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Economic Benefit of Tuberculosis Control

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Abstract

Tuberculosis is the most important infectious cause of adult deaths after HIV/AIDS in low- and middle-income countries. This paper evaluates the economic benefits of extending the World Health Organization's DOTS Strategy (a multi-component approach that includes directly observed treatment, short course chemotherapy and several other components) as proposed in the Global Plan to Stop TB, 2006-2015. The authors use a model-based approach that combines epidemiological projections of averted mortality and economic benefits measured using value of statistical life for the Sub-Saharan Africa region and the 22 high-burden, tuberculosis-endemic countries in the world.

The analysis finds that the economic benefits between 2006 and 2015 of sustaining DOTS at current levels relative to having no DOTS coverage are significantly greater than the costs in the 22 high-burden, tuberculosis-endemic countries and the Africa region. The marginal benefits of implementing the Global Plan to Stop TB relative to a no-DOTS scenario exceed the marginal costs by a factor of 15 in the 22 high-burden endemic countries, a factor of 9 (95% CI, 8-9) in the Africa region, and a factor of 9 (95% CI, 9-10) in the nine high-burden African countries. Uncertainty analysis shows that benefit-cost ratios of the Global Plan strategy relative to sustained DOTS were unambiguously greater than one in all nine high-burden countries in Africa and in Afghanistan, Pakistan, and Russia. Although HIV curtails the effect of the tuberculosis programs by lowering the life expectancy of those receiving treatment, the benefits of the Global Plan are greatest in African countries with high levels of HIV.

This paper—a product of the Health, Nutrition and Population Department in the Human Development Network—is part of a larger effort in the department to contribute to global knowledge of health economics and financing. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Melinda Elias, telephone 202-458-2175, email address melias@worldbank.org. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The corresponding author may be contacted at ramanan@rff.org. August2007. (53 pages)

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1. Introduction

Adult mortality has a significant effect on national economies, both through the direct loss of productivity among those of working age and by altering fertility, incentives for risk-taking behavior, and investment in human and physical capital. Tuberculosis (TB) is the most important cause of adult death due to infectious disease after HIV/AIDS. Roughly 8.8 million new TB cases and 1.7 million TB-related deaths were reported in 2003 (Corbett, Watt et al. 2003), including 229,000 deaths of individuals who also were infected with HIV/AIDS. Almost all of those who died from the disease lived in low- and middle-income countries (Lopez, Mathers et al. 2006) and most were between age 15 and 49 (Styblo and Rouillon 1991). Table 1 provides estimates of TB-related deaths from the World Health Organization (WHO) in the 22 countries with the highest burden of TB in 2004.

TB places an extraordinary burden on those afflicted by the disease, their families, and communities and on government budgets. The greatest burden of TB falls on productive adults who, once infected, are weakened and often unable to work. The burden of taking care of sick individuals usually falls to other family members and, in addition to putting them at greater risk of infection, can lower their productivity. Besides loss of productivity, the cost of treating TB also can be significant. Mean household spending on TB can account for as much as 8–20 percent of annual household income, varying by region (Russell 2004). Children also are affected. Each year, a significant proportion of children from families in India in which the primary breadwinner has TB are forced to drop out of school or seek employment (Rajeswari, Balasubramanian et al. 1999). However, the most devastating impact of TB is death; without treatment, two-thirds of smear-positive cases die within five to eight years, with most dying within 18 months of being infected (Styblo and Rouillon 1991).

Impact of adult mortality on economic growth

Adult deaths place an especially high economic burden on societies. The loss of working-age adults represents a loss of human capital and has a profound effect on household economic well being. A cross-sectional study of the effects of adult mortality

on small farmers engaged in cotton and maize production in Zambia found that an adult death resulted in a decline in crop output of roughly 15 percent (Larson, Hamazakaza et al. 2004). Yamano and Jayne (2004) find that an adult death and associated funeral expenses reduce purchases of agricultural inputs, such as farm animals and fertilizer, and jeopardize agricultural production. In addition, these studies find that the effect of adult mortality is greatest on households that were relatively poor to begin with, in part because they are less able to cope with unanticipated shocks (Beegle 2005). Other studies have shown that adult mortality has a deterrent effect on the acquisition of human capital.[2] Individuals may be less willing to get a higher education or make investments that pay off in the longer term, especially those that cannot be transferred to future generations in the same way as financial investments, if there is a greater risk that they may not be around to enjoy the returns of that investment.

There is a large literature on the economy-wide impact of adult deaths, mostly in the context of understanding the impact of the sharp decline in mortality rates that characterized much of the 20th century (Bhargava, Jamison et al. 2001; Bloom, Canning et al. 2004). Boucekkine finds that more than two-thirds of pre-industrial European economic growth between 1700 and 1820 was accounted for by reductions in adult mortality (Boucekkine, Croix et al. 2003). Researchers have tried to understand and estimate the causal pathways by which health, more specifically adult mortality, affects growth. Greater adult mortality implies a lower rate of return to human capital investments, which in turn is a determinant of economic growth. One study in which individuals make optimal schooling investment choices in the face of a constant probability of death found a 1% increase in schooling for each percentage decline in mortality (Kalemli-Ozcan, Ryder et al. 2000).

Another key route by which mortality affects growth is through fertility. Exogenous mortality declines have been linked to a lower precautionary demand for children and greater investment in children's human capital, both of which have a beneficial impact on growth of per capita GDP (Kalemli-Ozcan 2002). Kalemli-Ozcan also finds evidence of

[2] See Kalemli-Ozcan et al. (2000) for instance, who show that lower mortality increases individual time horizons and hence the incentive to invest in human capital.

increased fertility and lowered school enrollment between 1985 and 2000 in many African countries, as a consequence of HIV/AIDS deaths (Kalemli-Ozcan 2005).

The links between mortality and economic wellbeing are not always straightforward. Becker et al show that life expectancies worldwide converged between 1960 to 1990 while incomes diverged over the same period, indicating that life expectancies were probably not a significant predictor of economic growth (Becker, Philipson et al. 2003). In their study of the relative importance of contracting and property rights institutions, Acemoglu and Johnson find a negligible effect of life expectancy on per capita GDP (Acemoglu and Johnson 2006). Finally, Young used a calibrated simulation model to show that HIV/AIDS could improve economic prosperity by lowering fertility (Young 2005). This comes about directly because of a lower willingness to engage in unprotected sex, and indirectly by increasing labor scarcity and driving up women's wage rates. The effect of these two mechanisms outweighs the adverse impact of the disease on education.

Recent work has tried to provide a more consistent estimate of the different channels – increased risky behavior, lower investment and higher fertility – by which adult mortality affects economic growth (Lorentzen, McMillan et al. 2005). Estimates of the growth effect of adult mortality ranges from 0.8 to 1.4 percentage points associated with a one standard deviation increase in mortality, which implies that adult mortality could explain the growth shortfall in Africa between 1960 and 2000. An important caveat to these estimates is that they do not separately identify the effect of poor health from those of a shorter planning horizon imposed by higher mortality rates, but they provide a carefully estimated set of estimates of the impact of mortality on growth.

In this paper, we estimate the mortality-related costs of TB in Sub-Saharan Africa and the 22 countries with the highest burden of TB using a value of statistical life (VSL) - based, full-income growth approach. Our goal is two-fold: first, to assess the order of magnitude of the economic impact of TB; and second, to evaluate the benefits and benefit-cost ratios of DOTS programs (under two scenarios) to reduce TB cases and deaths. We ignore the morbidity effects of TB because premature death, rather than morbidity, is responsible for more than 80 percent of the disability-adjusted life years lost

to TB (Dye 2006). Also, a significant proportion of the TB-afflicted population may be unemployed prior to developing the disease (Rajeswari, Balasubramanian et al. 1999) and labor supply may be fairly elastic; therefore, morbidity-related productivity costs are likely to be small relative to the economic burden of deaths caused by TB.

2. TB, DOTS and Global Strategies

Current Situation

The Millennium Development Goals (MDG) for TB call for halting and beginning to reverse the incidence of TB by 2015, while the Stop TB Partnership goals call for halving prevalence and death rates by 2015 relative to 1990 rates. These goals are thought to be achievable if at least 70 percent of new infectious (smear-positive) cases worldwide are detected and at least 85 percent of those cases are treated successfully.

Much progress has been made toward reaching these targets, mainly facilitated by tremendous improvements in case detection and treatment. The case-detection rate through the introduction and expansion of the WHO's DOTS Strategy (a multi-component approach that includes directly observed treatment, short course chemotherapy and several other components) increased from 11 percent globally in 1995 to 53 percent in 2004. More than 21 million TB patients were treated in DOTS programs between 1994 and 2004 (WHO 2006). However, achieving the MDGs will be challenging given the rapid increase in the incidence of TB in Sub-Saharan Africa and Eastern Europe during the 1990s.

In Sub-Saharan Africa, the number of new TB cases was rising at 3–5 percent per year despite the DOTS program until around 2005, and efforts to control the disease are challenged by the problem of co-infection with HIV. In 2003, 33 percent of new TB cases in this region were in adults also infected with HIV, leaving approximately12 million adults co-infected with TB and HIV.

In Eastern Europe, economic factors, such as increasing levels of unemployment and deteriorating public health systems, are responsible for the increasing number of TB

cases. Multi-drug-resistant TB (MDR-TB) in particular poses a significant challenge (Kazionny, Wells et al. 2001); TB patients in Eastern Europe and Central Asia are 10 times more likely to have MDR-TB than in other regions of the world, and 5.5 percent of new cases are multi-drug resistant (Dye, Espinal et al. 2002).

Evidence on the effect of treatment (DOTS programs) on TB incidence, prevalence, and mortality

Before drawing a link between DOTS and declines in TB mortality, we review the evidence on the effectiveness of DOTS in controlling TB. Although TB declined before the introduction of drug treatment in many parts of the world, the decline has been accelerated since the 1950s by good chemotherapy programs, as seen in Western Europe (Styblo 1991), part of Northern Africa, and Latin America (e.g., Chile, Cuba, Uruguay). Data from Morocco and Peru provide two recent examples of the effect of treatment on transmission and incidence. Between 1994 and 2000, the incidence of pulmonary TB among Moroccan children 0–4 years of age fell at more than 10 percent per year, suggesting that the risk of infection was falling at least as quickly (Ministry of Health Morocco, unpublished data). The average age of TB cases also has been increasing for more than 20 years in Morocco as a consequence of falling transmission rates. The overall reduction in the incidence rate of pulmonary TB over the past decade was 4 percent per year. In Peru, DOTS was launched in 1991, and high rates of case detection and cure have pushed down the incidence rate of pulmonary TB by 6 percent per year (Suarez, Watt et al. 2001).

Some countries have measured the reduction in TB prevalence over time in the presence of good chemotherapy programs, though the reduction cannot always be attributed entirely to drug treatment. The Republic of Korea carried out seven surveys at five-year intervals between 1965 and 1995, during which time the prevalence of bacteriologically positive cases (smear- and/or culture-positive) of disease fell from 940 per 100,000 to 219 per 100,000 (Hong, Kim et al. 1998). Two prevalence surveys done in China in 1990 and 2000 showed a 32 percent (95% CI, 5%–68%) reduction in the prevalence per capita of smear-positive TB in DOTS areas, as compared with a negligible

change in prevalence in other parts of the country (China Tuberculosis Control Collaboration 2004). A national survey in Indonesia in 2004 found that the prevalence of smear-positive TB had fallen by a factor of three since a set of regional surveys were carried out between 1979 and 1982 (Aditama 1991; Soemantri, Senewe et al. in press). Most of this reduction may be due to drug treatment (especially the widespread availability of rifampicin since the early 1980s), though not to treatment administered by the recently expanded, higher-quality DOTS program.

