2}{A_2} - \frac{\dot{A}_1}{A_1} = -\frac{\dot{p}_2}{p_2}.^{192} \tag{4}$$

(2) We assume that the factor shares of capital of type 1 and 2 are the same across sectors.

The first assumption is consistent with established praxis in the literature on growth impacts of ICTs, and discussed in some detail in Chapter 4.5.[193] (To simplify notation, we

[192] Where we use a more general notation, referring to x_j, x_2 is defined by Eq. (4), and x_1 equal to 1.

use x to denote the growth rate of A_2, as introduced in Eq. (4).) The second assumption is, strictly speaking, implied by the first – if factor shares differ across sector, then productivity gains in the production of ICT equipment would also result in a change in relative prices owing to ICT-related capital deepening. On a more pragmatic level, in light of the small weight of the ICT producing sector in the few ICT-producing countries in our sample, and of the lack of availability of industry-level data for our countries of interest, there are no obvious gains from differentiating between factor shares across sectors. On the other hand, the assumption of equal factor shares allows for a considerably simplified presentation of the value of output (in terms of the numeraire), with

$$Y = AK_1^{\alpha_1} K_2^{\alpha_2} L^{1-\alpha_1-\alpha_2}, \tag{5}$$

with $\alpha_1 = \alpha_{11} = \alpha_{12}$, $\alpha_2 = \alpha_{21} = \alpha_{22}$, $K_1 = K_{1,1} + K_{1,2}$, $K_2 = K_{2,1} + K_{2,2}$, $L = L_1 + L_2$, and $A = A_1 + A_2 p_2$, the latter growing at the same rate as A_1 by virtue of Eq. (4).[194]

Using the constant-returns property of the production function, and transforming it into per-capita terms, gives

$$y = Ak_1^{\alpha_1} k_2^{\alpha_2}, \tag{6}$$

where $y \equiv Y/L$, and $k_i \equiv K_i / L$. The accumulation of capital of type j ($j \in \{1,2\}$) is governed by

$$\dot{k}_j = \frac{s_j y}{p_j} - (\delta_j + n) k_j, \tag{7}$$

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[193] See, for example, the brief discussion of the "dual approach to productivity measurement" in Jorgenson (2005a), or Schreyer (2002) and Triplett (2004) for a more substantial treatment of the issue.

[194] Note that this representation of the value of output formalizes the point made elsewhere (Chapters 4.1, 4.2), that productivity gains in ICT-producing sectors, for producer countries, dissipate owing to falling relative prices of these products.

where a dot above a variable indicates a rate of change, s_j is the share of national output invested in capital goods of type j, and δ_j is the physical rate of depreciation of good j, and n the rate of population growth.

From Eq. (2), the rate of growth of output per capita is given by

$$g \equiv \frac{\dot{y}}{y} = \frac{\dot{A}}{A} + \alpha_1 \frac{\dot{k}_1}{k_1} + \alpha_2 \frac{\dot{k}_2}{k_2}. \tag{8}$$

To estimate the contribution of ICT-related capital deepening to growth, it is thus necessary to determine the growth rates of the stocks of non-ICT and ICT capital, and to establish values for the respective elasticities α_1 and α_2. By integrating Eq. (7), we obtain an estimate of the stock of capital, as

$$k_j(t) = \int_{-\infty}^{t} \frac{s_{j,\tau} y_\tau}{p_{i,\tau}} - (\delta_j + n_\tau) k_{j,\tau} d\tau . \tag{9}$$

For ICT equipment, this can be calculated (in a corresponding discrete-time presentation) based on the available data on spending on ICT equipment and the relevant prices, in addition to data on GDP per capita, population growth, and the rate of depreciation of ICT equipment. The rate of growth of the respective capital stocks is then defined as

$$\frac{\dot{k}_j(t)}{k_j(t)} = \frac{\frac{s_{j,t} y_t}{p_{j,t}} - (\delta_j + n_t) k_{j,t}}{\int_{-\infty}^{t} \frac{s_{j,\tau} y_\tau}{p_{j,\tau}} - (\delta_j + n_t) k_{j,\tau} d\tau}. \tag{10}$$

A key aspect of Eq. (10), for the purposes of estimating the growth impacts of ICT-related capital deepening, is the role of the relative price of ICT equipment, p_2.[195] Eq. (10) shows that the faster this price declines, the larger is the growth rate of the stock of ICT-

[195] Recall that we set $p_1 = 1$ by choice of numeraire.

related equipment. The same rate of ICT-related investment in period t as in earlier periods, owing to a lower relative prices at time t relative to earlier periods, translates into larger real increments to the capital stock of ICT equipment. (Vice versa, as ICT equipment was relatively more expensive in the past, the same rate of investment in the past bought little ICT equipment.

Steady-State Properties of Model

While the general framework just describes allows for a calibration of the economic impacts of advances in ICTs over time, analyzing the steady-state properties of the model is interesting because it conveys information about the long-term impacts of advances in ICTs, and as it allows for an analytically tractable description of the impacts of ICTs on economic growth. To this end, a key challenge in estimating the growth contribution of ICT-related capital deepening regards the elasticities α_1 and α_2, which cannot be measured directly. To this end, we use the steady-state version of the model spelled out above, in order to obtain a mapping from parameters that can be observed or estimated more directly to α_1 and α_2.

Provided that a steady-state with constant s_j, and constant growth rates of k_j, y, and p_i exists, Eq. (9) can be rearranged as

$$k_j(t) = \int_{-\infty}^{t} \frac{s_j y_t e^{g(\tau-t)}}{p_{j,t} e^{-x_j(\tau-t)}} - (\delta_j + n) k_{j,t} e^{\gamma_j(\tau-t)} d\tau, \tag{11}$$

where γ_j represents the steady-state growth rate of k_j (assumed constant), which simplifies to yield

$$k_{jt} = \frac{s_j y_t}{p_{jt}} \frac{1}{g + x_j} - \frac{\delta_i k_{j,t}}{\gamma_{i,j}}, \tag{12}$$

Rearranging, taking logs, and differentiating through Eq. (12) yields

$$\gamma_j \equiv \frac{\dot{k}_j}{k_j} = g + x_j, \quad \text{i.e.,} \quad \frac{\dot{k}_1}{k_1} = g \quad \text{and} \quad \frac{\dot{k}_2}{k_2} = g + x. \tag{13}$$

Substituting back into Eq. (12) , and solving the capital-output ratios k_1 / y and pk_2 / y, gives

$$\frac{k_1}{y} = \frac{s_1}{g + \delta_1 + n} \quad \text{and} \quad \frac{p_2 k_2}{y} = \frac{s_2}{g + x + \delta_2 + n} \tag{14), (15}$$

Returning to our objective of estimating the elasticities α_1 and α_2, we first note that in a world characterized by constant returns, the elasticities α_1 and α_2 are associated with the factor shares for the respective capital goods. While the factor shares for ICT- and non-ICT-related equipment are not generally available, estimates for the overall factor share of capital (denoted α) are available, and α_1 and α_2 need to satisfy

$$\alpha_1 + \alpha_2 = \alpha. \tag{16}$$

A second relationship between α_1 and α_2 can be derived from a no-arbitrage condition – the condition that the rate of returns should be equal across different types of assets, after controlling for changes in relative prices of different assets and depreciation. In our context, this means that

$$\frac{dy}{dk_1} - \delta_1 = \frac{dy}{p_2 dk_2} - x - \delta_2 . \tag{17}$$ [196]

Differentiating the aggregate production function (Eq. (6) with respect to k_1 and k_2, this implies that

[196] This no-arbitrage condition is related to the concept of rental costs of capital used in the tradition of Griliches and Jorgenson (1966, 1967) to calibrate the rates of return on different types of assets, and the notion of the quality of capital (i.e., the services obtained from a unit of capital) used by Jorgenson in more recent publications (see, for example, Jorgenson, 2005a).

$$\alpha_1 \frac{y}{k_1} - \delta_1 = \alpha_2 \frac{y}{p_2 k_2} - x - \delta_2 . \tag{18}$$

Using Eqs. (14) and (15) to substitute for the (inverse of) the capital-output ratios in Eq. (18) yields

$$\alpha_1 \frac{g+\delta_1+n}{s_1} - \delta_1 = \alpha_2 \frac{g+x+\delta_2+n}{s_2} - x - \delta_2 . \tag{19}$$

As the variables and parameters, other than α_1 and α_2, can be observed or estimated, it is possible to use the relationship described by Eq. (17) to draw inferences regarding the underlying parameters α_1 and α_2. Using Eqs. (13) and (17) then yields a solution for α_2, for given g, x, δ_1, δ_2, n, s_1, and s_2, with

$$\alpha_2 = s_2 \frac{\alpha(g+\delta_1+n)+s_1(x+\delta_2-\delta_1)}{s_2(g+\delta_1+n)+s_1(g+x+\delta_2+n)} . \tag{20}$$

Using the estimate of α_2 obtained through Eq. (20), it is possible to establish the link between falling prices of ICT-related equipment and growth. Using Eq. (8), and substituting for the growth rates of k_1 and k_1 from Eq. (13), we obtain

$$g \equiv \frac{\dot{y}}{y} = \frac{1}{1-\alpha}\left[\frac{\dot{A}}{A} + \alpha_2 x\right], \tag{21}$$

which implies that

$$\frac{dg}{dx} = \frac{\alpha_2}{1-\alpha} = \alpha_2 + \alpha_2 \frac{\alpha}{1-\alpha} . \tag{22}$$

In light of Eqs. (8) and (13), this overall impact of changes in the pace of technical advances in ICTs can be broken down into the direct impacts of a change in x on the rate of accumulation of ICT capital Eq. (8)) and thus on growth (Eq. (13), represented by α_2, and the indirect effects that arise as higher growth in turn results in a faster rate of accumulation of capital (see Eq. (8)), represented by $\alpha_2 \frac{\alpha}{1-\alpha}$.

The latter effect, however, arise over time (compare Eqs. (7), (10)). If the economy does not strictly follow a steady-state growth path, equation (22) may therefore give a misleading picture regarding the impacts of advances in ICTs over time. Notably, as the rate of price declines of ICT equipment fluctuates (implying shocks that would move the economy away from the steady-state growth path), a steady-state assumption is implausible, and adopting Eq. (22) would result in exaggerated estimates of the impact of changes in the pace of technological advances in ICTs when they occur, while missing out on the lagged impacts that occur through the induced changes in the rate of capital accumulation.

To address these shortcomings of an analysis built on steady-state relationships between key variables, and to gain an improved understanding of the impacts of advances in ICTs over the last years, we will therefore adopt a different approach below, interpreting changes in the rate of technological advances in ICTs as (a series of) one-off shock(s) to an economy moving around the steady-state growth path, and explicitly analyzing the implications of those shocks over time.

Impact of ICT-Related Innovations Over Time

To get a grip on the impacts on economic growth over time of falling prices of ICT equipment, we use perturbation techniques, treating the falling prices of ICT equipment as time-variant disturbances to growth around a steady-state growth path. As it considerably simplifies notation, we adopt a discrete-time version of the model discussed above (with identical properties regarding the steady-state links between advances in ICTs and economic growth).

We denote a shock to growth at time t as γ_t, with

$$\gamma_t = -\alpha_2 \partial p_{2,t} / p_{2,t-1}, \tag{23}$$

where we use " ∂ " to denote a deviation from a steady-state growth path.[197,198] As we have already accounted for changes in relative prices of ICT equipment through the disturbance term γ_t, we can simplify the analysis considerably by focusing on the capital stock in terms of the numeraire good, which allows us to focus on the evolution of the aggregate capital stock.[199]

We use $\partial y_t / y_{t-1}$ to represent a perturbation to economic growth relative to the steady-state, which is equal to the sum of γ_t and the impacts of the induced perturbations to the accumulation of capital, i.e.

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha \frac{\partial k_t}{k_{t-1}}. \quad (24)$$

The accumulation of capital is determined by the difference equation

$$k_t = s y_{t-1} + (1 - \delta - n) k_{t-1}. \quad (25)$$

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[197] The quality of some of our assumptions rests on the extent to which price shocks are correlated over time. Some of our assumptions implicitly assume that changes in (but not levels of) γ_t are uncorrelated. If this is not the case, price shocks would result in shifts of the steady-state growth path, whereas we analyze them as disturbances around a steady-state growth path.

[198] In the discussion of the steady-state of the model, we derived an explicit solution for the impact of falling prices of ICT capital on growth. For perturbations around a steady-state growth path, the link between a change in relative prices, the induced growth rate of the stock of ICT equipment in real terms, and output growth rests on the need to equate rates of return across different types of capital. A drop in the relative price of ICT equipment implies an equiproportionate increase in the gross rate of return. Under the functional specification we adopt, this results in a reallocation of capital (or a disproportionate share of investment going to ICT equipment) until the nominal weights of ICT capital and other forms of capital are restored to the level at which rates of return are equal across assets. The overall effect on growth of this reallocation of capital is equal to the decline in prices of ICT equipment, weighted by the factor share a_2.