Some investigations of the effect of DOTS programs have shown that after several years of implementation, TB incidence appears not to be falling as expected, as judged from nationally aggregated data. Vietnam apparently exceeded the targets for case detection and treatment success since 1997, and yet the case-notification rate remained approximately stable over that period (Huong, Duong et al. 2006). Closer inspection of surveillance data shows that while case-notification rates are falling among adults aged 35–64 years (especially women), they are increasing among 15–24 year-olds (especially men) (World Health Organization 2007). The program of drug treatment, therefore, does appear to be having the anticipated effect on transmission in one segment of the population─ middle-aged women. The increase in TB incidence among young adults is likely to be due, in part, to HIV co-infection.

The southern Indian states of Kerala and Tamil Nadu, among others, showed an increase in the average age of TB cases over the past decade, which may reflect falling transmission, corresponding with the expansion of the revised national TB control program (RNTCP). The RNTCP has yet to demonstrate that TB incidence is falling on a large geographical scale (e.g., across a whole state) as a result of its activities, though transmission and prevalence have been reduced in the model DOTS project in the Tiruvallur District in Tamil Nadu (Gopi, Subramani et al. 2006; Subramani, Santha et al. 2006).

Although it is not straightforward to evaluate the effect of DOTS on transmission because large-scale public health programs are not carried out as controlled experiments and because major changes in TB incidence happen over decades, it is widely believed that high-quality drug treatment, properly administered under DOTS, can markedly

reduce the TB case-fatality rate and already has saved the lives of millions of TB patients (Dye, Fengzeng et al. 2000; Suarez, Watt et al. 2001; Khatri and Frieden 2002).

Stop TB Strategy and the Global Plan to Stop TB (2006-15)

Since the launch of the DOTS strategy during the 1990s, a series of specific, emerging problems in TB epidemiology and control have demanded specific solutions. These include *M. tuberculosis* and HIV co-infection, drug resistance, the poor quality of treatment in the private sector, and the need to evaluate the epidemiological effect of TB control (not simply the implementation of DOTS). For this reason, DOTS has been extended as the Stop TB Strategy (Raviglione and Uplekar 2006; World Health Organization 2007). The blueprint for implementing the Stop TB Strategy over the next decade is the Global Plan to Stop TB (2006–15) (Stop TB Partnership and World Health Organization 2006). The plan sets out and compares three scenarios (also see Table 2 and Figures 1 and 2):

Scenario 1: No DOTS. This assumes that the DOTS strategy was never introduced in any region, so chemotherapy would continue as it was pre-DOTS, with variable rates of case detection and typically lower rates of cure. This gives a baseline against which to compare gains that already have been made and that might be made in the future.

Scenario 2: Sustained DOTS. Case-detection and treatment success rates increase until 2005 and then remain steady until 2015. Approximately 50 million patients would be treated under DOTS between 2006 and 2015, as compared with more than 20 million in the previous decade, 1996–2005.

Scenario 3: Global Plan Strategy or Enhanced DOTS. Case-detection and treatment success rates continue to increase beyond 2005, up to 2015. As in scenario 2, roughly 50 million patients would be treated between 2006 and 2015 (a higher proportion of patients treated sooner means that, as a result of reduced transmission, there are fewer patients later). To reach high rates of case detection and cure requires various additions to the basic DOTS strategy, including community-based care, a syndromic approach to diagnosing and treating TB among other respiratory conditions, and improved collaboration between public and private health sectors. To improve the management of

drug-resistant disease, more patients will be given drug-sensitivity tests, and approximately 800,000 MDR-TB patients will be treated with regimens including second-line drugs. HIV testing and counseling will be provided to 27 million TB patients, and antiretroviral therapy and co-trimoxazole preventive therapy will be offered to 3.2 million. Approximately 200 million people infected with HIV will be screened for TB, and 24 million will be offered isoniazid preventive therapy.

The scenarios do not account for the implementation of new technology (drugs, diagnostics, and vaccines) that may emerge due to research investments specified in the Global Plan.

3. Methodology

In this paper we evaluate the economic benefits of extending the World Health Organization's DOTS strategy (a multi-component approach that includes directly observed treatment, short course chemotherapy and several other components) using a model that combines epidemiological projections of averted mortality and economic benefits measured using a value of statistical life (VSL) approach. Other methodological approaches to this evaluation and the rationale for selecting the VSL-based approach are described in another paper that preceded these analyses (Laxminarayan 2006). Briefly these include cost-of-illness approaches using the human capital method or stated preference; sectoral approaches estimating the effect of disease on a particular sector of the economy (such as of malaria on tourism); and macroeconomic estimates based on models or cross-country growth regressions. These other approaches may lead to different estimates of economic benefits.

Here we describe the full-income approach to estimating the economic burden of a baseline scenario of No DOTS and then evaluate the economic benefit of moving to the Sustained DOTS and the Global Plan (enhanced DOTS) scenarios described earlier. An important methodological challenge is posed by the large number of TB-infected people worldwide, especially in Sub-Saharan Africa, who also are co-infected with HIV. Since there is no easy way to disentangle the effects of the two diseases, two sets of estimates are presented for TB-related deaths, one excluding HIV co-infection and another

including HIV co-infection. Estimates excluding the benefits of lowering TB–HIV co-infections may underestimate the benefits of DOTS coverage but avoid the risk of double-counting the costs of TB and HIV. To a large extent, the benefits of TB-control programs depend on the availability of antiretroviral treatments, and the benefits of TB control and treatment are likely to be greatest in countries where the life expectancy of co-infected patients is not curtailed by AIDS.

Incorporating health gains in GDP measures: full-income approach

GDP measures are the most widely used measures of economic activity in countries, but they have well-known, serious shortcomings, such as not measuring nonmarket goods (health, for instance) and home production. Two countries could have the same per capita GDP, but life in one country could be long and healthy while it is short and unhealthy in the other. GDP calculations fail to take account of health because they are based on what an economy produces rather than on the aggregate utility (or happiness) of the country's population.[3]

A growing literature on the economic value of health improvements has focused on expanding the idea of GDP to include improvements in health (Usher 1973; Nordhaus 2002; Becker, Philipson et al. 2003; Murphy and Topel 2005).[4] This concept, known as full-income GDP, incorporates both annual income and the number of years over which this income is enjoyed. In short, full-income approaches impute the value of increased life expectancy on economic well-being using revealed-preference approaches to value each year of longer life. Longevity gains can be quantitatively important when measuring welfare. Becker and colleagues find that when longevity gains are taken into consideration, average yearly "full income" grew 4.1 percent between 1960 and 2000 for the poorest 50 percent of countries, of which 1.7 percentage points were due to health (Becker, Philipson et al. 2003). The implication is that much of the welfare improvement

[3] GDP measures do take into account what a country spends on health but do not measure or value the output of the health sector.

[4] A recent WHO report incorporated these methods to measure the economic effect of chronic disease (WHO 2005) and determine changes in full-income attributable to reductions in chronic disease in regions where there have been significant improvements.

in poorer countries over the past few decades has come in the form of improved health and that the economic contribution of these longevity increases is important.

A formal approach used to calculate the economic value of increased longevity is based on translating increases in survival rates into incremental annual incomes required to yield the same utility level as with the original survival probability (Becker, Philipson et al. 2003) and is presented in Annex 1 in Laxminarayan (2006).

Valuing improvements in health

To value the improvement in health status represented by TB-control programs, an appropriate “price” to place on health must be found. Although most would agree that saving someone from certain death is a moral imperative that a value cannot be placed on, preventing every single probabilistic death is unaffordable and infeasible, even in the wealthiest countries in the world. The term "value of a statistical life" (VSL) is used widely in economics and regulation to denote not the value placed on a particular life but on the public-health measures that can reduce the statistically expected number of deaths by one.

Three principal approaches are used to evaluate VSL or willingness to pay for reducing risks to life. The most common approach is based on wage-risk tradeoffs, whereby workers are paid risk premiums to accept jobs with a higher risk of death or injury. The VSL is defined as the willingness to pay for a risk reduction divided by the risk reduction. Therefore, if lifetime wages for a high-rise construction worker with a 1/1,000 greater probability of death on the job are $500 more than for a worker with a similar job but with a lower risk of death, VSL is calculated as $500,000. VSLs are estimated through revealed-preference approaches (as distinct from stated-preference methods where respondents are asked how much they would hypothetically pay for lower risk of death), such as hedonic wage studies that use labor-market data to estimate the effect of morbidity and mortality risk on wage differences between occupations with differing levels of risk, after controlling for other variables that would explain wages. For example, all else being equal, a construction worker employed on a high-rise building

will have to be paid more than one working on a single-storey building to compensate him for a the greater probability of dying on the job.

A second approach is based on observing the behavior of consumers to see how much they are willing to pay in exchange for safety features, such as automobile seat belts or safer vehicles, to lower the risk of death. The third approach differs from the first two approaches, which are based on observing actual behavior, and instead is based on survey responses to hypothetical questions about the willingness to pay for a lower risk of death or disability. There are a number of problems with the stated-preference approach that could introduce bias in VSL estimates, but these methods have improved substantially over the years. The VSL estimates used in our study are based on the first approach.

There have been some conceptual and implementation-related critiques of VSL. [For a fuller discussion, see a working paper by Grüne-Yanoff (http://www.infra.kth.se/~gryne/VLS061120.pdf). Arguments against VSL relate to specific measurement practices and particular contexts of applications and do not rule out the use of VSL as an instrument for policy evaluation. The include a) problems with the practice of using a uniform VSL for all contexts – for instance a VSL that is measured in the context of work-related risks may not be applicable to a context of diet-related risks to health; b) commonly used measurement approaches make it difficult to interpret the resulting risk-wage tradeoff function; and c) risk preferences are correlated with risk exposures leading to overstated VSLs.]

A number of studies and meta-analyses have been published on VSLs (Viscusi 1993; Miller 2000). For the purposes of this study, we anchor VSLs to a central estimate of $6.1 million in 2004 dollars as recommended by the U.S. Environmental Protection Agency after an extensive analysis of the theoretical and empirical literature (U.S. Environmental Protection Agency (USEPA) 2000).

Relationship of VSL to GDP

Since hedonic wage studies have not been conducted in most low-income countries, a method known as benefits-transfer has been used to translate VSL estimates developed in

high- and middle-income countries to low-income countries. Benefits-transfer involves adjusting VSL estimates developed in other countries for income differentials between countries. There are disadvantages to using such a benefits-transfer method; the most important one being that individual preferences with respect to risk are influenced strongly by cultural factors and may be quite different in low-income countries. Moreover, differences in the extent of the availability and cost of health services are likely to influence wage-risk tradeoffs in these countries.

The benefits-transfer methods used in this analysis rely on estimates developed by Viscusi and Aldy (Viscusi and Aldy 2003). Based on more than 60 studies of mortality-risk premiums from 10 countries, they estimate an income elasticity of the value of a statistical life[5] of about 0.5 to 0.6, but their elasticity estimates are influenced downward by three extreme observations for India. Dropping these observations yields an elasticity of roughly one (Becker and Elias 2003) and is the value used in more recent studies (Becker, Philipson et al. 2003). Using the lower elasticity would yield implausibly high estimates of VSL in low-income countries.

Using an income elasticity of VSL of one and starting from the U.S. VSL of $6.1 million (associated with a U.S. real per capita GDP in 2004 of roughly $40,000), we can compute the VSL of India (with real per capita GDP in 2004 of $625) to be $94,721. This translates to $3,162 per year of life saved, at a 3 percent discount rate[6].

Mortality projections

Data on TB incidence and mortality from 2006–2015 are derived from WHO epidemiological models (WHO 2006). These models project TB incidence (both total and HIV+ cases), prevalence, and mortality for the years 2004–2015 under three scenarios: No DOTS, Sustained DOTS, and Global Plan strategy. The 2004 data from this report

[5] This refers to the percentage change in VSL for a one percent change in GDP.

[6] An alternative, although arbitrary approach, adopted by some authors is to assume that VSL is 100 times GDP per capita (Jamison, Sachs et al. 2001; WHO 2005). Since we assume an elasticity of VSL with respect to GDP of one (Becker and Elias 2003), our estimates of VSL are a direct multiple of GDP in the same ratio as for the United States and indicate a VSL to GDP ratio of roughly 150.

(the most recent year available at the time of this study) provide a baseline indicating the proportion of TB cases, TB cases co-infected with HIV, and deaths allocated to each country within a region. Since Global Plan projections are only available by region and not by country, for each subsequent year (2005–2015) we allocate region-specific TB deaths to each country in the same proportion as in the baseline year of 2004. This overestimates TB deaths in countries where deaths are expected to decline at a faster rate than the rest of the region and underestimates deaths in countries where TB deaths in coming years are likely to grow more rapidly than the rest of the region.

Since prevalence surveys are lacking in most countries, estimates of the number of TB cases in most countries are based on case-notification data. Estimates based on case-notification data can be unreliable (Murray, Lopez et al. 2004), since case-notification rates can be poorly correlated with actual prevalence, as shown by one study from India where the majority of TB cases are treated in the private sector (Borgdorff, Nagelkerke et al. 2000). However, WHO projections do make use of data from prevalence surveys wherever they are available. Given the difficulties in determining prevalence in individual countries, WHO's TB department has tended to rely more on forecasts of relative changes rather than on absolute numbers of cases and deaths. Typically, these forecasts are accompanied by multivariate uncertainty and sensitivity analyses (see Dye, Garnett et al. 1998 for instance) to provide a range on the estimates as discussed later in this section.

Value of Statistical Life Year Calculations

We estimated the economic burden of TB deaths under the three scenarios outlined above for the 22 countries with the highest burden of TB. Region-specific life expectancies were derived from the Disease Control Priorities Project (www.dcp2.org). We followed WHO methods in assuming that a person faces the same probability of death at each subsequent age as the existing population. This is equivalent to supposing

that period life expectancy is identical to cohort life expectancy.[7] Based on studies from South Africa, the average age of death from TB is 40 (Statistics South Africa 2006), so years of life lost are calculated by region as life expectancy at 40. Life expectancy for TB patients co-infected with HIV was assumed to be 10 (Morgan and Whitworth 2001). World Bank data on GDP levels for 2004 and projected growth rates for 2006–2015 were used.

The value of statistical life-years (VSLYs) represents annuitized, age-specific VSLs based on age-specific years of life expectancy and a three percent discount rate[8] as per the equation below (Moore and Viscusi 1988).

$$VSLY = \frac{r.VSL}{\left(1-(1+r)^{-L}\right)}$$

where r is the discount rate and L is life expectancy at birth. VSLYs are calculated for the United States using U.S.-specific life-expectancy estimates. Constant VSLYs were calculated for the two Africa regions (high HIV cases and low HIV cases) and for each of the 22 high-burden TB countries relative to a U.S. baseline VSLY of $200,310 and using an elasticity of VSL with respect to income of one and varied in a sensitivity analysis from 0.8 to 1.2.[9]

Full-Income GDP Growth Rate Calculations

Baseline estimates of full-income growth rates were based on the assumption that these were consistent with a Sustained DOTS scenario. Starting from this baseline, we calculated the reduction in full-income growth if DOTS was not sustained at the 2005 level and the increase in full-income growth associated with implementing the Global Plan. Life expectancy data are from the United Nations Statistical Database

[7] This is a good approximation for interventions that have little effect on overall life expectancy or the cohort survival curve. It has the effect, however, of making every intervention appear less effective when overall mortality is high; effectiveness is inversely correlated with disease burden.
[8] The constant discount rate of 3% per year recommended by Gold and colleagues is routinely used in evaluating health interventions in the United States (Gold, Siegel et al. 1996).
[9] Although there is some intuitive appeal to the idea that each year of life should be worth the same, recent estimates of VSLs from labor-market hedonic studies indicate that VSLYs may vary with age (Aldy and Viscusi 2006). However, they disagree on the shape of the VSLY curves with respect to age.

(http://unstats.un.org), while GDP growth rates are from the International Monetary Fund (www.imf.org).

Sensitivity Analysis

We used the Latin Hypercube Sampling (LHS) method to assess uncertainty surrounding the effect of each scenario in each region (McKay, Beckman et al. 1979), which has been used extensively by epidemiologists to evaluate a number of different models (Blower and Dowlatabadi 1994; Tanaka, Small et al. 2000; Currie, Williams et al. 2003). Because each input parameter is treated as a separate random variable, LHS is an efficient sampling design for dealing with large numbers of input parameters and is significantly more efficient than simple random and fractional-stratified sampling designs (see Blower and Dowlatabadi 1994).[10]

We generated 100 samples of the model parameters for each region (as computed in the program *Palisade @Risk*), assuming that model parameters act independently and take values that are triangularly distributed between lower and upper limits and the point estimate (Table 3). This analysis of unpredictability allows for three sources of uncertainty: (1) in regional trajectories of the TB epidemic before implementation of the Global Plan; (2) in the epidemiological response to a combination of interventions, given our imperfect understanding of TB's natural history; and (3) in whether the interventions will be carried out precisely as specified in the Global Plan scenarios described below. To account for variation of the third kind, we allowed for errors of ± 20 percent in the annual case detection rate and ± 10 percent in treatment success. Thus, for example, case-detection ranges between 80 percent and 120 percent of the anticipated value in each year of implementation of the Global Plan. The elasticity of the VSLY with respect to GDP also was included.

[10] In a standard Monte Carlo simulation, each input parameter is randomly selected from within a probability distribution function (pdf) for each simulation. In LHS, each parameter distribution is stratified into equiprobable intervals and each interval is sampled exactly once (without replacement). An input vector is then generated composed of the random samples of each of the input parameters for each simulation and each value of every parameter is only used once, which increases efficiency.

Parameter estimates were run through our model, and sample results were used to provide 95 percent confidence intervals for our estimates. Ninety-five percent confidence intervals were computed for the 22 high-burden endemic countries and the Africa region.

4. Results

To calculate economic benefits, we first calculated the estimated number of deaths for each country from 2006–2015, which is presented in Table 4. Results for the economic benefits and costs of TB control for Sub-Saharan Africa are presented in Tables 5 and 6 and for the 22 high-burden countries in tables 7 and 8. All estimates are in 2006 U.S. dollars and are based on a 10-year projection over the period 2006–2015 using a discount rate of 3 percent. Implementation costs, which are assumed to be paid for by expenditures raised from national tax revenues, for the Sustained DOTS and Global Plan strategies were obtained from the Stop TB program at the WHO. This imposes economic welfare losses because people or firms change their behavior to reduce the amount of tax they must pay. To reflect these welfare losses (also known as the marginal excess burden of taxation), the WHO cost estimates were scaled by a factor of 1.3 (Ballard, Shoven et al. 1985; Browning 1987).[11]

We find that the economic burden of deaths associated with TB (including HIV co-infection) in Sub-Saharan Africa is $519 billion (95% CI, $475–$563) when there is no DOTS coverage (Table 5). The corresponding estimate when HIV co-infections are excluded is $239 billion (95% CI, $210–$268). The economic benefit of sustaining DOTS in Sub-Saharan Africa at 2005 levels of coverage is estimated to be $129 billion (95% CI, $113–$146), of which approximately 75 percent of the benefit is in countries with a high HIV burden (Table 6a). The benefits of moving from No DOTS to the Global Plan strategy are even greater at $217 billion (95% CI, $200–$235). The economic cost of implementing Sustained DOTS in Sub-Saharan Africa is $12.24 billion, representing

[11] Warlters and Auriol estimate the marginal cost of public funds to be 1.17 based on a sample of 38 African countries (Warlters and Auriol 2005). However, we decided to use the 1.3 figure both to obtain a more conservative estimate of benefit-cost ratio, as well as to reflect that in many countries a significant proportion of national TB-control program budgets will be funded by external assistance from high-income countries.

about a ten-fold difference between the economic benefits and costs. The economic cost for implementing the Global Plan strategy for Sub-Saharan Africa is $22.24 billion, and again the benefits exceed costs by a factor of ten. Incremental benefits of implementing the Global Plan strategy relative to maintaining DOTS coverage at 2005 levels are $88 billion (95% CI, $83–$93), while the incremental cost is $10 billion. Excluding benefits associated with lowering deaths in HIV co-infected patients significantly reduces the benefits, especially in countries with a high prevalence of HIV, but the benefits of implementing the Global Plan strategy relative to No DOTS still exceed the cost by a significant margin (Table 6b and Figure 3).

The economic burden of TB between 2006 and 2015 for the 22 high-burden countries is estimated to range from $3.33 billion (95% CI, $3.07–$3.58) for Zimbabwe to $1,175 billion (95% CI, $1,074–$1,277) for China under the No DOTS scenario (Table 7). China alone accounts for more than a third of the overall economic burden in these countries, and India and China together account for more than half. Despite having more than a third of the TB deaths, high-burden countries in Sub-Saharan Africa only account for about a tenth of the burden.

Sustaining DOTS at 2005 coverage levels in the 22 high-burden countries would result in an estimated economic gain of around $1.6 trillion (over the period 2006–2015), ranging from $0.74 billion (95% CI, $0.64–$0.84) in Zimbabwe to $748 billion (95% CI, $638–$857) in China. While countries with a significant TB burden accrue the majority of benefits, approximately one-seventh of the benefits of sustained-DOTS programs accrue to the high-burden countries in Africa.

Benefit-cost ratios for each of the 22 high-burden countries are provided in Table 8 and Figure 3. Thailand has a benefit-cost ratio of more than 500, which is significantly greater than other countries, due in part to the low cost of implementation, while the Russian Federation, despite a significant burden, has a very low ratio, due both to the high cost of implementation as well as a low predicted reduction in mortality attributed to DOTS. In high-burden countries in Africa, benefit-cost ratios are all positive, with only Zimbabwe and the Democratic Republic of the Congo having ratios below 10.

The incremental benefit of moving from a strategy of No DOTS to the Global Plan is much greater than that of moving from Sustained DOTS to the Global Plan because much of the benefits of TB control are captured in moving from no DOTS to sustained DOTS. Due to the greater uncertainty surrounding implementation of the Global Plan relative to Sustained DOTS, in some countries, notably Indonesia, Vietnam, and the Philippines, the range of benefits may be quite large and not statistically different from zero. Nevertheless, for half the countries the estimated benefits could exceed the costs by more than a factor of 10, suggesting that there are significant economic benefits in reaching beyond 2005 DOTS-coverage levels to achieve Global Plan targets.