[199] As noted before in a more general context, our analysis assumes that changes in γ_t are uncorrelated over time.

Importantly, this relationship incorporates the behavioral assumption that savings rates remain constant as the growth rates change. For an infinite time horizon, Eq. (25) implies that

$$k_t = s\sum_{i=1}^{\infty}\left[(1-\delta-n)^{i-1} y_{t-i}\right] \tag{26}$$

Differentiating and dividing by k_{t-1}, the induced perturbation to the growth rate of capital follows

$$\frac{\partial k_t}{k_{t-1}} = s\sum_{i=1}^{\infty}\left[(1-\delta-n)^{i-1}\frac{\partial y_{t-i}}{k_{t-1}}\right], \tag{27}$$

which expands to $\dfrac{\partial k_t}{k_{t-1}} = s\sum_{i=1}^{\infty}\left[(1-\delta-n)^{i-1}\dfrac{\partial y_{t-i}}{y_{t-i-1}}\dfrac{y_{t-i-1}}{y_{t-1}}\right]\dfrac{y_{t-1}}{k_{t-1}}$ (28)

This is the point were the perturbation techniques come in, drawing on properties of the steady-state growth path to approximate the consequences of perturbations. Specifically, we approximate the capital-output ratio by its steady state value $k/y = s/(\delta+n+g)$, and substitute $(1+g)^i$ for y_{t-1}/y_{t-i-1}. Eq. (28) then becomes

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\sum_{i=1}^{\infty}\left[\left[\frac{1-\delta-n}{1+g}\right]^{i-1}\frac{\partial y_{t-i}}{y_{t-i-1}}\right] \tag{29}$$

Using Eq. (24), Eq. (29) yields a difference equation describing the induced perturbation to the growth rate of the capital stock as a function of past disturbances to output growth (γ) and past disturbances to the growth rate of the capital stock,

$\dfrac{\partial k_t}{k_{t-1}} = \dfrac{(\delta+n+g)}{1+g}\sum_{i=1}^{\infty}\left[\left[\dfrac{1-\delta-n}{1+g}\right]^{i-1}\left[\gamma_{t-i}+\alpha\dfrac{\partial k_{t-i}}{k_{t-i-1}}\right]\right]$, which implies that (30)

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\left[\gamma_{t-1}+\alpha\frac{\partial k_{t-1}}{k_{t-2}}\right]+\frac{1-\delta-n}{1+g}\frac{\partial k_{t-1}}{k_{t-2}} \tag{31}$$

Rearranging and expanding backwards towards an infinite horizon yields a presentation of $\partial k_t / k_{t-1}$ as a distributed lag of past disturbances γ, with

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\sum_{i=0}^{\infty}\left[\left[\frac{1+\alpha g-(1-\alpha)(\delta+n)}{1+g}\right]^i \gamma_{t-1-i}\right]. \qquad (32)$$

For changes to the rate of output growth, Eq. (A9), together with Eq. (A1), yields

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha\frac{(\delta+n+g)}{1+g}\sum_{i=0}^{\infty}\left[\left[\frac{1+\alpha g-(1-\alpha)(\delta+n)}{1+g}\right]^i \gamma_{t-1-i}\right]. \qquad (33)$$

Eq. (33) represents changes to output growth as the sum of the immediate impact of a disturbance (γ_t), and the transitional impacts on growth of past disturbances playing out through capital accumulation as the economy returns to its steady state.

Regarding the long-term impact of a one-off disturbance to growth at time t, γ_t, Eq. (32) implies that

$$\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}} = \frac{1}{1-\alpha}\gamma_t, \qquad (34)$$

and that the long-term impact of a disturbance γ_t on output is

$$\sum_{i=0}^{\infty}\frac{\partial y_{t+i}}{y_{t+i-1}} = \gamma_t + \alpha\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}} = \frac{1}{1-\alpha}\gamma_t, \qquad (35)$$

or, equivalently (using Eq. (23)),

$$\sum_{i=0}^{\infty}\frac{\partial y_{t+i}}{y_{t+i-1}} = \gamma_t + \alpha\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}} = -\frac{\alpha_2}{1-\alpha}\frac{\partial p_{2,t}}{p_{2,t-1}}, \qquad (35)$$

which closely corresponds to the steady-state presentation in Eq. (22), with γ_t corresponding to the immediate impact of declining prices, weighted by the respective elasticity.

D. The Contribution of ICT Equipment to Economic Growth

Building on the theoretical framework developed in the preceding section, we are now in a position to assess the growth impacts of technological advances in ICTs in low- and lower-middle-income countries. As most of these countries do not produce ICT equipment, the principal impacts of ICTs may arise through ICT-related capital deepening (in addition to more fundamental transformations in the structure of the global and national economies, which are beyond the scope of this study). The present section evaluates the growth impacts of ICT-related capital deepening, setting out by discussing some key variables and parameters. The middle part of the section provides an analysis of the contributions of ICT-related capital deepening to growth in 2001–06, using the steady-state framework outlined above. The concluding part discusses the contribution of ICT-related capital deepening to growth over the 1990–2006 period, based on the evolution of ICT-related capital stock, and also allowing the role of ICTs (i.e., the elasticity of output with respect to ICT-related capital) to evolve over time.

Key Variables and Parameters

For our analysis of the growth impacts of ICT-related capital deepening, we need to draw on some macroeconomic and national accounts data. Data on nominal GDP, real GDP growth, and aggregate investment were obtained from the IMF's *World Economic Outlook* database (IMF, 2008). Data on population size and the rate of population growth are based on the estimates by the United Nations Population Division, which are included in and were also downloaded from the *World Economic Outlook* database.

ICT-related investment was estimated following the approach described in Chapter 4.5 (Appendix Table 1 provides the average investment rates for the years 2001–05). For most countries, the estimates are based on the level of net imports of IT- and communications-related investment, respectively, applying a mark-up to account for various costs and taxes not included in the data on net imports. For some countries, the investment data are based on available data on spending; for a few countries, adjustment to the data had to be made to account for domestic production of ICT-related equipment.

A crucial variable that affects the magnitude of the growth effects of ICT-related capital deepening is the rate of decline of relative prices of ICT-related equipment. The price series we use (see Chapter 4.5, Table 6) are based on prices indices from the U.S. National Income and Product Accounts and Producer Price Indices.[200] For communications equipment, we adopt a modified series based on Doms (2005), which introduces various improvements to the official series regarding the measurement of changes in the quality of communications equipment.[201]

There are three technological parameters that our analysis requires – the overall factor share of capital α ($=\alpha_1+\alpha_2$) and the rates of depreciation of non-ICT- and ICT-equipment, δ_1 and δ_2. Estimates of α are available from numerous studies, including empirical studies estimating the elasticity of output with respect to capital directly, or (especially for countries with sophisticated national accounts) studies identifying the parameter α as the factor share of capital in GDP, and in growth accounting exercises the parameter α commonly is assumed to take a value of 0.35– 0.40. The study with the most comprehensive coverage of low- and lower-middle-income countries, which are the focus of the present study, is Senhadji (2000), providing estimates for α for 24 of the countries covered in our study. Based on his study, we assume a value for the parameter α of 0.5, which is between the median (0.47) and the mean (0.52) of the country level estimates presented by Senhadji (2000) for the 24 countries of interest here.[202]

Our choices for depreciation rates follow the estimates compiled by Jorgenson and Stiroh (2000, also included in Jorgenson, Ho and Stiroh, 2005). For IT equipment ("computers and

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[200] See U.S. Department of Commerce, Bureau of Economic Analysis (2008), and U.S. Department of Labor, Bureau of Labor Statistics, 2008.

[201] The work by Doms has been endorsed by prominent researchers in the field, including Jorgenson (2005). The series developed by Doms (2005) do not cover the whole 1990–2005 period that our study focuses on, for the outer years, we adopt an extrapolation (see Chapter 4.5 for more explanations).

[202] The numbers regard the model estimated in levels. Senhadji (2000) also provides alternative estimates for a model estimated with first differences, which are very similar.

peripheral equipment"), they propose a depreciation rate of 31.5 percent, and for communications equipment, a depreciation rate of 11 percent (this excludes structures related to telecommunications). For non-ICT capital, we adopt a depreciation rate of 6 percent – while many types of equipment are characterized by depreciation rates in the vicinity of 10–15 percent, our choice reflects that our investment data also include residential and other structures, for which Jorgenson and Stiroh propose depreciation rates mostly between 1 and 5 percent.

Steady-State Analysis

A steady-state analysis based on averages of key variables over a period of time may be a good approximation regarding the stock of ICT capital, as high rates of price decline and physical depreciation imply that investments in previous years carry a low weight in the stock of ICT capital. However, the estimates could be misleading owing to cyclical factors (business cycles, post-conflict recovery) resulting in unusual levels of ICT investment over the period under consideration. Additionally, the role of ICTs in the economy may be evolving over time (with implications for the relation between ICT investment and growth), and a steady-state analysis would not capture these effects.

Setting aside these caveats for the time being, we conduct a steady-state analysis of the contributions of ICT-related capital deepening to growth, for 97 countries for which key macroeconomic data were available over the 2000–2006 period,[203] using the analytical framework described in the preceding section (notably, Eqs. (20) and (22)). In addition to the parameters described above, which are assumed to apply across countries, our estimates of the elasticities of output (See Eq. (20)) with respect to IT equipment and communications equipment are based on country-level estimates of GDP growth and population growth based on IMF (2008).

[203] For a few countries (see Appendix Table 1), overall investment rates were not available. For these countries, we substitute the sample average of investment rates. For Afghanistan, our estimates relate to 2002–06.

Table 1. Impact of ICT-Related Capital Deepening on Growth (Steady-State Analysis), Selected Countries, 2001–06

	IT Equipment	Communications Equipment	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r.t. Communications Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communications Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)				(Percentage Points)		
Bangladesh	0.52	0.91	0.004	0.005	0.11	0.09	0.20
China,P.R.: Mainland[1]	0.46	...	0.003	...	0.10	...	...
Egypt	0.23	0.80	0.002	0.004	0.05	0.08	0.14
Ethiopia	0.80	1.52	0.006	0.007	0.17	0.14	0.31
India	0.88	1.76	0.006	0.009	0.19	0.16	0.35
Indonesia	0.41	1.48	0.003	0.008	0.09	0.15	0.24
Nigeria	0.36	1.34	0.002	0.006	0.07	0.11	0.18
Pakistan	0.58	1.20	0.004	0.006	0.13	0.12	0.25
Philippines	0.84	0.96	0.006	0.005	0.18	0.10	0.28
Vietnam	0.58	1.67	0.004	0.008	0.12	0.15	0.28
Memorandum Items							
All countries[2]	0.74	1.39	0.006	0.007	0.16	0.14	0.30
LIC	0.6	1.3	0.005	0.007	0.13	0.13	0.26
LMC	1.0	1.5	0.007	0.008	0.19	0.16	0.35

Source: Author's calculations, as described in text (see discussion of steady-state analysis), based on data from IMF (2008), Global Insight (2006), and UN Statistics Division (2008). The table shows country-level estimates for the 10 most populous low- and lower-middle-income countries. For more details (average investment rates, growth rates of GDP and population), and country-level estimates of the 87 other countries covered, see Appendix Table 1. The totals under memorandum items relate to all countries covered by our analysis, not only the ones shown in the present table.

[1] For China, data on investment in communications equipment were unavailable.

[2] Totals exclude China (as estimates on investment in communications equipment were unavailable) and Paraguay (the latter owing to severe inconsistencies in published trade data).

Table 1 summarizes our findings for the 10 most populous low- and lower-middle-income countries (Appendix Table 1 provides more details and estimates for all 97 countries covered by our analysis). Overall, we estimate that ICT-related capital deepening contributed 0.3 percentage points to economic growth in 2001–06, with just over one-half attributed to IT equipment. While the contribution of IT and communications equipment is about the same for low-income countries, IT equipment plays a larger role in lower-middle-income countries. For the 10 countries covered in Table 1, the contribution of ICT equipment to growth amounts to between 0.14 and 0.35 percentage points (for Egypt and India, respectively). It appears that variations in IT-related investment account for the bulk of cross-country variations in the contribution of ICT equipment to growth, with a contribution from IT investment between 0.05 and 0.19 percentage points, and the contribution from communications equipment ranging from 0.08 to 0.16 percentage points. This reflects a pattern that also applies for the full set of countries covered (Appendix Table 1), for which the variance in the contribution of IT equipment to growth is 60 percent higher than the variance in the growth contribution of communications equipment.