Annual GDP growth rates are contrasted with annual full-income growth rates in Table 9. Since full-income growth rates incorporate benefits from increased longevity, they are greater than GDP growth rates in countries where life expectancy is increasing. Only in South Africa, where life expectancy is declining, are full-income growth rates lower than GDP growth rates. Implementation of either type of TB-control strategy (Sustained DOTS or Global Plan) does not make a significant difference to annual full-income growth rates ─ differences are on the order of 0.002-0.015 percentage points.

Uncertainty analysis

Partial rank correlation coefficients (PRCCs) were calculated in the same manner as Blower and Dowlatabadi (1994) for input parameters sampled using the Latin hypercube scheme and the two outcome variables (deaths and economic burden). PRCCs help to determine the independent effects of each parameter on outcome variables, even when the parameters are correlated, and the relative importance of input variables in determining the imprecision of the result can be assessed by comparing PRCCs. Correlation coefficients are presented in Tables 10–12 (for the three scenarios for the Africa region).[12] We find that the fraction of infections leading to progressive primary disease was the most significant input parameter in evaluating the range of the result. Other parameters, including death rates, fraction of infected individuals susceptible to re-

[12] PRCCs also were calculated for high-HIV+ countries and low-HIV+ countries in the Africa region, as well as for other regions and countries, with similar results.

infection, fraction of infections smear-positive, the natural recovery rate, the reactivation rate of HIV+ individuals, and the income elasticity of VSL all were statistically significant.

5. Discussion

We estimate the economic burden of TB mortality and the economic benefits of reducing TB-related deaths for the WHO Africa region, separately by high-HIV and low-HIV countries and individually for the 22 high-burden, TB-endemic countries in the world using a VSL-based full-income approach. Starting from the baseline economic burden of TB-related deaths with no DOTS, we estimate the economic benefit of moving to: 1) a Sustained DOTS scenario where DOTS coverage from 2006–2015 continues at 2005 levels; and 2) a Global Plan scenario where DOTS coverage is expanded and a number of other initiatives are introduced to aggressively control TB worldwide. We also evaluate the benefits of moving from Sustained DOTS to the Global Plan scenario and compare these to the marginal costs of implementing the Global Plan strategy.

One could make a case for any DOTS intervention where the benefits exceed costs (or the benefit-cost ratio exceeds one). For the 22 high-burden countries, we find that there are significant benefits to Sustained DOTS coverage or Global Plan coverage relative to a baseline of no DOTS and relatively more modest benefits for moving from Sustained DOTS to the Global Plan scenario. Since much of the benefit of DOTS already is being reaped by the current level of coverage, increasing coverage likely will see declining marginal benefits. Benefit-cost ratios of moving from No DOTS to Sustained DOTS are in the order of 10, while the benefit-cost ratios of moving from Sustained DOTS to the Global Plan scenario are relatively lower in the 22 high-burden countries. The benefits of Global Plan coverage exceed costs in high-burden countries in Africa and for the continent as a whole.

Economic impact estimates under the full-income approach are sensitive to changes both in per capita GDP and life expectancy attributable to TB interventions. A higher per capita GDP (which translates to a higher VSLY) and a greater number of years of potential life lost, both have the effect of increasing the estimated economic burden of

TB-related deaths. Although the change in life expectancy attributable to the sustained DOTS program or the Global Plan strategy, and therefore changes in full income growth rates, is fairly small (since TB only accounts for about two percent of all deaths in low- and middle-income countries), the small change is scaled by the value of life, which is a large number. With rapid economic growth in many TB-endemic countries, VSLYs are projected to be even greater in the future, accounting for the sizable estimates of economic benefits.

Among the 22 high-burden countries, the economic impact of TB deaths and the benefits of TB control are greatest in China and India, where the combination of growing incomes and a relatively high number of TB deaths translates into a significant economic effect. Although the greatest number of TB deaths occurs in Africa, the economic benefit of either DOTS scenario in Africa is modest in comparison to Asia for two reasons. One, income-growth projections for Africa over the next 10 years are more modest than for Asia. Second, the benefits of TB treatment in Africa are curtailed by the large burden of HIV co-infection. Nevertheless, the economic burden of TB in Africa is significant and the benefits of both Sustained DOTS and the Global Plan strategies are large and exceed the costs by a wide margin.

Even if benefits of TB control programs exceed costs, the ratio of benefits to costs may be used to prioritize programs in resource-constrained settings. Tables 12a and 12b show benefit-cost ratios for other interventions targeted at young adults and projects supported by the World Bank in non-health sectors. Our estimates of benefit-cost ratios indicate that even among projects where benefits exceed costs, TB control programs offer very high returns in terms of economic benefits.

Caveats

Our estimation of economic benefits depends critically on epidemiological projections of mortality reductions attributable to DOTS and to the value of a statistical life in low-income countries. Further work is needed to develop more reliable estimates of epidemiological impact on the one hand, and VSLs on the other hand. There are

alternative approaches to VSL, each of which has pros and cons. The results of this model-based study are interpretable only to the extent that the approach is valid.

WHO's projections are based largely on case notifications that depend on the extent to which TB is treated in the public sector and the quality of health reporting in individual countries. Since the precision of benefits evaluated depend both on the evaluation of the VSL in individual countries and on the precision of mortality projections provided by WHO, we have subjected these numbers to an extensive sensitivity analysis that suggests that even if WHO's estimates overstate mortality reductions, the economic benefits of Sustained DOTS typically exceed the costs. Benefit-cost ratios of the Global Plan scenario exceed one relative to no DOTS, but the incremental benefit relative to Sustained DOTS is not statistically significant in a number of countries.

In addition, there is considerable uncertainty about the effects of DOTS on the transmission and incidence of TB. As such, this paper illustrates a VSL-based approach to measuring the benefits and cost–benefit ratios of global TB control. A more precise assessment of benefits evaluated in this paper will depend on more complete assessments of the effects of DOTS on mortality, transmission, and incidence.

One might argue that our full-income estimates overestimate the effect of TB because we have not adjusted VSLs for the specific socioeconomic groups where death from TB is most likely. TB is a disease of poverty in many countries where it is prevalent. Malnutrition and overcrowding create ideal conditions for transmission of infection from person to person, and the disease is concentrated not just in the poorer countries of the world but also in the more disadvantaged socioeconomic groups within these countries. The poor are at greater risk of unemployment than their wealthier counterparts, even when they are not infected with TB, potentially limiting the economic effect of the disease. However, the socioeconomic dynamics of TB may be changing in Africa, where the greatest increases in future burden are predicted. Because of the relatively high co-infection rate with HIV/AIDS and the relatively high prevalence of HIV among urban Africans in higher socioeconomic groups, our estimates for Africa may not be greatly biased upwards.

We have also not considered the behavioral responsiveness of patients to the availability of treatment. Others, most notably Tomas Philipson and colleagues, have shown that individuals modify their risk taking in response to perceptions of disease risk (Geoffard and Philipson 1996; Philipson 1999). However, in the case of TB, infection is almost always involuntary; people have to breathe, and they become infected when they inhale air that contains the TB bacteria, a risk that is higher in crowded living conditions among the poor. In general, exposure to the risk of infection is reduced with improvements in living standards, which is subject to socio-economic circumstances rather than changes in individual behavior. Therefore, the effects of behavioral changes on our estimates are likely to be minimal.

Also our assessment of benefits errs on the conservative side in two respects. First, the morbidity-reduction benefits of either DOTS scenario are excluded in our calculations**.** Second, the averted deaths used in our calculations exclude any benefits that may arise from investment in R&D that form part of the costs of the Global Plan strategy. Any new tools, especially a new vaccine, which would have the biggest effect on deaths in the long term, will not be available within the 10-year horizon of the Global Plan and are excluded from our cost–benefit assessment.

Economic Benefits and Costs of the Global Plan in Africa

The annual cost of implementing the Global Plan in Africa is $2.6 billion, of which $2.13 billion is for countries with a high burden of HIV co-infection. Our results indicate that the benefits of implementing a Global Plan strategy exceed the costs by a wide margin (relative to the no-DOTS baseline) even if the benefits of expanded coverage on lowering deaths in individuals with HIV co-infection were to be ignored. When the benefits of TB control in HIV co-infected patients are included, the benefit-cost ratio of the Global Plan in Africa is roughly ten-to-one (relative to No DOTS) and nine-to-one (relative to Sustained DOTS). Although HIV does curtail the effect of DOTS programs by lowering the life expectancy of those receiving treatment, the Global Plan does appear to be welfare-improving (relative to Sustained DOTS) in African countries with high levels of HIV.

Benefit-cost ratios of the Global Plan strategy relative to Sustained DOTS were unambiguously greater than one in only 12 of the 22 high-burden countries. These include all nine that are in Africa, and also Pakistan, Afghanistan, and Russia. These results highlight the large avertable burden of TB in Africa and the significant economic benefits of the Global Plan strategy, in spite of challenges such as slow economic growth and high HIV co-infection.

Table 13 shows benefit-cost ratios for investments in youth in selected countries (Knowles 2003) and for selected development bank-supported investments (Gaag and Tan 1998). The benefit-cost ratios of the Global TB Plan compare favorably with those estimated for these investments. Such comparisons must be interpreted with caution, given the methodological and data challenges noted elsewhere in this paper. In addition, there are practical issues that affect their use. For example, Jack (2000) points out that the benefit-cost ratio of a program is irrelevant as long as it is greater than one, in which case the program should be implemented. However, policymakers face the reality of resource constraints and cannot fund everything. While it is useful to take into account the relative benefits of potential investments in different programs, the decision criteria often are multiple. Country investment decisions often result from analyses and negotiations about the relative emphasis to put on competing interests and programs. While this paper will contribute to broader discussions at the global and country levels, the full scope of comparisons and decisions is beyond its scope.

6. Conclusions

We evaluated economic benefits associated with DOTS for the Sub-Saharan Africa region and for the 22 countries with the highest burden of TB. The Global Plan to Stop TB, which covers the period 2006–2015, projects TB cases, TB cases that are co-infected with HIV, and TB deaths under three scenarios: no DOTS, sustained DOTS, and the Global Plan to Stop TB. Here we estimate the economic benefit of moving from a baseline of no-DOTS to one of sustained DOTS or to the Global Plan strategy as well as of moving from sustained DOTS to the Global Plan scenario.

Based on a full-income approach that values deaths using the VSL, we estimated the economic burden of TB deaths in Africa between 2006 and 2015 to be $519 billion (95% CI, $475–$563) in a scenario with no DOTS coverage anywhere. Of this figure, $418 billion (95% CI, $386–$450) is attributable to the burden in countries with a high level of HIV co-infection and $101 billion (95% CI, $89–$114) to the burden in countries with a low level of HIV co-infection. The present discounted benefit of moving from no DOTS to the scenario of sustained DOTS at 2005 coverage levels is $129 billion (95 % CI, $113–$146) and to a Global Plan strategy (from no DOTS) is $218 billion (95% CI, $200–$235). In comparison, the costs of implementation are $12.2 billion for a sustained DOTS program and $22.2 billion for the Global Plan strategy. These estimates represent a ten to one ratio of benefits to costs for sustained DOTS coverage and roughly nine to one for Global Plan implementation in the Africa region, relative to the baseline of no DOTS. A similar benefit-cost ratio is estimated for the Global Plan relative to sustained DOTS.

The discounted burden in the countries with the highest burden of TB when a no-DOTS strategy is implemented between 2006 and 2015 is estimated to be more than $3 trillion and ranges from $3.3 billion (95% CI, $3.07–$3.58) for Zimbabwe to $1,175 billion (95% CI, $1,074–$1,277) for China. The discounted benefit of maintaining DOTS at the 2005 coverage levels or implementing the Global Plan strategy between 2006 and 2015 for the 22 high-burden countries is more than $1.6 trillion and $1.9 trillion, respectively, relative to a no-DOTS strategy. Benefit-cost ratios for a sustained-DOTS scenario (relative to no DOTS) typically exceed those for moving from sustained DOTS to a Global Plan strategy, except in Afghanistan, Russia, and South Africa.

A full-income approach based on changes in the GDP growth rates related to changes in life expectancy found that implementation of either type of TB-control strategy (sustained DOTS or Global Plan) does not make a significant difference to full-income growth rates ─ differences are on the order of 0.002–0.015 percentage points.

Our estimation of economic benefits depends critically on epidemiological projections of mortality reductions attributable to DOTS and to the value of a statistical life in low-income countries. Further work is needed to develop more reliable estimates of

epidemiological impact on the one hand, and VSLs on the other hand. There are alternative approaches to VSL, each of which has pros and cons. The results of this model-based study are interpretable only to the extent that the approach is valid.

Appendix 1: Modeling the Effect of the Global Plan to Stop TB

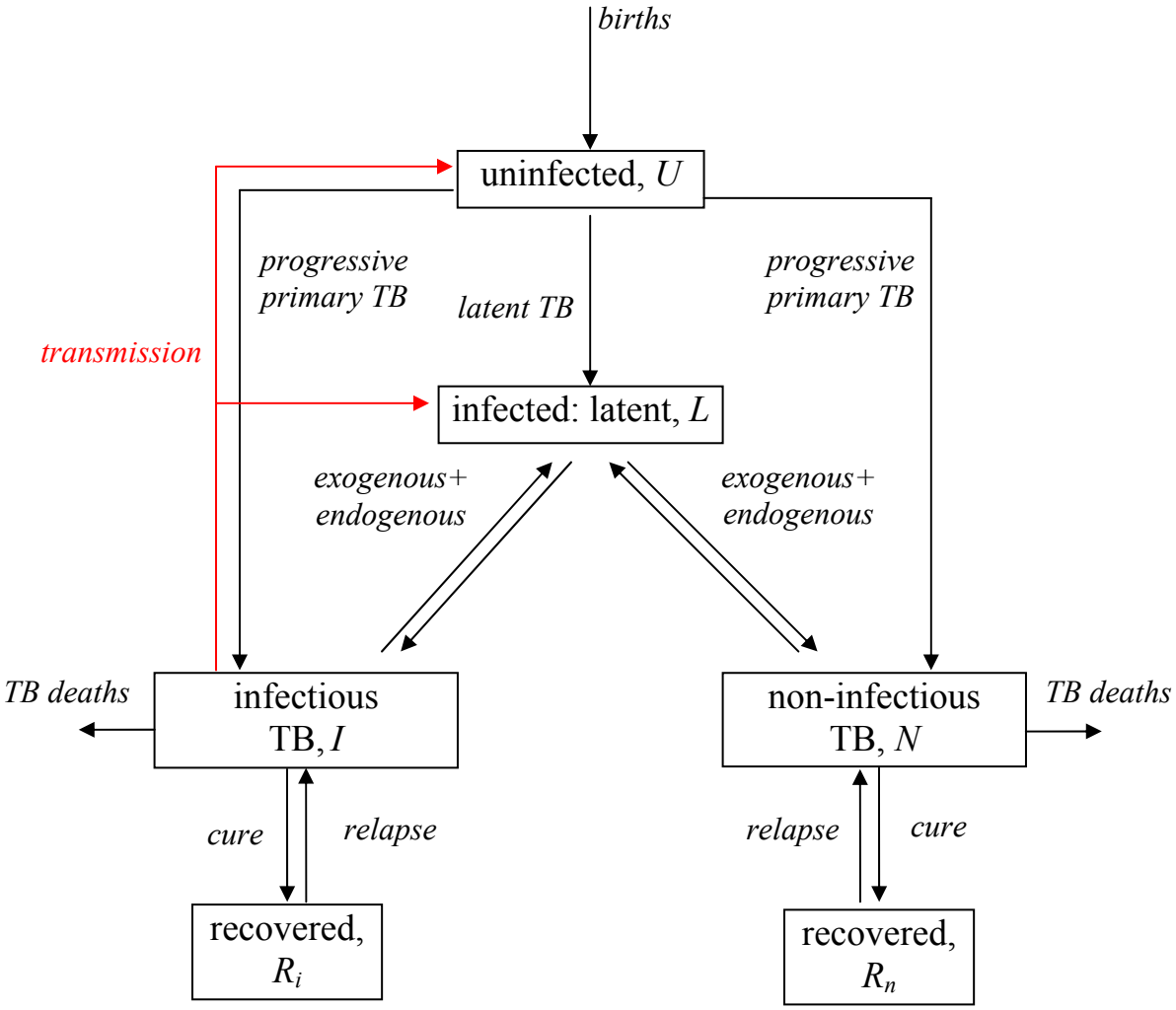

Figure A.1. Flow diagram of the compartmental model for tuberculosis. Refer to equations below for a formal description of the model, and to Table 3 for definitions and values of parameters.

The potential impact of scenarios 2 and 3, as compared with scenario 1, has been evaluated with a mathematical transmission model describing, as in previous models (Blower, McLean et al. 1995; Dye and Williams 2000; Dye and Espinal 2001), how the planned interventions can be expected to reduce TB incidence, prevalence, and death rates through time. The structure of the core TB model is based on literature describing the natural history of TB, and fitted quantitatively to data defining the course of TB epidemics in seven regions of the world (Dye, Scheele et al. 1999; Corbett, Watt et al. 2003; World Health Organization 2007). The core model is sketched as a flow chart in Figure A.1. We previously have shown how models of this kind can replicate the

observed effect of drug-treatment programs carried out from the 1950s onwards (Dye, Garnett et al. 1998).

Written in difference equations, as programmed in Visual Basic and Microsoft Excel, the basic TB model is as shown below. For simplicity and transparency, these equations describing the core model exclude the complications of HIV co-infection and multidrug resistant (MDR)disease, though both are included in the full model used to carry out calculations for the Global Plan. We assume that homogeneously mixing individuals in a model human population affected by TB belong to one of the six mutually exclusive groups:

Uninfected:

$$U[t] = U[t-1](1-\mu) + \mu_i I[t-1] + \mu_n N[t-1] - \lambda[t-1]U(t-1)$$

Latent infection:

$$L[t] = L[t-1](1-\mu) + \lambda[t-1](1-f)(1-\mu)U[t-1] - (\nu + \lambda fx)L[t-1]$$

Active infectious TB:

$$\begin{aligned} I[t] &= I[t-1](1-\mu-\mu_i) \\ &+ (\lambda[t-1]fsU[t-1] + \nu sL[t-1] + \lambda[t-1]fsxL[t-1])(1-\delta_D\kappa_D - \delta_O\kappa_O)(1-\mu-\mu_i) \\ &- \rho I(t-1) \end{aligned}$$

Recovered from infectious TB:

$$\begin{aligned} R_i[t] &= R_i[t-1](1-\mu) + \rho I[t-1](1-\mu) \\ &+ (\lambda[t-1]fsU[t-1] + \nu sL[t-1] + \lambda[t-1]fsxL[t-1])(\delta_D\kappa_D + \delta_O\kappa_O)(1-\mu) \end{aligned}$$

Active non-infectious TB:

$$\begin{aligned} N[t] &= N[t-1](1-\mu-\mu_n) + (\lambda[t-1]f(1-s)U[t-1] \\ &+ \nu(1-s)L[t-1] + \lambda[t-1]f(1-s)xL[t-1])(1-\delta_D\kappa_D - \delta_O\kappa_O)(1-\mu-\mu_n) \\ &- \rho N(t-1) \end{aligned}$$

Recovered from non-infectious TB:

$$\begin{aligned} R_n[t] &= R_n[t-1](1-\mu) + \rho N[t-1](1-\mu) \\ &+ (\lambda[t-1]f(1-s)U[t-1] + \nu(1-s)L[t-1] + \lambda[t-1]f(1-s)xL[t-1])(\delta_D\kappa_D + \delta_O\kappa_O)(1-\mu) \end{aligned}$$

The model does not distinguish people by age and sex. Among uninfected (U) individuals who acquire *M. tuberculosis* infection from contagious individuals (I) at time-dependent

rate $\lambda[t]$ ($= \beta I[t]$, usually called the "annual risk of infection"), fraction f develop progressive primary TB within one year of contact. By contrast, fraction 1-f move into the latent class (L), from which they breakdown relatively slowly (endogenous reactivation at rate ν) to active disease. TB can arise from latent infection many years after the infection was acquired. However, the progression from latency to active disease can be accelerated by (exogenous) re-infection, provided re-infection overcomes the partial immunity (measured by proportion x) acquired from the primary infection.

Active disease is either infectious pulmonary TB (I, arising in fraction s of cases), in which most patients have a positive-sputum smear on microscopic examination, or non-infectious pulmonary or extrapulmonary TB (N, fraction 1-s). Patients with active TB have an elevated death rate, which is higher for infectious (μ_i) than for non-infectious disease (μ_n), and much higher than the mortality rate from all other causes (μ). These death rates are expressed in terms of survival (e.g. 1- μ) from one time step to the next, which allows us to assign different survival rates to patients in the same state but who have with different fates. The notation *[t]* and *[t-1]* represents the value of state variables at, respectively, the current and at the previous time step (1 year ago).

Birth and death rates are assumed equal so the total population remains constant. A small proportion of human TB cases are caused by mycobacteria other than *M. tuberculosis*, especially *M. bovis*, but they are not relevant to this analysis. More important are the effects of HIV and MDR-TB, which are modeled as extensions of the above equations (not shown here, but see e.g., (Dye and Williams 2000).

Before drugs became available to treat TB in the 1940s, a proportion of patients self-cured. Self-cure is still a part of TB natural history and is represented in this model by ρ. Case-detection rates (δ) are different for DOTS (subscript D) and non-DOTS or other programs (subscript O). In general, the efficacy of drug treatment (cure, κ) is higher when administered in DOTS programs than elsewhere. Patients that are cured, either naturally or by drug treatment, move to the recovered class (R_i or R_n), where they are assumed to remain (i.e., this version of the model does not allow relapse).

Parameter values used for this investigation are similar to those used in previous modeling analyses (Vynnycky and Fine 1997; Dye, Garnett et al. 1998; Lietman and Blower 2000; Young and Dye 2006), and are given in Table 3. To reconstruct the recent epidemiological history of TB in seven regions of the world (representing the whole world except the established market economies and central Europe), the model was fitted to WHO estimates for incidence, prevalence, and deaths from 1990 (the baseline for the Millennium Development Goals [MDG]) to 2003 (the latest data available at the time of writing the Global Plan). The fitting was carried out principally by adjusting parameters determining the contact rate (β) and the natural recovery rate (ρ). An example of the fit (for the Western Pacific Region) is illustrated in Figure A.2.

The effect of control is determined by inputs set out in the seven regional plans, as described in Table 11 of Annex 1 to the Global Plan (Stop TB Partnership and World Health Organization 2006). Case detection and cure rates are based on, and extended

from, data compiled in WHO's annual reports on Global Tuberculosis Control (World Health Organization 2007). While the model calculates incidence, prevalence, and deaths, only deaths are used in the analysis of economic effect (Figure A.2).