To place our estimates of the growth impacts of ICT-related capital deepening in a global context, it is desirable to compare our estimates for low- and lower-middle-income countries to the impacts of ICTs in the most advanced economies. To this end, we construct estimates or the role of ICTs based on Global Insight's *Global IT Navigator* (Global Insight, 2006), which has a high coverage of high- and upper-middle-income countries. The estimates provided in Global IT Navigator dataset we use extend through 2005 only, and do not identify spending on communications equipment. We therefore need to narrow the focus of analysis to the scale and the impacts of IT-related capital deepening, and change the period under consideration to 2001–05.

Table 2. Impact of IT-Related Capital Deepening on Growth (Steady-State Analysis), Global Insight Dataset, 2001–05

		IT-investment:		
Country Group	GDP per capita (U.S. dollars)	(Percent of GDP)	(Percent of total investment)	Contribution to growth (Percent)
28 high-income countries	26,929	1.18	5.6	0.27
18 upper-middle-income countries	4,478	1.14	5.8	0.25
18 lower-middle-income countries	1,502	0.73	3.3	0.16
5 low-income countries	624	0.72	4.1	0.16
Memorandum items:				
50 lower-middle-income countries[1]	1,748	0.88	3.8	0.20
47 low-income countries[1]	409	0.59	3.0	0.13

Source: See Appendix Table 2, and author's calculations for OECD countries.
[1] Based on the analysis presented in Table 1 for the full set of low- and lower-middle-income countries. Estimates were adjusted to take into account the shorter period covered by Global Insight (2006).

Table 2 summarizes our findings based on the *Global IT Navigator* dataset. It appears the impact of IT-related capital deepening on growth is similar between high- and upper-middle income countries (0.27 and 0.25 percentage points, respectively), whereas the growth impacts are about 0.1 percentage points lower for the lower-middle-income countries and the (few) low-income countries covered by the *Global IT Navigator* dataset, reflecting that IT-related investment is 0.4 percent of GDP lower in these countries, compared to high- and upper-middle-income countries.

Our analysis for the full sample of low- and lower-middle-income countries, however, suggests that the *Global IT Navigator* database may yield misleading results for these countries, owing to limited coverage. Adapting our estimates presented earlier to the shorter period (2001–05) covered by Table 2, we find that the growth impacts of IT-related capital deepening in low-income countries are about half of the impact in high- and upper-middle-income countries, and that the impacts in lower-middle-income countries are about half-way between the impacts in low-income countries and the impacts in high- and upper-middle-income countries.

Figure 1. Contribution of ICT-Related Capital Deepening to Growth

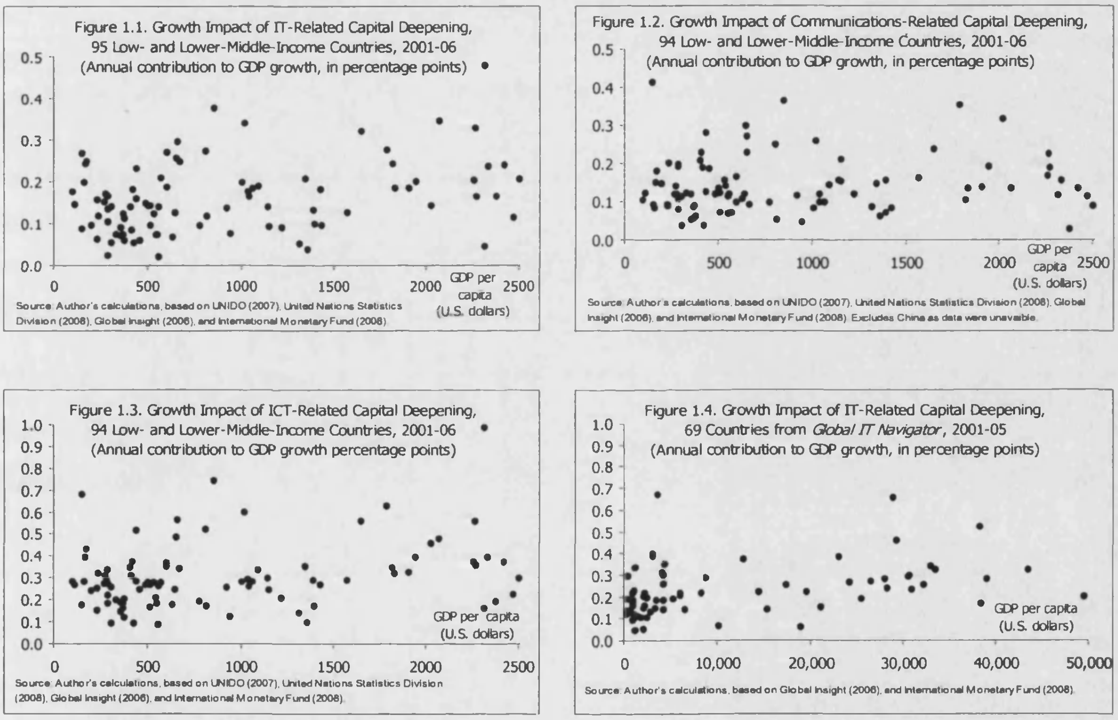

Figure 1 summarizes our findings on the country level.[204] As in our discussion of the pattern of ICT-related spending across countries (Chapter 4.2), we see very substantial

[204] To facilitate comparisons between countries, Figure 1.1 and 1.2 are truncated at 0.6 percentage points, and Figure 1.3 does not show estimates exceeding 1.0 percentage points. As a result, the figures do not show estimates of the growth impact of IT-related capital deepening for Kiribati and Paraguay (the latter is also excluded from any averages or aggregates report in the present study, owing to severe inconsistencies in published trade data). Appendix Table 1 provides more detailed data, and also covers the 2 countries not shown in Figure 1.

variation in the growth impacts of ICT-related capital deepening across low- and lower-middle-income countries with similar levels of GDP per capita. For IT-related capital deepening, the growth impact appears to be correlated with GDP per capita, reflecting the clustering of low-income countries at a growth impact of less than 0.2 percentage points. For communications equipment, the pattern across countries is less clear. Figure 1.4 shows the growth impacts of IT-related capital deepening for the *Global IT Navigator* dataset. While Figure 1.4 suggests a positive link between the growth impact of IT-related capital deepening and GDP per capita, this largely reflects the differences between high- and upper-middle income countries on one hand, and low- and low-middle income countries on the other hand. However, our discussion of growth impacts of IT-related capital deepening across countries (as well as Figure 1.1), suggest that any relations suggested by Figure 1.4 could be misleading, owing to limited coverage of low- and lower-middle-income countries in the *Global IT Navigator* dataset.

Contribution of ICT-Related Capital Deepening to Growth, 1990–2006

While a steady-state analysis as presented in the previous section can yield important insights regarding the magnitude of the impacts of advances in ICTs on growth through ICT-related capital deepening, it is not well suited to identify the evolving impacts of ICTs over time, for two main reasons.

- First, the role of ICT equipment in the economy may change over time. Our analytical framework spells out a link between investment rates in ICT equipment and the elasticity of output with respect to ICT equipment. As investment in ICT equipment has generally accelerated over the period 1990, this also points to an increase in the elasticity of output with respect to ICT equipment.

- Second, the pace of innovation in ICTs, as measured by the rates of price decline of ICT equipment, is not constant. Our analysis interpreting innovations in ICTs as perturbations around a steady-state growth path suggests that the full impact of such perturbations evolve over time, and may involve long time lags. Applying a steady-state framework, in this context, results in exaggerations of the immediate impacts of an innovation, while missing out on the lagged impacts of previous innovations.

Data issues

At the outset, we drop several countries from the analysis, owing to data limitations. Afghanistan, Liberia, and Timor-Leste were dropped as GDP data were available only from 2000 (Liberia, Timor-Leste) or 2002. Lesotho, Namibia, and Swaziland were eliminated as the UN Comtrade database subsumes trade data for these countries under the Southern African Customs Union prior to 2000. For Kiribati, Paraguay, and São Tomé & Príncipe, complete data were available, but the countries were dropped from cross-country analysis as the series for ICT-related equipment were characterized by large outliers.[205]

For some countries, investment rates were not available; in these cases, we substitute the unweighted sample averages for investment rates for the respective year.[206] In some cases, macroeconomic data for the early 1990s were not available (largely former Yugoslav and Soviet republics). In these cases, we applied simple extrapolations for the missing data.

Elasticities of Output With Respect to ICT Capital

Below, we capture the (potentially) evolving aspects of the impact of advances in ICTs over time by allowing the elasticity of output with respect to IT and communications equipment to differ not only across countries, but also over time. Figure 2 illustrates the importance of allowing for changes in the role of ICT equipment over time. Overall, investments both in IT-related equipment and communications equipment roughly doubled as a percentage of GDP between 1990 and 2006. Figure 2 also suggests some notable differences in the evolution of the role of ICT equipment between low-income countries and lower-middle-

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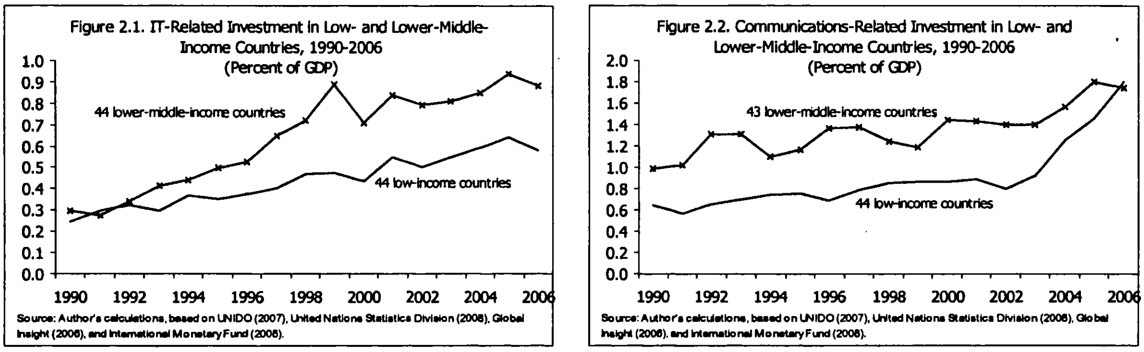
[205] For Paraguay, our estimates of IT equipment (based on net imports) rise from 2.8 percent of GDP to 17 percent of GDP by 2006. Interpretation of these trends are complicated by the fact that published trade data for Paraguay (self-reported or reported by partners in UN ComTrade database, international data like IMF (2008) show very substantial inconsistencies. The series for Kiribati (in 1992) and São Tomé & Príncipe (in 1994) show investment in communications equipment of around 30 percent in isolated years. While these may reflect very large communications investments (bearing in mind the small size of the economies), these outliers would have a dominant impact within the sample for the years indicated.

[206] The sample averages exclude Haiti and Macedonia, where investment rates in the IMF's World Economic Outlook database (IMF, 2008) exceed 100 percent of GDP for some years.

income countries. Starting at about the same level, investments in IT-related equipment have accelerated markedly in lower-middle-income countries, as compared to low-income countries. At the same time, investment in communications equipment started out lower in low-income countries, but has accelerated markedly, notably since 2002, catching up with low-middle-income countries by 2006.[207]

Figure 2. ICT-Related Investment in Low-and Lower-Middle-Income Countries, 1990–2006



In light of the apparently shifting role of ICT equipment in low- and lower-middle-income countries, we allow for variations in the elasticities of output with respect to IT equipment and communications equipment over time (in addition to cross-country differences). However, some of the variation in investments in ICT equipment appears spurious or related to business cycles, rather than reflecting short-term fluctuations in the role of ICTs in the economy. To capture the variations over time and across countries, we calibrate the elasticities of output with respect to IT and communications equipment as

$$\alpha_{IT,jt} = c_{IT,j} \cdot (\kappa_{IT} + \lambda_{IT,t} \cdot t) \quad \text{and} \quad \alpha_{COM,jt} = c_{COM,j} \cdot (\kappa_{COM} + \lambda_{COM,t} \cdot t). \qquad (36)$$

As a first step towards calibrating $\alpha_{IT,jt}$ and $\alpha_{COM,jt}$ (the elasticities of output with respect to IT equipment and communications equipment for country *j* at time *t*), elasticities were

[207] The increase in investment in communications equipment in low-income countries after 2002 cannot be attributed to specific outliers, but reflects substantial increases in a large number of low-income countries. While investment in communications equipment accelerated by at least 1 percent of GDP in 20 low-income countries between 2002 and 2006, it fell by at least 1 percent of GDP in only one country.

calculated for each country and each period, using the steady-state approximations discussed earlier (Eq. 20). Second, the linear trends $\kappa_{IT} + \lambda_{IT,t} \cdot t$ and $\kappa_{COM} + \lambda_{COM,t} \cdot t$ were obtained through regressions based on the sample averages for each period of the elasticities obtained in step 1. Third, the elasticities generated in step 1 were normalized and detrended by dividing them by the linear trends obtained in step 2. Fourth, the country-specific parameters $c_{IT,j}$ and $c_{COM,j}$ were obtained as the averages for each country of the detrended series obtained in step 3.[208] Concretely, we adopt the following specification:

$$\alpha_{IT,jt} = c_{IT,j} \cdot (0.0025 + 0.00022 \cdot t) \quad \text{and} \quad \alpha_{COM,jt} = c_{COM,j} \cdot (0.006 + 0.00018 \cdot t),^{209} \quad (37)$$

which implies that the average elasticity of output with respects to IT capital has grown from 0.0025 in 1990 to 0.006 in 2006. Meanwhile, our estimates suggest that the average elasticity of output with respect to communications equipment has increased from 0.006 in 1990 to 0.009 in 2006.