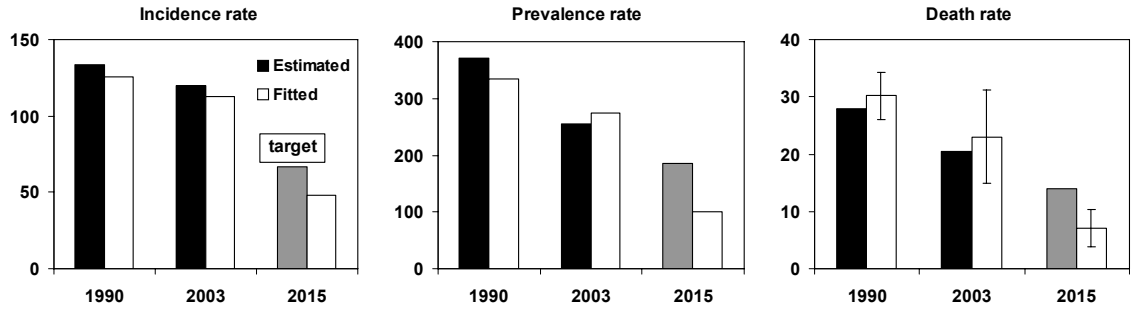

Figure A.2. TB model fitted (white bars) to WHO estimates (black bars) of incidence, prevalence, and death rates per 100,000 population in the Western Pacific Region, 1990 and 2003. Grey bars are the MDG target values for 2015 and the corresponding white bars for 2015 are the expected outcome of implementing the Global Plan (scenario 3). The third panel shows the standard errors on calculated death rates, as derived from multivariate uncertainty analysis.

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Figure 1: Total Deaths from TB, 2006 to 2015

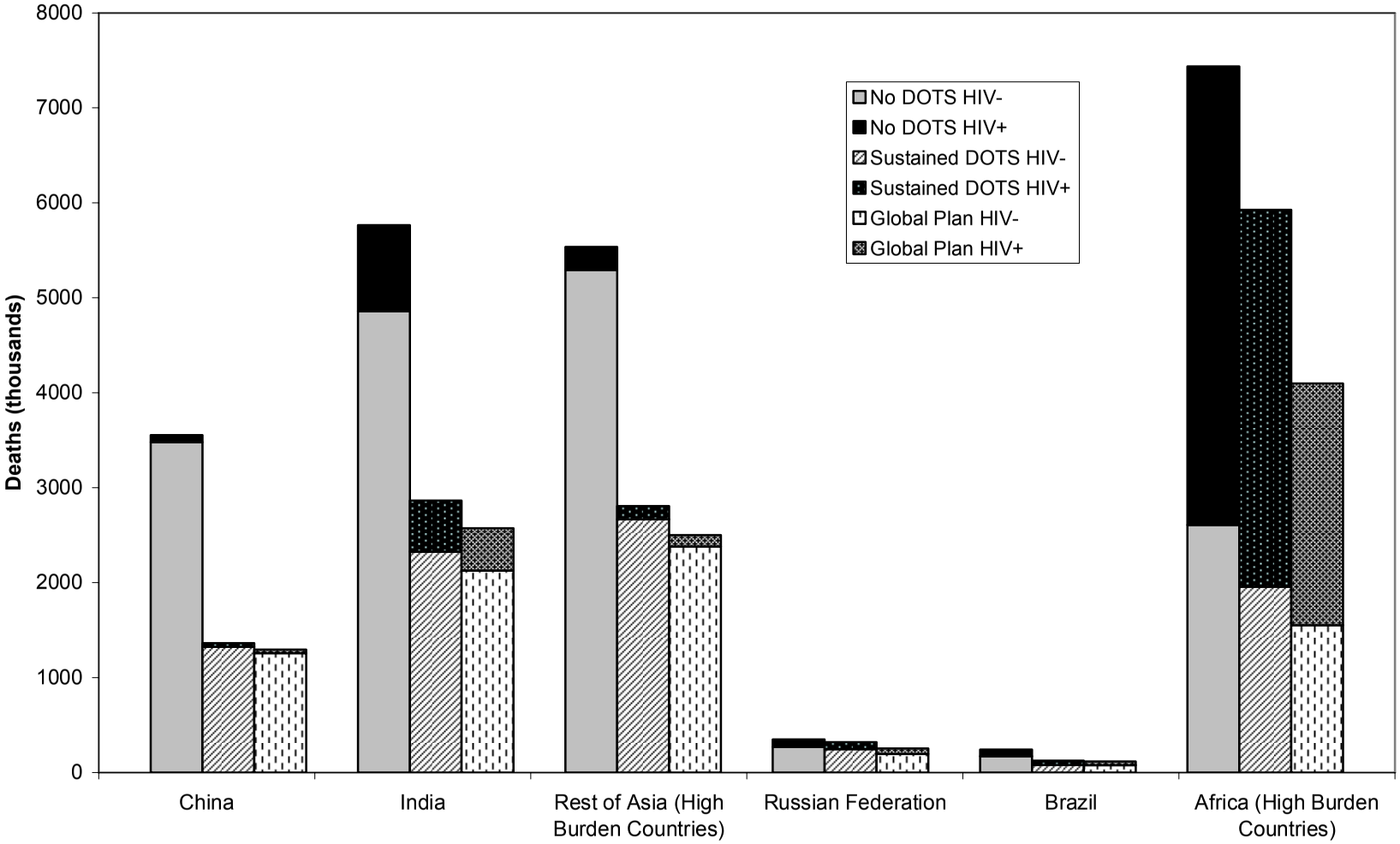


Figure 2: Predicted trends of TB incidence under following scenarios; No DOTS; DOTS sustained at 2005 level; and implementation of Global Plan to Stop TB, 2006-15 (WHO 2006)

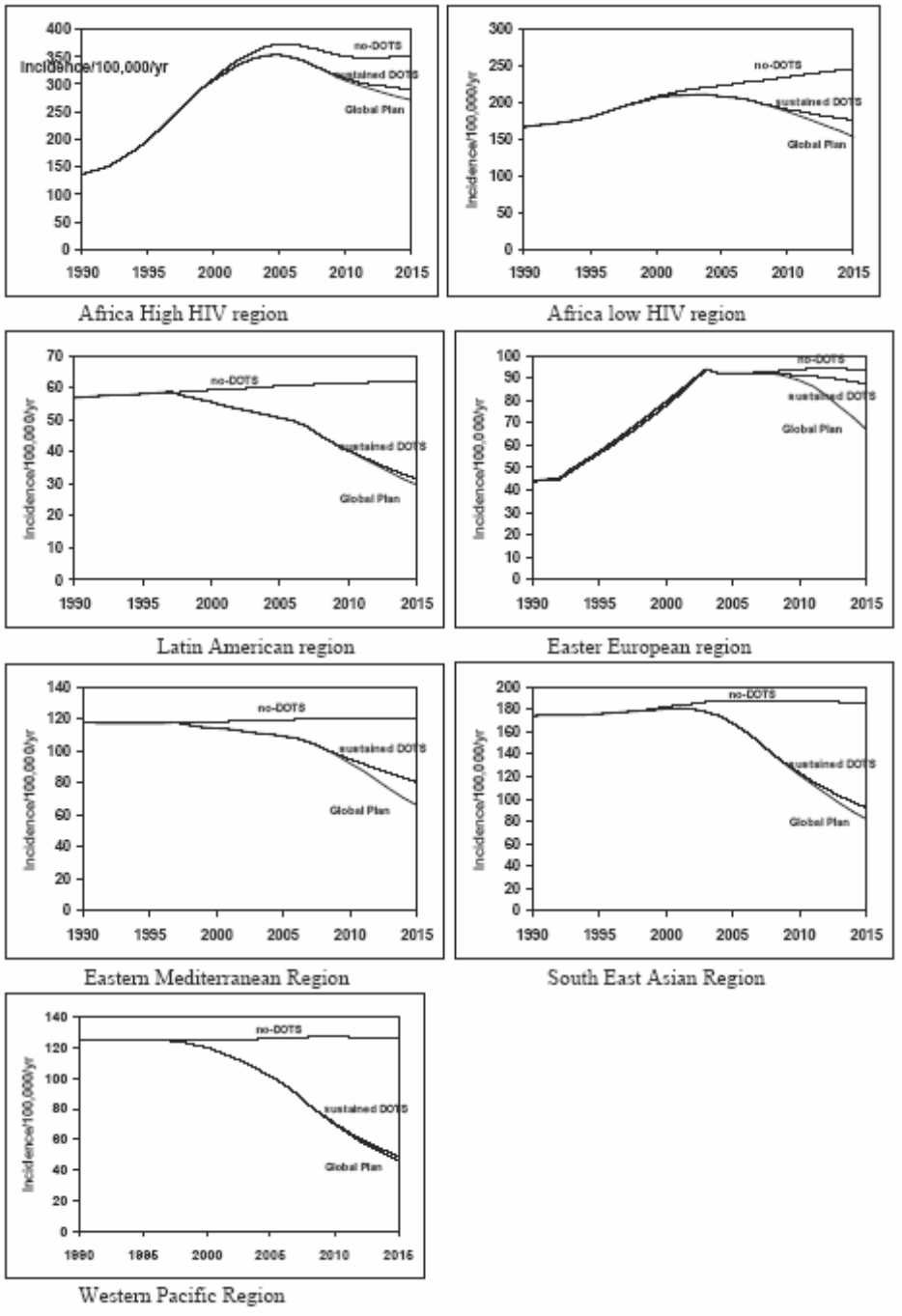


Table 1: Deaths in 22 high burden countries TB endemic countries, 2004

Countries	Total Deaths	HIV+ Deaths	Excluding HIV+ Deaths
Afghanistan	12,645	5	12,640
Bangladesh	86,506	268	86,238
Brazil	16,608	4,450	12,158
Cambodia	13,804	2,484	11,320
China	229,978	3,274	226,705
DR Congo	68,506	36,317	32,189
Ethiopia	91,501	27,085	64,416
India	419,773	66,761	353,012
Indonesia	119,376	3,479	115,897
Kenya	77,554	58,047	19,507
Mozambique	39,681	49,655	0
Myanmar	9,798	1,582	8,217
Nigeria	161,877	93,730	68,147
Pakistan	71,795	607	71,188
Philippines	43,797	214	43,583
Russian Federation	34,144	2,902	31,242
South Africa	54,512	73,739	0
Thailand	15,877	3,856	12,021
Uganda	42,267	34,824	7,443
UR Tanzania	46,605	36,547	10,058
Vietnam	21,524	1,994	19,530
Zimbabwe	27,483	34,345	0
Total	**1,705,612**	**536,162**	**1,205,513**
African Region Sub-Total	***609,986***	***444,289***	***201,760***

Table 2: Three scenarios outlined by Global Plan

No DOTS	This assumes that the strategy was never introduced in any region, so treatment would continue as it was pre-DOTS, with variable rates of case detection and typically lower rates of cure. This gives a baseline against which to compare acquired and future gains.
Sustained DOTS	Sustaining DOTS implementation at 2005 level (no new activities). Case detection and treatment success rates increase until 2005, and then remain steady until 2015.
Global Plan	Full implementation of the Global Plan to Stop TB 2006–2015 (the Global Plan) including expansion of DOTS coverage, programs to address TB/HIV coinfection and multi-drug resistant TB, new TB diagnostics, drugs, and vaccines; and efforts in advocacy, communications, and social mobilization.

Source: DOTS Expansion Working Group Strategic Plan 2006 – 2015
whqlibdoc.who.int/hq/2006/WHO_HTM_TB_2006.370_eng.pdf

Table 3. Values of key parameters in the TB model The three values given for each parameter specify the base and apex of a triangular distribution. Values of β and ρ, parameters that are varied to fit the model to WHO estimates, are for the Western Pacific Region.

	Symbol		Parameter values
Model Parameters	**HIV neg**	**HIV pos**	**(low, point, high)**
Infectious contacts/person/yr	β	β_h	9, 9.5, 10
Reactivation rate/person/yr	v	v_h	0.0001, 0.000138, 0.0002
Proportion infections leading to progressive primary disease	f	f_h	0.12, 0.15, 0.18
Proportion active cases sm+	s	s_h	0.4, 0.45, 0.5
Proportion infected persons Susceptible to reinfection	x	x_h	0.1, 0.35, 0.6
Natural recovery rate from TB/patient/yr	ρ	ρ_h	0.08, 0.1, 0.12
Non-TB death rate/person/yr	μ	μ_h	0.01, 0.015, 0.02
TB (sm+) death rate/patient/yr	μ_i	$\mu_{i\,h}$	0.1, 0.13, 0.16
TB (sm-) death rate/patient/yr	μ_{in}	$\mu_{in\,h}$	0.025, 0.05, 0.075
Efficacy IPT for HIV+ (TST+)		e_{ipt}	0.3,0.4,0.5
Efficacy ART+CPT		e_{art}	0.3,0.4,0.5
Efficacy CPT		e_{cpt}	0.5,0.6,0.7

Parameters e_{ipt}, e_{art} and e_{cpt} specify the efficacy of isoniazid preventive therapy for people with latent infection (IPT), antriretroviral therapy (ART) and co-trimoxazole preventive therapy (CPT), the latter two for people who are HIV-positive. Note $b_h = b$

Table 4: Deaths in 22 High Burden TB-Endemic Countries (2006-2015)

	Deaths (thousands)			HIV+ Deaths (thousands)			Deaths Excluding HIV+ Deaths (thousands)		
Countries	No DOTS	Sustained DOTS	Global Plan	No DOTS	Sustained DOTS	Global Plan	No DOTS	Sustained DOTS	Global Plan
Afghanistan	199 (178-220)	132 (118-146)	109 (98-120)	0 (0-0)	0 (0-0)	0 (0-0)	199 (178-220)	132 (118-146)	109 (98-120)
Bangladesh	1372 (1228-1517)	690 (602-777)	609 (543-675)	4 (4-4)	2 (2-2)	2 (2-2)	1369 (1224-1513)	688 (600-775)	607 (541-673)
Brazil	281 (251-312)	138 (128-148)	133 (120-145)	72 (69-75)	46 (45-48)	40 (38-42)	209 (181-237)	92 (82-101)	93 (82-104)
Cambodia	238 (217-258)	89 (82-96)	85 (79-92)	57 (55-59)	30 (30-31)	28 (27-29)	181 (162-200)	59 (52-65)	57 (51-64)
China	3959 (3619-4299)	1483 (1366-1599)	1423 (1308-1539)	75 (72-78)	40 (39-41)	37 (36-38)	3884 (3546-4222)	1442 (1327-1558)	1386 (1271-1501)
DR Congo	854 (800-908)	666 (628-704)	477 (443-511)	405 (388-423)	331 (318-345)	214 (202-226)	449 (411-487)	335 (309-361)	263 (240-286)
Ethiopia	1141 (1068-1213)	890 (839-941)	637 (591-682)	302 (289-315)	247 (237-257)	160 (151-168)	839 (778-899)	643 (601-685)	477 (440-514)
India	6660 (5959-7360)	3347 (2924-3770)	2956 (2636-3276)	922 (891-953)	546 (525-566)	451 (437-465)	5738 (5059-6417)	2801 (2393-3209)	2505 (2194-2815)
Indonesia	1894 (1695-2093)	952 (831-1072)	841 (750-932)	48 (46-50)	28 (27-29)	24 (23-24)	1846 (1648-2044)	923 (804-1043)	817 (727-908)
Kenya	967 (905-1028)	754 (711-798)	540 (501-578)	648 (619-676)	529 (508-551)	342 (323-361)	319 (283-355)	225 (201-249)	198 (177-219)
Mozambique	495 (463-526)	386 (364-408)	276 (256-296)	554 (530-578)	453 (434-471)	293 (277-309)	8 (3-13)	2 (0-4)	7 (4-11)
Myanmar	155 (139-172)	78 (68-88)	69 (62-76)	22 (21-23)	13 (12-13)	11 (10-11)	134 (118-149)	65 (56-75)	58 (51-66)
Nigeria	2018 (1890-2146)	1575 (1484-1665)	1127 (1046-1207)	1046 (1000-1091)	854 (820-889)	552 (522-583)	972 (886-1059)	720 (662-778)	574 (522-626)
Pakistan	1129 (1009-1249)	750 (671-828)	620 (556-683)	11 (11-12)	9 (8-9)	6 (6-7)	1118 (998-1238)	741 (663-819)	613 (550-676)
Philippines	754 (689-819)	282 (260-304)	271 (249-293)	5 (5-5)	3 (3-3)	2 (2-2)	749 (684-814)	280 (258-302)	269 (247-291)
Russian Federation	401 (360-442)	383 (336-431)	294 (262-326)	82 (78-86)	78 (73-82)	60 (57-63)	319 (282-357)	306 (262-349)	234 (205-264)
South Africa	680 (636-723)	530 (500-561)	379 (352-407)	823 (787-858)	672 (645-700)	435 (411-459)	4 (0-8)	0 (0-1)	3 (1-6)
Thailand	252 (225-278)	127 (111-143)	112 (100-124)	53 (51-55)	32 (30-33)	26 (25-27)	199 (173-224)	95 (80-110)	86 (74-97)
Uganda	527 (493-560)	411 (388-435)	294 (273-315)	389 (372-405)	317 (305-330)	205 (194-217)	138 (120-157)	94 (82-106)	89 (78-99)
UR Tanzania	581 (544-618)	453 (427-479)	324 (301-348)	408 (390-425)	333 (320-347)	215 (204-227)	173 (152-194)	120 (106-134)	109 (97-121)
Vietnam	371 (339-402)	139 (128-150)	133 (122-144)	46 (44-47)	24 (24-25)	23 (22-23)	325 (294-356)	114 (104-125)	111 (100-121)
Zimbabwe	343 (321-364)	267 (252-283)	191 (178-205)	383 (367-400)	313 (300-326)	202 (191-214)	6 (2-9)	1 (0-3)	5 (3-7)

No DOTS estimates assume that TB treatment has continued at pre-DOTS levels from 2006–2015 along with the lower rate of case detection and cure and do not represent the current burden of TB-related deaths. Values in parentheses are 95% confidence intervals.

Table 5: Economic Burden of TB Deaths in African Countries, billions of dollars (2006-2015)

	Including HIV coinfection			*Excluding HIV coinfection*		
	No DOTS	***Sustained DOTS***	***Global Plan***	***No DOTS***	***Sustained DOTS***	***Global Plan***
Africa	$519.28 ($475.37-$563.19)	$389.85 ($361.03-$418.66)	$301.73 ($274.96-$328.50)	$239.06 ($210.21-$267.90)	$167.41 ($149.77-$185.04)	$146.48 ($129.33-$163.64)
Africa High HIV+	$417.98 ($386.27-$449.69)	$320.39 ($299.19-$341.59)	$240.26 ($220.51-$260.00)	$151.32 ($134.30-$168.33)	$108.47 ($98.26-$118.67)	$92.90 ($82.49-$103.32)
Africa Low HIV+	$101.30 ($88.75-$113.86)	$69.46 ($61.56-$77.36)	$61.48 ($54.29-$68.66)	$87.74 ($75.70-$99.78)	$58.94 ($51.40-$66.48)	$53.58 ($46.74-$60.41)
High Burden African Countries	$348.63 ($322.47-$374.79)	$267.57 ($250.06-$285.09)	$199.73 ($183.44-$216.02)	$126.03 ($112.34-$139.72)	$90.97 ($82.77-$99.16)	$76.62 ($68.23-$85.01)

Note: 3% annual discount rate; Estimates may vary slightly from other tables due to rounding; Values in parentheses are 95% confidence intervals.

Table 6a: Economic Benefit and Costs of TB Control Strategies in Sub-Saharan African Countries, billions of dollars (2006-2015)

	Sustained DOTS (relative to no DOTS)			Global Plan (relative to no DOTS)			Global Plan (relative to Sustained DOTS)		
	Benefits	**Costs**	**Ratio**	**Benefits**	**Costs**	**Ratio**	**Benefits**	**Costs**	**Ratio**
Africa	$129.44 ($112.81-$146.07)	$12.24	11 (9-12)	$217.55 ($200.15-$234.95)	$22.24	10 (9-11)	$88.12 ($82.95-$93.28)	$10.01	9 (8-9)
Africa High HIV+	$97.59 ($85.83-$109.35)	$9.45	10 (9-12)	$177.72 ($165.53-$189.92)	$18.18	10 (9-10)	$80.13 ($76.01-$84.26)	$8.74	9 (9-10)
Africa Low HIV+	$31.85 ($26.89-$36.80)	$2.79	11 (10-13)	$39.83 ($34.41-$45.25)	$4.06	10 (8-11)	$7.98 ($6.75-$9.22)	$1.27	6 (5-7)
High Burden African Countries	$81.06 ($71.34-$90.77)	$7.70	11 (9-12)	$148.90 ($138.83-$158.97)	$15.17	10 (9-10)	$67.84 ($64.38-$71.31)	$7.47	9 (9-10)

Note: 3% annual discount rate; Estimates may vary slightly from other tables due to rounding; Values in parentheses are 95% confidence intervals.

Table 6b: Economic Benefit of TB Control Strategies in Sub-Saharan African Countries Excluding HIV Co-Infection, billions of dollars (2006-2015)

	Sustained DOTS (relative to no DOTS)			Global Plan (relative to no DOTS)			Global Plan (relative to Sustained DOTS)		
	Benefits	**Costs**	**Ratio**	**Benefits**	**Costs**	**Ratio**	**Benefits**	**Costs**	**Ratio**
Africa	$71.65 ($59.63-$83.68)	$12.24	6 (5-7)	$92.57 ($80.72-$104.43)	$22.24	4 (4-5)	$20.92 ($18.09-$23.76)	$10.01	2 (2-2)
Africa High HIV+	$42.85 ($35.46-$50.23)	$9.45	5 (4-5)	$58.41 ($51.68-$65.15)	$18.18	3 (3-4)	$15.56 ($13.58-$17.54)	$8.74	2 (2-2)
Africa Low HIV+	$28.80 ($24.03-$33.57)	$2.79	10 (9-12)	$34.16 ($28.91-$39.42)	$4.06	8 (7-10)	$5.36 ($4.19-$6.53)	$1.27	4 (3-5)
High Burden African Countries	$35.06 ($29.05-$41.08)	$7.70	5 (4-5)	$49.41 ($43.99-$54.83)	$15.17	3 (3-4)	$14.35 ($12.62-$16.07)	$7.47	2 (2-2)

Note: 3% annual discount rate; Values in parentheses are 95% confidence intervals.