Fluctuations in Rate of Decline of Relative Prices of ICT Equipment

Regarding the impact of changes in the prices of ICT equipment over time, our analytical framework – interpreting innovations in ICTs as shocks to the prices of ICT equipment – allows us to distinguish the immediate effect of a price shock on the capital stock and the transitional effects as the economy (notably, the capital-output ratio) gradually reverts towards its steady-state growth path following a shock. Figures 3 and 4 illustrate the relevance of this point. The annual rates of price decline for ICT equipment, notably for IT equipment, fluctuate considerably (Figure 3), ranging from 8.8 percent to 26.4 percent for IT equipment, and from 5.6 percent to 10.7 percent for communications equipment. Meanwhile, Figure 4 tracks the impact of a shock to relative prices of ICT equipment over

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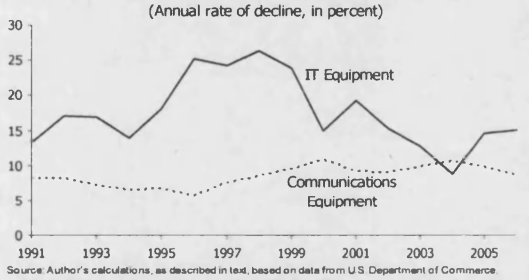
208 Taking logs and running a panel regression with a time trend would yield similar results. As most of our data are based on net imports, this would have required a reduction in the sample or other adjustments to take account of occasional negative values.

209 The R^2 of the regressions estimating the linear trend in step 2 of our approach was 0.85 for the elasticity with respect to IT equipment and 0.47 for the elasticity with respect to communications equipment.

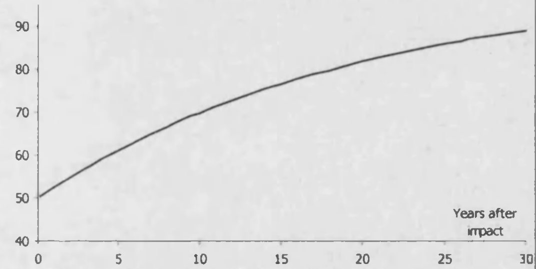
time. The immediate impact accounts for only 50 percent of the long-run effects, and the subsequent adjustment is sluggish, with half of the adjustment taking about 13 years. The persistence of the impacts of shocks to relative prices, as well as the fluctuations in the rate of price declines over time, thus validate our point that an analysis of the impacts of ICTs based on steady-state properties of the model may yield misleading results.

Figure 3. Rates of Price Decline of ICT Equipment, 1991-2006
(Annual rate of decline, in percent)



Source: Author's calculations, as described in text, based on data from U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005).

Figure 4. Impact of Shock to Relative Price of ICT Equipment Over Time
(Percent of long-term impact))



Source: Author's calculations, based on model and parameters described in text.

Estimating the Impacts of Advances in ICTs over Time

Our analysis of the impacts of advances in ICTs is based on the perturbation analysis developed above, in particular Eq. (33) and Eq. (23) which is repeated here for convenience.

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha \frac{(\delta + n + g)}{1+g} \sum_{i=0}^{\infty} \left[\left[\frac{1 + \alpha g - (1-\alpha)(\delta + n)}{1+g} \right]^i \gamma_{t-1-i} \right], \text{ with} \quad (33)$$

$$\gamma_t = -\alpha_2 \partial p_{2,t} / p_{2,t-1}. \quad (23)$$

The validity of this approach rests on the extent to which shocks to relative prices of ICT equipment affect the steady-state growth path. Such changes to the steady-state growth path can occur if agents perceive a decline in the rate of price declines of ICT equipment. This would reduce the user cost of ICT capital, and agents would allocate a larger share of the capital stock to ICT capital. While our perturbation analysis is based on the capital stock in terms of the numeraire good (we account for the change in relative prices separately), such a reallocation would affect the rate of depreciation of the overall capital stock (a weighted average of the depreciation rates of ICT-related capital and non-ICT-related capital). However, the small share of ICT equipment in the capital stock suggests that any changes to the average rate of depreciation and thus the steady-state capital-output ratio (assumed constant in our perturbation analysis) would be very limited.

One issue that we need to address is the fact that our approach requires very long time series for prices of ICT equipment (see Eq. (33), Fig. (4), beyond the beginning of the period of consideration. For IT equipment, we adopt the price index for "computers and peripheral equipment," a component of private nonresidential investment, from the U.S. National Income and Product accounts, which is available from 1960. For communications equipment, we do not have earlier price series, and apply a rate of price decline of 8 percent for earlier years, roughly in line with our estimates for the early 1990s. Regarding the elasticity of output with respect to ICT equipment (required to translate the original price shock into an output shock, see Eq. 23), extending our estimation backwards to cover years before 1990 increasingly results in problems regarding the availability of data. For this reason, we use our estimates of the respective elasticities for 1990 for the earlier periods.

Figure 5 and Table 3 summarize our estimates for the impacts of declining prices of ICT equipment on economic growth. (Appendix Table 2 provides the estimates for each of the 88 countries covered by our estimates.) The magnitude of the contributions of IT equipment and communications equipment to growth, respectively, are similar, rising from about 0.09 percent at the beginning of the period covered to 0.13 towards the end. While rates of investment in communications equipment are normally considerably higher than investment rates for IT equipment (according to Figure 2, by a factor of about 2 on average), the rates of price declines for IT equipment are higher (on average, exceeding the rates of price decline for communications equipment by a factor of about 2.2 over the 1990–2006 period), so that the magnitude of the growth effects are similar.

One interesting exception to this broad picture regards the years 1996–2000, in which the contribution of capital deepening arising from declining prices of IT equipment to growth peaks (and exceeds the contribution from communications equipment). This is the period which has motivated much of the early work on the economic impacts of advances in ICTs in the United States (e.g., Gordon (2000), Jorgenson (2001), or Oliner and Sichel (2000)). Our estimates are in line with this earlier literature (unsurprisingly, as our international price data are based on U.S. price indices). However, our distinction between the direct effects of shocks to prices of IT equipment and the indirect (and longer-term) effects through capital accumulation, which arise as the economy moves towards the steady-state growth path following a shock, provides a more differentiated picture, as the dampening impact on growth of the slowdown in the rate of decline of relative prices is partly offset by a gradual increase in the induced effects through capital accumulation.

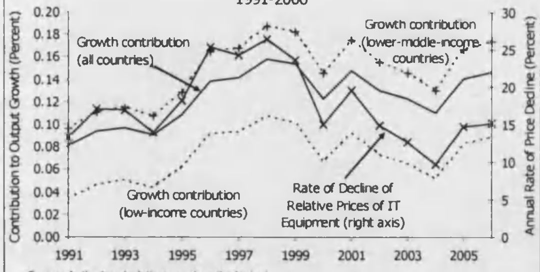
Regarding the role of the impacts of the direct impacts of declining relative prices of equipment and the indirect effects through an induced acceleration in capital accumulation, we find that the magnitude of the direct and indirect effects is similar, in line with the steady-state properties of the model.[210] Almost all of the variations in the growth impacts of falling prices of ICT equipment on a year-to-year basis reflect the direct effects of changing prices, this is a mathematical necessity as the indirect effects can be represented as a distributed lag of past price shocks with a long memory (for typical parameters, we obtain a half-time of about 13 years). However, changes in the indirect impacts play some role over longer time horizons, and contribute about one-sixth to the acceleration of the growth impacts of advances in ICTs between 1990 and 2006.

The lower part of Figure 5 (Figs. 5.5 and 5.6) summarize the overall growth effects of falling relative prices of ICT equipment for low- and lower-middle-income countries. Overall, the impacts are about one-third smaller in low-income countries, compared to lower-middle-income countries. Apart from the scale of the impact, the pattern of the impacts over time is similar between low- and lower- middle-income countries, owing to the fact that the weights of investment in IT equipment are similar across these income groups, and our assumptions regarding the evolving role of ICT equipment, reflected in the modeling of the parameter α_2.

[210] See our discussion of Eq. (22). Our choice of a value of 0.5 for the parameter α implies that the size of the direct and indirect effects is equal in steady state.

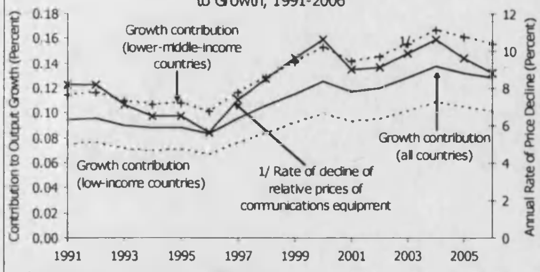
Figure 5. Impact of Declining Prices of ICT Equipment on Growth, 1990–2006

Figure 5.1. Contribution of Declining Prices of IT Equipment to Growth, 1991-2006



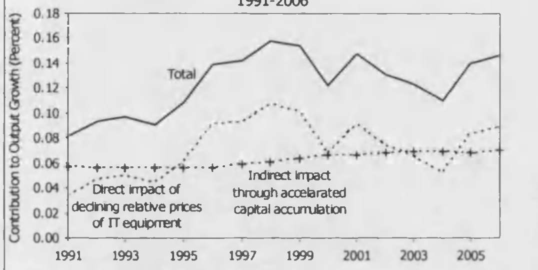
Source: Author's calculations, as described in text.

Figure 5.2. Contribution of Declining Prices of Communications Equipment to Growth, 1991-2006



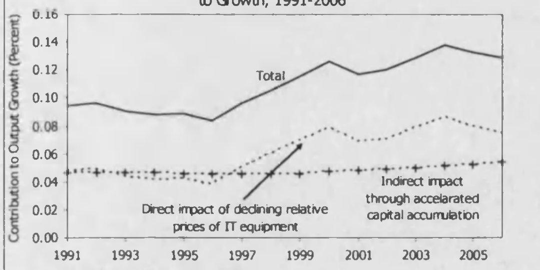
Source: Author's calculations, as described in text.

Figure 5.3. Contribution of Declining Prices of IT Equipment to Growth, 1991-2006



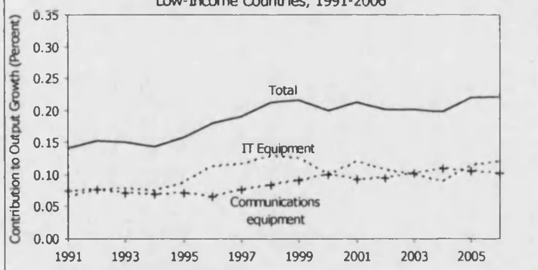
Source: Author's calculations, as described in text.

Figure 5.4. Contribution of Declining Prices of Communications Equipment to Growth, 1991-2006



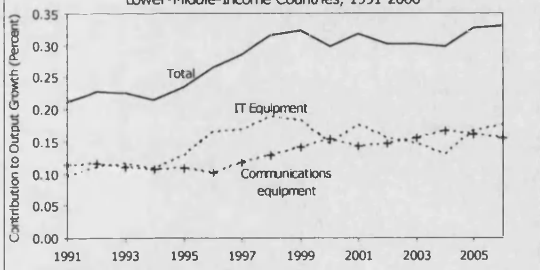
Source: Author's calculations, as described in text.

Figure 5.5. Contribution of Declining Prices of ICT Equipment to Growth, Low-Income Countries, 1991-2006



Source: Author's calculations, as described in text.

Figure 5.6. Contribution of Declining Prices of ICT Equipment to Growth, Lower-Middle-Income Countries, 1991-2006



Source: Author's calculations, as described in text.

Table 3. Impact of ICT-Related Capital Deepening on Growth, Selected Countries, 1990–2006

Country	IT Equipment			Communications Equipment			Total ICT Equipment		
	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006
Bangladesh	0.04	0.06	0.06	0.03	0.04	0.05	0.07	0.10	0.10
China,P.R.: Mainland[1]	0.14	0.22	0.21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.03	0.04	0.04	0.07	0.08	0.09	0.09	0.12	0.13
Ethiopia	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.16
India	0.08	0.12	0.11	0.10	0.11	0.14	0.18	0.23	0.25
Indonesia	0.05	0.08	0.08	0.14	0.16	0.19	0.19	0.24	0.27
Nigeria	0.05	0.07	0.07	0.06	0.07	0.09	0.11	0.14	0.15
Pakistan	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Philippines	0.09	0.14	0.13	0.21	0.24	0.29	0.30	0.39	0.43
Vietnam	0.09	0.14	0.13	0.14	0.16	0.20	0.23	0.30	0.33
Country groups (unweighted averages)									
All countries covered	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
Low-income countries	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
Lower middle-income-countries	0.11	0.17	0.16	0.11	0.13	0.15	0.22	0.30	0.31

Source: Author's calculations. See Appendix Table 2 for country-level estimates of all 88 countries covered by our analysis.

Finally, a few more words are in order about differences in the pattern of investment in IT and communications equipment over time, the estimates of the growth impacts of falling prices of ICT equipment obtained from the steady-state analysis, and the estimates from our analysis treating changes in relative prices of ICT equipment as perturbations to an economy moving along (or close to) a steady-state growth path. Conceptually, the key differences are that (1) while the steady-state analysis simply adds up the direct and the indirect impacts (through accelerated capital accumulation) of falling prices of ICTs, the indirect effects occur very slowly in the perturbation analysis, and (2) that the assumptions regarding the elasticity of output with respect to ICT capital differ.

We have already discussed the first of these points at some length. The second point also does have some consequences for our estimates, as a comparison of the results of the steady-state and the perturbation analysis shows. Low-income countries experienced a strong acceleration in investment in communications equipment after 2000 (see Chapter 4.2 and 4.5). The calibrated elasticity of output with respect to communications equipment in the steady-state analysis, which is based on the behavior of key variables for that period only, reflects this acceleration. In our perturbation analysis, we allow the elasticities of output with respect to ICT equipment to change only slowly over time, allowing for a linear time trend. A temporary acceleration in the rates of investment in ICT equipment (the key determinant of our estimates of the respective elasticities) therefore has a modest impact on the calibrated elasticities in the perturbation analysis. For these reasons, the gap between the growth impacts of falling prices of communications equipment between low- and lower-middle-income countries is closer in the steady-state analysis than it is in the perturbation analysis.

E. ICT Production and Growth

Regarding the production of ICT equipment, the situation in low- and lower-middle-income countries is very different from the situation in OECD countries which has motivated most of the literature on the growth effects of advances in ICTs. While most OECD countries feature at least a small ICT-producing sector,[211] this applies to only a handful of low- and lower-middle-income countries. Partly for this reason, the few studies with a substantial coverage of non-OECD countries (notably, Bayoumi and Haacker (2002) and Jorgenson and Vu (2005a, 2005b, 2007)) have focused on the impacts of ICT-related capital deepening.[212] However, as production of ICT equipment does play an important role in some low- and lower-middle-income countries, an assessment of the growth effects of advances in ICTs in these countries would be incomplete without capturing the productivity gains on the production side.

Conceptually, estimating the (direct) contribution of productivity gains in the production of ICT equipment to growth is relatively straightforward. In terms of the framework developed above, the contribution of productivity gains in the ICT producing sector to growth can be calculated as

$$\frac{Y_2}{Y} \cdot \frac{\dot{A}_2}{A_2},$$

[211] See, for example, Bayoumi and Haacker (2002) for production volumes across a large number of countries, including developing economies, Pilat and Wölfl (2004) for the OECD, and Jorgenson (2005a, 2005b) or Jorgenson, Ho, and Stiroh (2005) for the G7.

[212] Additionally, Bayoumi and Haacker (2002) (and Pilat and Wölfl (2004), drawing on the former study), point out that the gains to producers largely dissipate owing to declining prices. This is particularly relevant if the bulk of ICT production is exported, as is the case in low- and lower-middle-income countries with an ICT-producing sector that is large relative to GDP.

i.e., the rate of productivity gains in the ICT-producing sector (indexed "2") $\dot{A}_2 / A_2$, weighted by the sector's share in the economy Y_2 / Y.

One factor that is complicating the assessment of the contributions of productivity gains in the production of ICT equipment to growth is the fact that we know little about the inputs to the production of ICT equipment, notably inputs of certain ICT-related components which embody most of the technological advances and productivity gains in ICTs. Some of our production data are available on a gross basis only, while others identify value added and the costs of inputs, but not in a form that allows us to identify inputs of interest. In other words, we are not in a good position to distinguish a low-tech manufacturing plant which simply assembles imported components, and a high-tech plant that produces electronic components embodying technological advances in ICTs.

To mitigate the problem, we include net exports of electronic microcircuits (SITC 2 category 7764) in our estimates of the production of ICT equipment. The advantages of doing so arise in two areas. First, as microcircuits are an integral part of ICT equipment, and arguably the commodity in which technological progress in ICT is most pronounced and clearly defined, including them in production statistics to measure the contribution of advances in the production of ICT equipment to growth makes sense. Second, as much of the technological advances in ICT equipment are embodied in microprocessors, controlling for net exports allows us to distinguish, to some extent, countries which largely assemble imported components from countries producing the commodities embodying the technological advances. At the same time, focusing on net exports rather than production of electronic microcircuits avoids double-counting of domestically produced electronic microcircuits which are used in the production of ICT equipment.

As explained in some detail elsewhere (see Chapter 4.5), and reflecting established practice in the literature, we are using the rate of decline of prices of ICT equipment as a measure of productivity gains in the production of ICT equipment, using data from the U.S. Producer Price Indices and the U.S. National Income and Product Accounts. For communications equipment, the deflators were modified, drawing on the work of Doms (2005).

Table 2 summarizes our findings on the contributions of the production of ICT equipment to growth. In most countries covered by Table 2 the growth impacts are miniscule, reflecting that we placed the bar for inclusion in the Table very low. The growth impact of the production of IT equipment exceeds 0.1 percentage points in only one low-income country (Vietnam), and 4 lower-middle-income countries. In three countries (China, Philippines, and Thailand), the impact of production of IT equipment on growth exceeds ½ percentage point at least in 2001–05.

The role of production of communications equipment is less pronounced, with a growth impact that exceeds 0.1 percentage points in only two countries (India, Iran) in 2001–05, although it had a larger impact in the Philippines and Thailand in the 1991–05 period. However, it is important to note that owing to data constraints the estimates on the role of communications equipment exclude China, a country for which informal calculations suggest that the growth impact of the production of communications equipment could also be around 0.2 percent in 2001–05.[213]

[213] China has been a net exporter of communications equipment since 2000, with net exports rising to about 1.5 percent of GDP by 2005. Including plausible values for domestic sales of communications equipment, this points to a level of domestic production of communications equipment that could exceed 2 percent, consistent with a growth contribution of 0.2 percentage points or more.

Table 4. Contribution of ICT Production to Growth, Selected Countries, 1990–2005
(Contribution to Annual GDP Growth, in Percentage Points)

	IT Equipment			Communications Equipment			Electronic Microcircuits (Net Exports)			Total		
Country	1991–1995	1996–2000	2001–2005	1991–1995	1996–2000	2001–2005	1991–1995	1996–2000	2001–2005	1991–1995	1996–2000	2001–2005
Low-Income Countries												
Kyrgyz Republic	0.03	0.01	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.03	0.02	0.02
Vietnam	0.00	0.23	0.15	0.00	0.10	0.00	0.00	-0.04	-0.09	0.00	0.29	0.06
Zimbabwe	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Lower-Middle-Income Countries												
Albania	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.03	0.04
China,P.R.: Mainland	0.07	0.27	0.51	n.a.	n.a.	n.a.	-0.02	-0.09	-0.21	n.a.	n.a.	n.a.
Egypt	0.00	0.01	0.00	0.02	0.03	0.03	0.00	0.00	0.00	0.03	0.04	0.03
India	0.05	0.06	0.04	0.07	0.09	0.11	0.00	-0.01	-0.01	0.12	0.15	0.14
Indonesia	0.04	0.23	0.20	0.07	0.22	0.20	0.00	0.02	0.01	0.11	0.47	0.41
Iran, I.R. of	0.01	0.03	0.01	0.03	0.10	0.06	0.00	0.00	0.00	0.03	0.13	0.07
Moldova	0.00	0.02	0.01	0.00	0.01	0.01	0.00	0.00	-0.01	0.00	0.03	0.01
Morocco	0.00	0.04	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.06	0.02
Peru	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Philippines	0.07	0.84	0.68	0.33	0.00	0.00	0.14	2.70	1.51	0.53	3.54	2.19
Sri Lanka	0.03	0.16	0.06	0.01	0.01	0.01	0.00	0.00	-0.01	0.03	0.16	0.06
Thailand	0.07	0.66	0.60	0.39	0.09	0.00	0.00	0.05	0.05	0.46	0.80	0.66
Ukraine	0.02	0.03	0.03	0.00	0.01	0.06	0.00	-0.02	-0.01	0.01	0.02	0.08
Memorandum Items												
Rate of decline in relative prices	-15.87	-22.99	-14.35	-7.30	-8.36	-9.65	-9.38	-19.77	-10.69	...	...	...

Source: Author's calculations, based on data from UNIDO (2007), Global Insight (2006), and United Nations Statistics Division (2008) for data on production, trade, or spending; IMF (2008) for data of GDP; U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005) for data on prices of ICT products.

Incorporating data on net exports of electronic microcircuits in the analysis refines the findings regarding the growth impact of ICT-related production in two areas. First, for some countries (notably Vietnam and China), net imports of electronic microcircuits account for a substantial proportion of the value of production of ICT equipment, which suggests that these countries largely assemble ICT equipment from imported components.[214] Second, including net export of electronic microcircuits, Philippines – by some margin – emerges as the country where the role of production of ICT equipment is largest. In 2001–05, the total contribution of the production of ICT equipment to growth in Philippines amounted to 2.2 percentage points, of which net exports of electronic microcircuits accounted for 1.5 percentage points.

Finally, some notes on interpreting these findings. First, our estimates are based on price indices for the respective commodity categories from the United States. If the composition of production in our countries of interest differs substantially from the commodity bundles underlying the U.S. price indices, this would introduce some margin of error to our estimates. Second, to relate our estimates of the growth contribution of the production of ICT equipment to official data on GDP growth, it is necessary to know which deflators have been applied to the production of ICT equipment in the national accounts data. Only if national price indices fully reflect changes in the quality of ICT equipment is it possible to attribute a share of the growth rate of GDP to our estimated contributions from ICT-related production. If, at the other extreme, the national price indices do not capture changes in the quality of ICT products at all, then it would be necessary to correct the national estimates of GDP growth by adding our estimates of the growth contribution from productivity gains in the ICT-producing sector. Third, as pointed out earlier, it is important to bear in mind that a high contribution of ICT-related production to GDP – literally – does not buy much, as the productivity gains, regarding national income, dissipate owing to the terms-of-trade effect of falling prices of ICT products.

[214] This also applies to Albania, India, Moldova, Sri Lanka, and Ukraine, although the low levels of production there make it more difficult to assess the extent to which ICT production reflects the assembly of imported components.

F. Conclusions and Outlook

The first lesson from our analysis is that capital deepening related to technological advances in ICTs (i.e., falling relative prices of ICT equipment) matters in low- and low-middle-income countries. Overall, we estimate that between 1996 and 2006 the direct and indirect effects of falling prices of ICT equipment added about 0.2 percentage points to economic growth for low-income countries, and 0.3 percentage points for lower-middle-income countries. Relative to high-income countries, a preliminary analysis suggests that the growth impacts of falling prices of IT equipment in low-income countries are about one-half of the level attained in high-income countries, and about three-quarters in lower-middle-income countries. Regarding the relative roles of IT and communications equipment, we find that the magnitudes of the contributions to growth are similar – while investment in communications equipment is about double the level of investment in IT equipment, both in low- and in lower-middle-income countries, the relative prices of IT equipment decline at a faster rate, so that the overall impact comes out about the same.

A key obstacle to a comprehensive assessment of the economic role of ICTs in low- and lower-middle-income countries is the lack of sufficiently detailed national accounts data for most countries. To address this problem, we construct estimates of investment in ICT equipment based on trade data (and, where necessary, production data), addressing some shortcomings of existing databases (see Chapter 4.5 for details), and compiling a database covering essentially all low- and lower-middle-income countries. However, it is important to bear in mind that trade data are a noisy indicator for ICT-related spending, especially for small countries. Additionally, to account for costs which would be included in investment data, but are not captured in trade data, we estimate an mark-up to "translate" trade data into spending figures in a national accounts framework. While a necessary adjustment, this is also an additional source of noise, as we miss out on the variation in these mark-ups across countries.

The most important determinant of the link between falling prices of ICT equipment and the impact on economic growth is the elasticity of output with respect to ICT equipment. We estimate these elasticities based on a steady-state version of our analytical framework, imposing the condition that rates of return to capital be equal between different types of assets, and estimated investment data. A key challenge, to which we do not have a sound answer, is the interpretation of changes in investment rates, which may be spurious, reflect business cycles, or changes in the structure of the economy (i.e., in the elasticity of output with respect to capital). An explicit model deriving appropriate weights is beyond the scope of the present study – we use country fixed effects combined with a linear trend, as this is easily tractable and as we are not primarily interested in idiosyncrasies on the country level; other specifications that are built on an explicit model, giving more weight to year-to-year variations or difference across countries could yield improved estimates of the elasticities.

Finally, it is important to recall the limitations of our analysis. While it is true that benefiting from advances in ICTs does require the use of ICT equipment, and therefore the scale of the absorption of ICT equipment is an important indicator of the scale of the economic role of ICTs in an economy, the economic impacts are much broader, and differ systematically between countries. For example, in high-income countries, spending on IT-related services plays a much higher role than in low-income countries. On the other hand, ICTs have expanded the class of labor-intensive services that is tradable, and it is questionable whether investment in ICT equipment adequately captures the benefits from advances in ICTs in the economies exporting such services. Last, one specific feature of communication technologies (and of some aspects of information technologies) is that utilization of such technologies requires the existence of a related infrastructure (which is partly captured in our investment data), but also subscription to communication services, which means that the structure of the market for telecommunications services, which is characterized by imperfect competition, may affect the way in which advances in ICTs and falling international prices of ICT equipment affect national economies.

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Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001–06

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r. t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Low-Income Countries										
Afghanistan, I.R. of	39.4	0.62	2.67	4.1	11.7	0.004	0.010	0.12	0.20	0.31
Bangladesh	23.9	0.52	0.91	1.9	5.7	0.004	0.005	0.11	0.09	0.20
Benin	18.1	0.43	0.69	3.3	4.1	0.003	0.004	0.09	0.07	0.16
Burkina Faso	17.8	0.42	0.56	3.2	6.1	0.003	0.003	0.09	0.05	0.14
Burundi	10.5	0.79	1.01	3.5	2.7	0.006	0.005	0.17	0.10	0.28
Cambodia	18.5	0.34	1.36	1.8	9.6	0.002	0.006	0.07	0.12	0.19
Central African Rep.	8.0	0.21	0.29	1.7	-0.2	0.002	0.002	0.05	0.04	0.09
Chad	35.4	0.28	0.48	3.6	12.3	0.002	0.002	0.05	0.04	0.09
Comoros	10.0	0.31	1.31	2.7	2.5	0.002	0.007	0.07	0.14	0.21
Congo, Dem. Rep. of	11.1	0.67	1.23	3.0	4.5	0.005	0.006	0.15	0.12	0.27
Côte d'Ivoire	9.9	0.39	0.77	1.7	0.0	0.003	0.005	0.09	0.10	0.19
Eritrea	24.3	1.12	1.75	4.1	2.0	0.009	0.009	0.25	0.18	0.43
Ethiopia	22.7	0.80	1.52	2.6	6.4	0.006	0.007	0.17	0.14	0.31
Gambia, The	24.7	0.62	2.05	3.1	4.6	0.005	0.010	0.13	0.20	0.33
Ghana	26.1	0.84	1.95	2.2	5.3	0.006	0.010	0.18	0.19	0.37
Guinea	12.8	0.25	0.54	1.9	2.9	0.002	0.003	0.06	0.06	0.12
Guinea-Bissau	12.8	0.84	0.69	3.1	-0.1	0.007	0.004	0.20	0.08	0.28
Haiti	27.5	0.24	1.50	1.6	-0.1	0.002	0.010	0.06	0.19	0.24
Kenya	17.3	0.64	1.32	2.6	4.0	0.005	0.007	0.14	0.13	0.27
Kyrgyz Republic	19.8	0.61	1.92	1.0	3.7	0.005	0.011	0.14	0.21	0.34
Lao People's Dem. Rep.	29.8	0.39	2.41	1.6	6.6	0.003	0.012	0.08	0.23	0.31
Liberia	...	1.06	3.15	2.6	-2.6	0.009	0.022	0.27	0.41	0.68
Madagascar	20.2	0.46	0.73	2.8	2.9	0.004	0.004	0.10	0.08	0.18
Malawi	18.6	1.08	1.41	2.6	2.8	0.008	0.008	0.24	0.15	0.39
Mali	18.6	0.35	0.90	3.0	6.2	0.003	0.004	0.07	0.08	0.16
Mauritania	37.5	0.65	1.23	2.9	5.2	0.005	0.006	0.14	0.12	0.26
Mozambique	21.6	0.82	1.35	2.4	8.7	0.006	0.006	0.17	0.12	0.28
Myanmar	11.9	0.44	1.12	0.9	12.8	0.003	0.005	0.09	0.09	0.18

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001–06

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r. t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Nepal	19.1	0.73	0.99	2.1	3.4	0.006	0.006	0.16	0.11	0.27
Niger	16.7	0.29	0.94	3.6	5.3	0.002	0.005	0.06	0.09	0.15
Nigeria	25.0	0.36	1.34	2.5	10.2	0.002	0.006	0.07	0.11	0.18
Pakistan	16.4	0.58	1.20	1.8	5.3	0.004	0.006	0.13	0.12	0.25
Papua New Guinea	18.8	1.07	0.80	2.4	1.7	0.009	0.005	0.25	0.09	0.34
Rwanda	17.5	0.73	0.94	2.5	5.4	0.005	0.005	0.16	0.09	0.25
São Tomé & Príncipe[1]	...	1.09	3.04	1.7	6.5	0.008	0.015	0.23	0.28	0.51
Senegal	26.1	1.24	0.95	2.6	4.2	0.009	0.005	0.27	0.10	0.37
Sierra Leone	12.3	0.50	2.03	4.1	12.6	0.003	0.008	0.09	0.15	0.24
Solomon Islands	29.8	0.91	0.64	2.6	2.3	0.007	0.004	0.21	0.07	0.28
Tajikistan	14.6	0.11	2.22	1.2	9.0	0.001	0.010	0.02	0.19	0.22
Tanzania	21.1	0.67	1.24	2.6	7.0	0.005	0.006	0.14	0.11	0.25
Togo	12.5	0.31	1.11	2.9	1.7	0.002	0.006	0.07	0.12	0.19
Uganda	20.5	0.71	1.27	3.2	5.5	0.005	0.006	0.15	0.12	0.27
Uzbekistan	25.1	0.73	1.25	1.5	5.7	0.005	0.007	0.16	0.12	0.28
Vietnam	32.1	0.58	1.67	1.4	7.6	0.004	0.008	0.12	0.15	0.28
Yemen, Republic of	19.0	0.09	0.66	3.0	4.0	0.001	0.003	0.02	0.07	0.09
Zambia	22.0	0.65	1.22	1.9	5.0	0.005	0.006	0.14	0.12	0.26
Zimbabwe	6.5	0.49	0.68	0.7	-5.1	0.005	0.006	0.14	0.12	0.25
Lower-Middle-Income Countries										
Albania	25.3	0.82	1.33	0.5	5.5	0.006	0.007	0.18	0.14	0.32
Algeria	23.5	0.51	1.07	1.5	4.4	0.004	0.006	0.11	0.11	0.22
Angola	11.2	0.50	0.88	2.9	11.7	0.003	0.004	0.10	0.07	0.17
Armenia	24.2	0.82	1.14	-0.4	12.4	0.006	0.005	0.16	0.10	0.26
Azerbaijan, Rep. of	39.8	0.46	1.52	0.5	14.7	0.003	0.006	0.09	0.12	0.20
Bhutan	58.8	0.36	0.53	2.5	8.2	0.003	0.002	0.07	0.05	0.12
Bolivia	13.6	0.87	0.76	2.0	3.3	0.007	0.004	0.20	0.08	0.28
Bosnia & Herzegovina	26.4	1.54	1.26	0.6	4.8	0.012	0.007	0.34	0.13	0.48
Cameroon	18.5	0.52	0.50	2.3	3.6	0.004	0.003	0.12	0.05	0.17
Cape Verde	35.2	1.14	1.07	2.4	6.1	0.008	0.005	0.24	0.10	0.34

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001–06

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r. t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
China,P.R.: Mainland[3,4]	39.3	0.46	...	0.7	9.8	0.003	...	0.10	...	...
Colombia	17.2	0.91	1.60	1.5	3.9	0.007	0.009	0.20	0.17	0.37
Congo, Republic of	23.3	0.60	1.56	2.4	4.4	0.005	0.008	0.13	0.16	0.29
Djibouti	17.8	1.68	3.59	1.9	3.1	0.013	0.019	0.38	0.36	0.74
Dominican Republic	22.3	0.35	0.83	1.6	4.6	0.003	0.005	0.08	0.09	0.16
Ecuador	21.9	0.74	1.86	1.2	5.2	0.006	0.010	0.16	0.19	0.35
Egypt	17.4	0.23	0.80	1.8	4.2	0.002	0.004	0.05	0.08	0.14
El Salvador	16.1	1.03	1.40	1.5	2.6	0.008	0.008	0.24	0.16	0.39
Georgia	26.3	0.64	1.54	-1.0	7.7	0.005	0.008	0.14	0.15	0.29
Guatemala	18.8	0.90	1.87	2.5	3.4	0.007	0.010	0.20	0.19	0.39
Guyana	25.2	1.39	2.08	0.1	1.2	0.012	0.014	0.34	0.26	0.60
Honduras	24.7	0.86	1.42	2.0	4.9	0.007	0.007	0.19	0.14	0.33
India	27.1	0.88	1.76	1.6	7.0	0.006	0.009	0.19	0.16	0.35
Indonesia	21.5	0.41	1.48	1.3	4.9	0.003	0.008	0.09	0.15	0.24
Iran, I.R. of	28.2	0.21	1.12	1.0	5.6	0.002	0.006	0.05	0.11	0.16
Jordan	23.9	0.68	3.58	3.0	6.2	0.005	0.017	0.14	0.32	0.46
Kiribati[1]	...	3.36	2.72	1.8	2.1	0.026	0.016	0.76	0.30	1.06
Lesotho	34.0	0.64	1.08	0.9	3.6	0.005	0.006	0.15	0.12	0.26
Macedonia, FYR	16.9	1.37	1.88	0.2	1.8	0.011	0.012	0.33	0.22	0.55
Maldives	32.3	2.28	5.70	1.6	6.9	0.017	0.027	0.48	0.51	0.98
Moldova	20.9	1.14	2.19	-1.3	6.6	0.009	0.012	0.26	0.23	0.48
Mongolia	24.9	1.36	2.80	0.9	6.4	0.010	0.014	0.29	0.27	0.56
Morocco	26.5	0.57	1.59	1.1	5.4	0.004	0.008	0.13	0.16	0.29
Namibia	24.9	1.08	1.30	1.4	4.7	0.008	0.007	0.24	0.13	0.37
Nicaragua	26.8	1.19	2.32	1.3	3.3	0.009	0.013	0.27	0.25	0.52
Paraguay[4]	18.6	5.62	1.98	2.0	2.9	0.042	0.011	1.21	0.21	1.42
Peru	18.2	0.93	0.85	1.2	4.8	0.007	0.005	0.21	0.09	0.29
Philippines	16.5	0.84	0.96	2.1	4.6	0.006	0.005	0.18	0.10	0.28
Samoa[1]	...	1.42	2.23	0.7	4.3	0.011	0.012	0.32	0.24	0.55

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001-06 (concluded)

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r.t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Sri Lanka	24.2	0.76	1.11	0.4	4.5	0.006	0.006	0.17	0.12	0.29
Sudan	15.8	0.32	1.13	2.1	6.9	0.002	0.006	0.07	0.11	0.17
Swaziland	18.3	0.78	1.17	1.2	2.4	0.006	0.007	0.18	0.13	0.32
Syrian Arab Republic	21.7	0.16	0.57	2.7	3.5	0.001	0.003	0.04	0.06	0.09
Thailand	25.5	0.73	0.25	0.7	5.1	0.006	0.001	0.16	0.03	0.19
Timor-Leste[1]	...	0.55	0.52	5.3	0.2	0.004	0.003	0.12	0.06	0.18
Tonga[1]	...	1.15	3.07	0.3	2.3	0.009	0.019	0.27	0.35	0.63
Tunisia	23.9	0.53	1.23	1.1	4.6	0.004	0.007	0.12	0.13	0.25
Turkmenistan[1]	...	0.11	0.21	1.4	15.3	0.001	0.001	0.02	0.02	0.04
Ukraine	21.4	0.94	1.44	-0.8	7.6	0.007	0.008	0.20	0.14	0.35
Vanuatu[1]	...	0.79	0.75	2.6	1.9	0.006	0.004	0.18	0.08	0.26
Memorandum Items										
All countries[4]	22.1	0.74	1.39	1.9	5.1	0.006	0.007	0.162	0.139	0.301
LIC	20.2	0.6	1.3	2.5	4.8	0.005	0.007	0.131	0.128	0.259
LMC[4]	23.8	1.0	1.5	1.4	5.3	0.007	0.008	0.213	0.151	0.364

Source: Authors calculations, as described in text, based on data from IMF (2008), Global Insight (2006), and UN Statistics Division (2008).

[1] Investment rates were unavailable. Elasticities and contributions of ICT equipment to growth were estimated based on the sample average for investment rates (22.0 percent).

[2] For Afghanistan, data relate to 2002–2006

[3] For China, data on investment in communications equipment were unavailable.

[4] Totals exclude China (as estimates on investment in communications equipment were unavailable) and Paraguay (the latter owing to severe inconsistencies in published trade data).

Appendix Table 2. Contribution of ICT-Related Capital Deepening to Growth, 88 Countries, 1990–2006

Country	IT Equipment			Communications Equipment			Total ICT Equipment		
	1991–1995	1996–2000	2001–2006	1991–1995	1996–2000	2001–2006	1991–1995	1996–2000	2001–2006
Albania	0.14	0.22	0.20	0.03	0.03	0.04	0.17	0.25	0.24
Algeria	0.07	0.11	0.10	0.06	0.07	0.08	0.13	0.18	0.18
Angola	0.09	0.13	0.12	0.09	0.10	0.12	0.17	0.23	0.24
Armenia	0.07	0.11	0.10	0.10	0.12	0.14	0.17	0.22	0.24
Azerbaijan, Rep. of	0.06	0.09	0.08	0.27	0.31	0.37	0.33	0.40	0.46
Bangladesh	0.04	0.06	0.06	0.03	0.04	0.05	0.07	0.10	0.10
Benin	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Bhutan	0.12	0.19	0.17	0.12	0.14	0.17	0.24	0.33	0.35
Bolivia	0.09	0.13	0.12	0.11	0.13	0.15	0.20	0.26	0.28
Bosnia & Herzegovina	0.14	0.21	0.20	0.08	0.10	0.12	0.22	0.31	0.32
Burkina Faso	0.07	0.11	0.10	0.04	0.05	0.06	0.11	0.16	0.16
Burundi	0.11	0.17	0.15	0.07	0.08	0.10	0.18	0.25	0.25
Cambodia	0.04	0.06	0.06	0.07	0.08	0.10	0.11	0.14	0.15
Cameroon	0.05	0.08	0.08	0.03	0.04	0.04	0.09	0.12	0.12
Cape Verde	0.17	0.26	0.24	0.12	0.14	0.17	0.29	0.40	0.41
Central African Rep.	0.05	0.07	0.07	0.04	0.05	0.06	0.09	0.12	0.12
Chad	0.04	0.07	0.06	0.04	0.05	0.06	0.08	0.11	0.12
China,P.R.: Mainland	0.14	0.22	0.21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Colombia	0.12	0.18	0.17	0.10	0.12	0.14	0.22	0.30	0.31
Comoros	0.11	0.17	0.16	0.13	0.16	0.19	0.25	0.33	0.35
Congo, Dem. Rep. of	0.06	0.08	0.08	0.07	0.08	0.09	0.12	0.16	0.17
Congo, Republic of	0.09	0.14	0.13	0.07	0.08	0.10	0.16	0.22	0.23
Côte d'Ivoire	0.07	0.11	0.10	0.05	0.06	0.07	0.12	0.17	0.17
Djibouti	0.15	0.23	0.21	0.20	0.23	0.27	0.35	0.46	0.48
Dominican Republic	0.07	0.11	0.10	0.07	0.08	0.10	0.14	0.19	0.20
Ecuador	0.10	0.15	0.14	0.09	0.10	0.13	0.19	0.26	0.27
Egypt	0.03	0.04	0.04	0.07	0.08	0.09	0.09	0.12	0.13
El Salvador	0.13	0.20	0.19	0.08	0.10	0.12	0.21	0.29	0.30
Eritrea	0.08	0.12	0.12	0.09	0.10	0.12	0.17	0.22	0.24
Ethiopia	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.16
Gambia, The	0.11	0.17	0.16	0.15	0.17	0.21	0.26	0.34	0.37
Georgia	0.07	0.10	0.09	0.08	0.10	0.11	0.15	0.20	0.21
Ghana	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
Guatemala	0.11	0.17	0.16	0.10	0.11	0.13	0.21	0.28	0.30
Guinea	0.04	0.06	0.05	0.05	0.05	0.07	0.09	0.11	0.12
Guinea-Bissau	0.13	0.20	0.19	0.08	0.09	0.11	0.22	0.30	0.30
Guyana	0.21	0.31	0.29	0.19	0.22	0.27	0.40	0.54	0.56
Haiti	0.03	0.05	0.05	0.06	0.07	0.09	0.10	0.12	0.13
Honduras	0.14	0.22	0.20	0.09	0.10	0.12	0.23	0.32	0.33
India	0.08	0.12	0.11	0.10	0.11	0.14	0.18	0.23	0.25
Indonesia	0.05	0.08	0.08	0.14	0.16	0.19	0.19	0.24	0.27
Iran, I.R. of	0.03	0.05	0.05	0.10	0.12	0.14	0.14	0.17	0.19
Jordan	0.10	0.16	0.15	0.14	0.16	0.19	0.24	0.32	0.34
Kenya	0.08	0.12	0.11	0.09	0.10	0.12	0.16	0.22	0.23
Kyrgyz Republic	0.10	0.16	0.14	0.11	0.13	0.16	0.22	0.29	0.30
Lao People's Dem.Rep	0.04	0.07	0.06	0.10	0.12	0.15	0.15	0.19	0.21
Macedonia, FYR	0.21	0.31	0.29	0.13	0.15	0.18	0.34	0.46	0.47
Madagascar	0.06	0.09	0.08	0.05	0.05	0.07	0.11	0.14	0.15
Malawi	0.13	0.19	0.18	0.10	0.12	0.14	0.23	0.31	0.32
Maldives	0.22	0.33	0.31	0.29	0.33	0.41	0.51	0.66	0.72

(Continued)

Appendix Table 2. Contribution of ICT-Related Capital Deepening to Growth, 88 Countries, 1990–06

Country	IT Equipment			Communications Equipment			Total ICT Equipment		
	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006
Mali	0.04	0.06	0.06	0.04	0.04	0.05	0.08	0.11	0.11
Mauritania	0.07	0.11	0.10	0.07	0.08	0.10	0.14	0.19	0.19
Moldova	0.18	0.27	0.24	0.09	0.11	0.13	0.28	0.38	0.37
Mongolia	0.12	0.18	0.17	0.16	0.19	0.22	0.28	0.37	0.39
Morocco	0.09	0.14	0.13	0.10	0.11	0.13	0.19	0.25	0.26
Mozambique	0.10	0.15	0.14	0.08	0.09	0.11	0.17	0.24	0.25
Myanmar	0.05	0.08	0.08	0.07	0.08	0.10	0.12	0.16	0.18
Nepal	0.08	0.13	0.12	0.05	0.06	0.07	0.14	0.19	0.19
Nicaragua	0.17	0.26	0.24	0.13	0.15	0.18	0.30	0.41	0.42
Niger	0.05	0.08	0.08	0.04	0.04	0.05	0.09	0.12	0.13
Nigeria	0.05	0.07	0.07	0.06	0.07	0.09	0.11	0.14	0.15
Pakistan	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Papua New Guinea	0.16	0.24	0.22	0.06	0.07	0.08	0.22	0.31	0.30
Peru	0.12	0.18	0.17	0.07	0.08	0.10	0.19	0.26	0.27
Philippines	0.09	0.14	0.13	0.21	0.24	0.29	0.30	0.39	0.43
Rwanda	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.17
Samoa	0.21	0.32	0.30	0.15	0.17	0.20	0.36	0.49	0.50
Senegal	0.11	0.17	0.16	0.06	0.06	0.08	0.17	0.24	0.24
Sierra Leone	0.14	0.21	0.19	0.12	0.14	0.17	0.26	0.35	0.36
Solomon Islands	0.13	0.20	0.19	0.08	0.09	0.11	0.21	0.29	0.29
Sri Lanka	0.09	0.14	0.13	0.09	0.10	0.12	0.18	0.25	0.26
Sudan	0.04	0.06	0.06	0.05	0.05	0.07	0.09	0.11	0.12
Syrian Arab Republic	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.08	0.08
Tajikistan	0.01	0.02	0.02	0.08	0.09	0.11	0.10	0.12	0.13
Tanzania	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
Thailand	0.09	0.14	0.13	0.17	0.20	0.24	0.27	0.34	0.38
Togo	0.06	0.10	0.09	0.08	0.09	0.10	0.14	0.18	0.19
Tonga	0.17	0.26	0.25	0.15	0.17	0.20	0.32	0.43	0.45
Tunisia	0.11	0.16	0.15	0.07	0.08	0.09	0.17	0.24	0.25
Turkmenistan	0.02	0.03	0.02	0.05	0.05	0.07	0.06	0.08	0.09
Uganda	0.07	0.11	0.11	0.05	0.06	0.07	0.13	0.17	0.18
Ukraine	0.13	0.20	0.18	0.09	0.11	0.13	0.23	0.31	0.31
Uzbekistan	0.06	0.09	0.08	0.08	0.09	0.11	0.14	0.18	0.19
Vanuatu	0.17	0.26	0.24	0.11	0.13	0.16	0.28	0.39	0.40
Vietnam	0.09	0.14	0.13	0.14	0.16	0.20	0.23	0.30	0.33
Yemen, Republic of	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.07	0.08
Zambia	0.13	0.20	0.19	0.08	0.09	0.11	0.21	0.29	0.30
Zimbabwe	0.13	0.19	0.17	0.11	0.13	0.15	0.24	0.32	0.33
Country groups (unweighted averages)									
All countries covered	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
LIC	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
LMC	0.11	0.17	0.16	0.11	0.13	0.15	0.22	0.30	0.31

Source: Author's calculations.

V. CONCLUSIONS

A. Introduction

The different chapters in this volume represent contributions to the literature on economic growth in the context of economic development, focusing on long-run changes in incomes (and health standards, as in parts of Chapter III), addressing issues that are particular relevant in developing countries (as our discussion of the impacts of HIV/AIDS, in Chapter II and parts of Chapter III), or extending the analysis of issues that have primarily been addressed in the context of the most advanced industrialized countries (notably the United States or other OECD countries) to a developing-country context (as in our analysis of the macroeconomic consequences of ICT-related capital deepening). Before discussing and summarizing the contributions from our studies in more detail, we present some of the key findings.

B. Key Findings

Macroeconomic impact of HIV/AIDS:

- Allowing for capital mobility, our analysis returns a stronger impact of HIV/AIDS on output and income per capita than the corresponding closed-economy models.
- The estimated impact on the informal sector is more pronounced than for the formal sector, reflecting a stronger impact of HIV/AIDS on savings rates.
- GDP per capita is lower in the scenario with comprehensive scaling-up of antiretroviral treatment, as rising costs of care and treatment affect savings rates.

Contributions of health (and income) to living standards:

- For leading industrialized countries, the contribution of health over long periods of time has been of similar magnitude as rising incomes, but the contribution of health has slowed down since about 1950.
- For developing countries, a similar slowdown occurred somewhat later.
- HIV/AIDS has resulted in steep declines in living standards in a number of countries in sub-Saharan Africa.

ICT-related capital deepening and growth:

- The estimated impact of ICT-related capital deepening on growth in developing countries is substantial (about 0.3 percentage points), although lower than comparable estimates for leading industrialized countries.
- Unlike in some industrialized countries, the impact of ICT-related capital deepening has not slowed down after 2000, owing to increased absorption of communications equipment.

C. Health, HIV/AIDS, and Economic Growth

The objectives of our analysis are two-fold. (1) On the methodological side, our study aims to assess certain properties of models commonly applied to the study of the economic impacts of HIV/AIDS. (2) Based on a review of the evidence on the impacts of HIV/AIDS on certain relevant variables, we provide an updated assessment of the economic impacts of HIV/AIDS, including – for the first time in an academic study – an assessment of the macroeconomic impacts of increased access to antiretroviral treatment.

In terms of the methodological aspects of our analysis, our study was motivated by an apparent incongruence between the closed-economy assumption adopted by most studies of the macroeconomic impacts of HIV/AIDS and the fact that many of the highly-affected countries are characterized by a high degree of capital mobility and a prominent role of foreign direct investment. We find that allowing for capital mobility invalidates an important channel that reverses much of the adverse macroeconomic impacts of HIV/AIDS in the literature – the link between a reduced population growth rate, the capital-labor ratio, and output per capita. Instead, in an open-economy setting, a decline in population growth results in a decline in the rate of return to capital, and a capital outflow (or fall in inward investment) until the equilibrium in the capital market is restored. In this open-economy setting, however, it is important to distinguish between output per capita and income per capita (as capital flows have implications for net income from abroad). Our analysis of the macroeconomic impacts of HIV/AIDS therefore also covers income per capita, with similar findings.

Our calibrated model returns an impact of HIV/AIDS on output per capita that is rather small – a decline of about 1 percent in a closed-economy setting,, rising to about 4 percent in the open-economy setting (the adverse impact is stronger in the open-economy setting for the reasons just discussed). In the dual-economy model, our findings point towards some distributional impacts of HIV/AIDS, as the adverse impacts of HIV/AIDS are more pronounced for the informal sector. This has also some implications for the impacts of HIV/AIDS on poverty, as the level of incomes is lower in the informal sector.

Regarding the economic consequences of increased access to antiretroviral treatment, our findings may seem counterintuitive at first sight – we find that scaling-up of treatment results has a negative impact on GDP per capita. While antiretroviral treatment reduces HIV/AIDS-related mortality and restores people living with HIV/AIDS to full productivity for many years, there are two effects offsetting these "gains." First, scaling-up of treatment most likely is associated with an expansion in government expenditures, as well as increased private expenditures on accessing treatment (even if external grants cover the costs of drugs and other costs). This results in a decline in national savings, eroding the capital stock. Second, increased access to treatment reverses some of the negative impact of HIV/AIDS on population growth, as well as any increases in the capital-labor ration associated with lower population growth. One notable property of our estimates is that the negative impacts of antiretroviral treatment on output per capita were more pronounced for the informal sector, as the costs of access to treatment (and the decline in savings rates) were higher relative to income in this sector.

One notable shortcoming of the different strands of analysis presented in this chapter regards the distribution of income. Some of our findings point to a disproportionate impact of HIV/AIDS on the informal sector, suggesting that the impact on poverty may be higher than what is suggested by estimated changes in income per capita. More generally, an important dimension of the economic impacts of HIV/AIDS are the uneven impacts across households, most importantly regarding the distinction between households affected by HIV/AIDS and those not affected. The use of aggregate models does not capture such distributional effects on the microeconomic level, even though these distributional effects may have important implications for the macroeconomic impacts (and especially for poverty-related indicators).[215]

A second area that our analysis touched only in passing are the differences between the economic impacts predicted by models synthesizing the immediate effects of HIV/AIDS on macroeconomic variables such as the savings rate, labor productivity, and the rate of population growth, and deriving the implications of such changes for economic growth, and models taking a longer-run approach, with forward-looking agents, allowing, for example, for impacts of HIV/AIDS on the accumulation of human capital or fertility rates. While the models discussed in our study predict a moderate negative impact of HIV/AIDS on GDP per capita, the models exhibiting more complex frameworks regarding agents forward-looking decision can return large impacts of HIV/AIDS on GDP per capita, range from severe contractions (see, for example, Bell, Devarajan, and Gersbach (2006)) to the more cheerful scenarios proposed by Young (2005). A discussion of the advantages and disadvantages of the different modeling strategies is beyond the scope of this review. However, we note that our findings regarding the consequences of allowing for some capital mobility also apply to the models featuring a richer microeconomic structure, in particular models in which declines in the rate of population growth and an associated increase in the capital-labor ration play an important role (as in Young (2005)).

D. Contribution of Health (and Income) to Living Standards

Our analysis on the role of health in changing living standards draws primarily on two strands of the literature – accounts of the economic history of countries through long periods of development, noting that improvements in income over this time have been accompanied by increases in life expectancy (see, for example, Crafts (1997), and the literature on the economic impacts of HIV/AIDS, where observers are sometimes puzzled by the large magnitude of the impact of HIV/AIDS on demographic and health indicators, whereas the

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[215] For a discussion of the impacts of HIV/AIDS on poverty and inequality, in a setting where GDP per capita changes only very little, see Salinas and Haacker

impacts on indicators like GDP per capita are of a much smaller magnitude (see. For example, Young (2005).[216]

While the microeconomic foundations of our analysis are straightforward and well-researched, our analysis is demanding as it covers not only long periods (up 136 years) in which incomes and the state of health have improved very significantly, but also episodes characterized by large declines in life expectancy in some countries. For these reasons, we have developed the analytical tools in order to adapt them to the analysis of large discrete changes in incomes and, in particular, life expectancy.

The choice of suitable parameters represents another challenge. Most of the valuations of health improvements relative to incomes are based on data from high- or higher-middle-income countries, with a disproportionate share of studies coming from the United States. In light of the very large differences in incomes per capita between advanced industrialized countries and low-income countries, adopting specifications which work for the high-income countries they were designed for in low-income countries may not make sense.[217] Based on the available evidence, we adopt a specification in which valuations of changes in life expectancy are proportional to the level of GDP per capita, motivated by the existing literature. However, it is important to note that this represents a second-best approach to a study that would more directly draw on evidence from developing countries.

Our study – in line with earlier studies – finds that increasing life expectancy has played an important role in improving living standards over long periods of development, roughly on par with improving income per capita (for a group of 17 (of today's) leading industrialized countries since 1970, and in a global dataset from 1950. However, our study finds that the contribution of improved health to living standards has declined – from about

[216] A third branch of the literature, which we are not directly concerned with but which was influential in developing the analytical tools we are using is the literature on the value of health improvements in specific country settings, for example to assess the value of medical research (see Murphy and Topel (2005) for an influential study) or to conduct cost-effectiveness analyses of some planned law or policy intervention.

[217] See our discussion of the work by Philipson and Soares (2005).

1950 for the leading industrialized countries, and somewhat later for the other countries included in the post-1950 sample. The analysis of global trends also points to the special situation in sub-Saharan Africa, which stands out as improvements in life expectancy (and the associated increases in living standards) have turned negative since 1990, which takes us to the second area of interest in our study, as the drop in the contribution of increasing life expectancy to living standards in sub-Saharan Africa can be attributed to the impact of the evolving HIV epidemic. The modest decline in life expectancy since 1990 is even more troublesome when considering that other health determinants have improved, so that the actual decline in life expectancy provides a gross underestimate of the impact of HIV/AIDS.

Using data from the United Nations Population Division (2007), which provides estimates of key demographic indicators, as well as a counterfactual no-AIDS scenario, we find that HIV/AIDS has resulted in a decline in life expectancy of almost 7 years, translating into a deterioration in living standards of 38 percent. In some countries, with losses in life expectancy of over 15 years, we estimate that the deterioration in living standards may well amount to around 70 percent. In terms of economic growth, the adverse impact of HIV/AIDS reversed some of the modest contribution of growth of GDP per capita in sub-Saharan Africa (0.6 percent annually), so that living standards improved by only 0.4 percent annually (and would have improved by more than 2.5 percent annually without the impact of HIV/AIDS).

As in our discussion of the impacts of HIV/AIDS on growth, our study introduces an analysis of the economic impacts of increased access to antiretroviral treatment. Based on estimates from United Nations Population Division (2007), we find that comprehensive access to antiretroviral treatment would reduce the adverse impact of HIV/AIDS on life expectancy in sub-Saharan Africa from 6.8 years to 5.6 years, and reduce the deterioration in living standards from 38 percent to 32 percent.

E. ICT Equipment Investment and Growth in Development

One of the challenges regarding the analysis of the impacts of ICT-related capital deepening is the lack of sufficiently detailed national accounts data. For this reason, a sub-chapter (IV.2) is devoted to the construction of a dataset of spending on ICT equipment across countries. As most developing countries (here, we focus on low- and low-middle income countries, as defined by the World Bank) do not produce ICT equipment (so that it is not necessary to take into account domestic production),[218] our estimates of ICT-related spending are based on trade data. As a number of other researchers (see, for example, Feenstra and others, 2005) we use partner country data to obtain estimates of trade flows for countries not reporting trade data themselves. The "value added" from the dataset that we construct arises from a correction in these indirectly observed trade data to account for trade between non-reporting countries, which would otherwise in a bias in our data that is correlated with key macroeconomic indicators such as GDP per capita.

The theoretical framework we use is based on the work originating from Griliches and Jorgenson (1966, 1967) and adapted to the study of the economic impacts of ICTs by Jorgenson and his collaborators (see Jorgenson and Stiroh (2000), or Jorgenson, Ho, and Stiroh (2000)), adapted to account for the limited availability of data in developing countries. Notably, owing to labor market developments, we estimate the contribution of ICT-related capital deepening to growth, but do not attempt to break down the remainder into contributions of labor inputs and other factors. In addition to the steady-state properties of the model, we also provide estimates of the contributions of ICT-related capital deepening over time, interpreting shocks to the relative prices of ICT equipment as perturbations around the steady-state growth path.

We find that ICT-related capital deepening contribute about 0.3 percentage points to economic growth for 97 low- and low-middle-income countries in 2001–06, with a somewhat lower contribution for low-income countries (0.26 percentage points) than for low-middle-income countries (0.35 percentage points). For low-income countries, the contributions of declining prices of IT equipment and of communications equipment, respectively, are about even (0.13 percentage points each), the differences between low- and low-middle-income countries are explained by higher levels of absorption of IT equipment (relative to GDP) in the latter countries.

[218] For the few ICT producers in this country group, we adopt a somewhat different approach.

In summary, our estimates suggest that ICT-related capital deepening does have a substantial impact on growth in low- and low-middle-income countries. However, our estimates of the growth impacts of ICT-related capital deepening are lower than available estimates for the United States or other OECD countries.[219] As these differences may reflect methodological, as well as underlying economic differences, we also estimate the contributions of IT-related capital deepening, using Global Insight's (2006) "Global IT Navigator" database on IT spending, which is geared towards high- and higher-middle-income countries. (Note that this exercise, unless the previous one, does not include communications equipment.) Based on these data, we estimate a contribution of ICT-related capital deepening for the 2001–2005 period of 0.27 percentage points for 28 high-income countries, 0.25 percentage points for 18 higher-middle income countries, and 0.16 percentage points both for 18 low-middle-income countries and only 5 low-income countries included in the Global Insight sample. Overall, our estimates of the growth impacts IT-related capital deepening thus suggest that the impacts in low-income countries are about half of the impacts observed in high-income countries., and that the impacts in low-middle incomes are somewhat higher than those in low-income countries.

Finally, we provide an analysis of the growth impacts of ICT-related capital deepening in low- and low-middle-income countries over time, interpreting shocks to the relative prices of ICT equipment as successive perturbations to a steady-state equilibrium, followed by a gradual adjustment. Overall, we find that the contribution of ICT-related capital deepening has been increasing between 1991 and 2006, both in low-income countries and in low-middle-income countries. Early on (notably between 1994 and 1998), the acceleration was driven by an acceleration in the rate of technological progress embodied in IT equipment. In this regard, the pattern of growth attributed to ICT-related capital deepening (on a lower overall level) mirrors the findings from studies focusing on the United States or other OECD

[219] For example, for the 1995–2004 period, van Ark, O'Mahoney, and Timmer estimate a contribution to growth from ICT-related capital deepening of 0.5 percentage points for the European Union, and 0.8 percentage points for the United States. Jorgenson, Ho, and Stiroh (2008) estimate contributions to growth from ICT-related capital deepening for the United States of 1.0 percentage points in 1995–2000, and 0.6 percentage points in 2000–2006.

countries. For the latter part of the period under consideration, the contribution of ICT-related capital deepening in low- and low-middle-income countries remains stable, as a declining role of IT-related capital deepening is compensated by an increasing role of communications equipment. These trends are in contrast with findings suggesting that the growth contribution of ICT-related capital deepening has peaked in the late 1990s in the United States and other OECD countries.

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