Table 7: Baseline Burden of TB and Cumulative Benefits and Costs of Sustained DOTS and Global Plan Strategy, billions of dollars (2006-2015)

	No DOTS	Sustained DOTS		Global Plan Strategy		Global Plan Strategy	
Countries	Baseline Burden	Benefit (relative to no DOTS)	Cost	Benefit (relative to no DOTS)	Cost	Benefit (relative to sustained DOTS)	Cost
Afghanistan	$7.06 ($6.30-$7.82)	$2.33 ($1.46-$3.20)	$0.42	$3.18 ($2.28-$4.07)	$0.46	$0.84 ($0.17-$1.51)	$0.04
Bangladesh	$97.83 ($87.17-$108.49)	$48.84 ($37.29-$60.40)	$0.80	$54.49 ($42.68-$66.29)	$0.98	$5.65 (-$1.38-$12.67)	$0.18
Brazil	$114.12 ($100.10-$128.15)	$60.92 ($46.09-$75.75)	$0.36	$61.16 ($46.17-$76.14)	$0.60	$0.23 (-$7.33-$7.80)	$0.24
Cambodia	$12.34 ($11.14-$13.55)	$8.16 ($6.86-$9.45)	$0.16	$8.25 ($6.95-$9.55)	$0.20	$0.09 (-$0.50-$0.68)	$0.04
China	$1,175.63 ($1,073.93-$1,277.32)	$747.82 ($638.44-$857.20)	$2.16	$764.06 ($654.68-$873.45)	$3.61	$16.24 (-$32.89-$65.37)	$1.45
DR Congo	$5.83 ($5.38-$6.28)	$1.36 ($1.20-$1.51)	$0.43	$2.44 ($2.27-$2.61)	$1.11	$1.09 ($1.03-$1.15)	$0.68
Ethiopia	$13.35 ($12.38-$14.31)	$3.02 ($2.69-$3.35)	$0.30	$5.74 ($5.37-$6.11)	$1.03	$2.72 ($2.59-$2.85)	$0.74
India	$688.91 ($607.76-$770.06)	$353.35 ($265.57-$441.14)	$1.85	$390.83 ($301.01-$480.65)	$3.60	$37.48 (-$15.55-$90.51)	$1.75
Indonesia	$329.92 ($293.58-$366.25)	$164.93 ($125.52-$204.35)	$0.99	$183.66 ($143.37-$223.95)	$1.30	$18.73 (-$5.32-$42.78)	$0.31
Kenya	$29.85 ($27.34-$32.37)	$7.26 ($6.39-$8.14)	$0.30	$12.24 ($11.26-$13.21)	$0.83	$4.97 ($4.67-$5.28)	$0.53
Mozambique	$9.39 ($8.63-$10.14)	$2.21 ($1.90-$2.52)	$0.22	$4.08 ($3.79-$4.37)	$0.70	$1.87 ($1.76-$1.98)	$0.47
Myanmar	$7.17 ($6.32-$8.03)	$3.76 ($2.84-$4.68)	$0.13	$4.17 ($3.22-$5.11)	$0.21	$0.41 (-$0.14-$0.95)	$0.08
Nigeria	$107.88 ($99.36-$116.40)	$25.55 ($22.59-$28.50)	$0.21	$45.65 ($42.32-$48.97)	$1.43	$20.10 ($18.99-$21.21)	$1.21
Pakistan	$110.57 ($98.70-$122.45)	$36.32 ($22.64-$49.99)	$0.73	$49.18 ($35.07-$63.29)	$1.11	$12.86 ($2.27-$23.45)	$0.38
Philippines	$131.24 ($120.10-$142.39)	$81.49 ($69.46-$93.51)	$0.31	$83.04 ($70.99-$95.09)	$0.38	$1.55 (-$4.04-$7.14)	$0.07
Russian Federation	$276.99 ($245.06-$308.92)	$13.95 (-$33.05-$60.96)	$2.20	$76.13 ($36.91-$115.36)	$4.89	$62.18 ($22.16-$102.20)	$2.69
South Africa	$154.71 ($143.48-$165.94)	$34.90 ($30.48-$39.31)	$5.69	$67.23 ($63.00-$71.46)	$7.99	$32.33 ($30.70-$33.97)	$2.30

Thailand	$103.51 ($90.75-$116.28)	$53.74 ($39.92-$67.56)	$0.10	$59.04 ($44.88-$73.20)	$0.20	$5.30 (-$3.10-$13.70)	$0.10
Uganda	$8.87 ($8.10-$9.64)	$2.20 ($1.93-$2.47)	$0.21	$3.59 ($3.28-$3.89)	$0.64	$1.39 ($1.30-$1.48)	$0.44
UR Tanzania	$12.54 ($11.46-$13.62)	$3.11 ($2.73-$3.49)	$0.17	$5.20 ($4.77-$5.63)	$0.74	$2.09 ($1.95-$2.22)	$0.58
Vietnam	$37.15 ($33.77-$40.53)	$23.88 ($20.25-$27.52)	$0.41	$24.27 ($20.63-$27.92)	$0.48	$0.39 (-$1.27-$2.05)	$0.07
Zimbabwe	$3.33 ($3.07-$3.58)	$0.74 ($0.64-$0.84)	$0.17	$1.33 ($1.24-$1.42)	$0.70	$0.59 ($0.56-$0.63)	$0.52

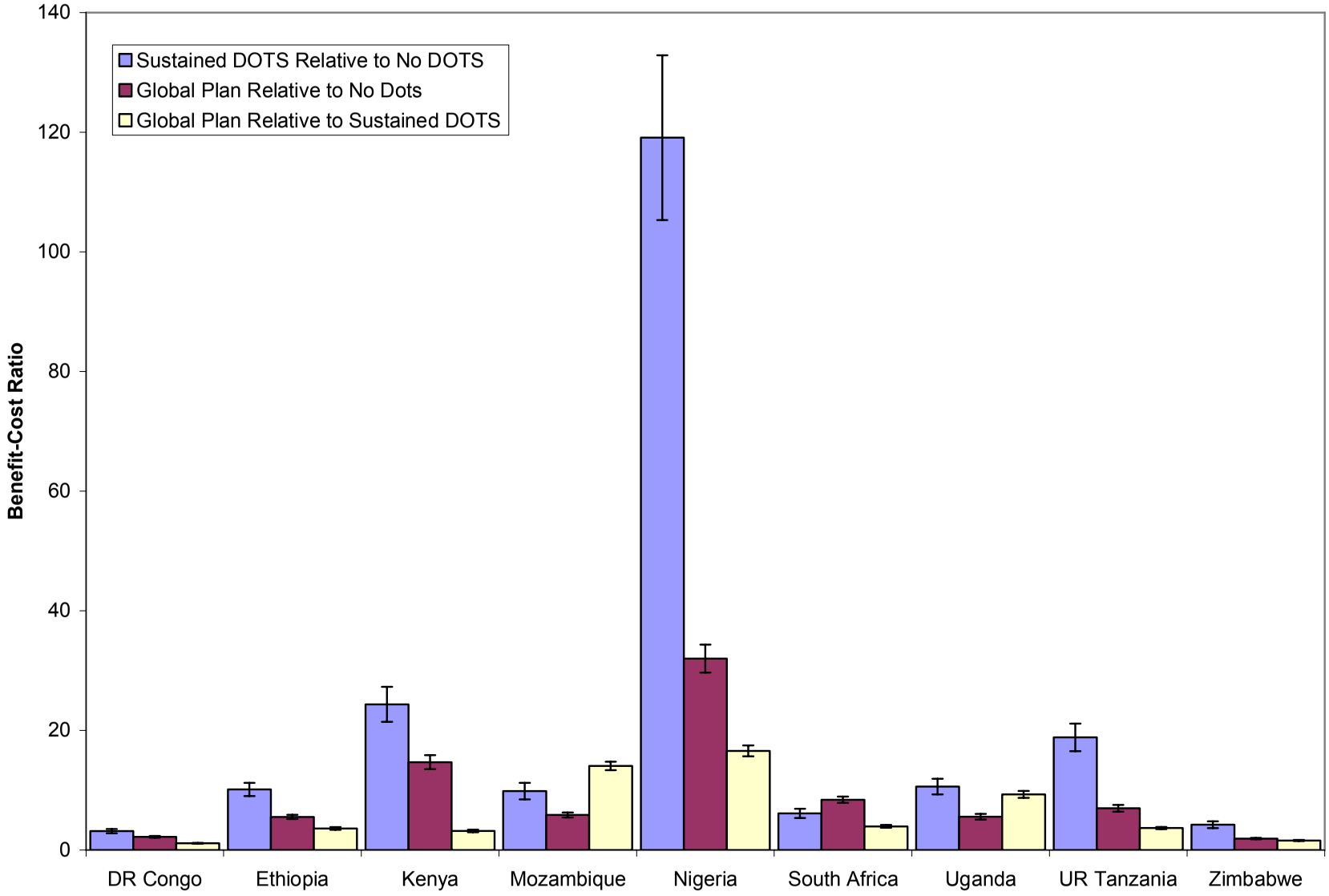
Note: Values in parentheses are 95% confidence intervals; Confidence intervals not available for total; 3% annual discount applied; HIV co-infections included

Table 8: Benefit-Cost Ratios for 22 High Burden TB Endemic Countries

Countries	Sustained DOTS Relative to No DOTS	Global Plan Relative to No Dots	Global Plan Relative to Sustained DOTS
Afghanistan	6 (3-8)	7 (5-9)	21 (4-38)
Bangladesh	61 (47-76)	56 (44-68)	32 (-8-71)
Brazil	167 (126-208)	102 (77-127)	1 (-31-33)
Cambodia	51 (43-59)	41 (34-47)	2 (-12-17)
China	346 (295-396)	212 (181-242)	11 (-23-45)
DR Congo	3 (3-4)	2 (2-2)	2 (2-2)
Ethiopia	10 (9-11)	6 (5-6)	4 (4-4)
India	191 (143-238)	109 (84-133)	21 (-9-52)
Indonesia	167 (127-207)	142 (111-173)	61 (-17-138)
Kenya	24 (21-27)	15 (14-16)	9 (9-10)
Mozambique	10 (8-11)	6 (5-6)	4 (4-4)
Myanmar	29 (22-36)	20 (15-24)	5 (-2-12)
Nigeria	119 (105-133)	32 (30-34)	17 (16-18)
Pakistan	50 (31-69)	44 (32-57)	34 (6-62)
Philippines	263 (224-302)	219 (187-251)	22 (-59-103)
Russian Federation	6 (-15-28)	16 (8-24)	23 (8-38)
South Africa	6 (5-7)	8 (8-9)	14 (13-15)
Thailand	546 (405-686)	298 (227-370)	53 (-31-138)
Uganda	11 (9-12)	6 (5-6)	3 (3-3)
UR Tanzania	19 (17-21)	7 (6-8)	4 (3-4)
Vietnam	58 (49-66)	50 (43-58)	6 (-18-29)
Zimbabwe	4 (4-5)	2 (2-2)	1 (1-1)

Note: Values in parentheses are 95% confidence intervals; Confidence Intervals for total not available

Figure 3: Benefit-Cost Ratios for TB Control Strategies in High Burden African Countries (2006-2015)



Note: Bars represent 95% confidence intervals.

Table 9: Comparison of annual GDP growth and full-income growth (2006-2015)

	GDP growth	*Full-income growth*		
Country	***Baseline***	***Sustained DOTS***	***No DOTS***	***Global Plan***
Afghanistan	8.68%	9.420%	9.418%	9.422%
Bangladesh	5.89%	6.538%	6.535%	6.539%
Brazil	3.02%	3.385%	3.384%	3.385%
Cambodia	7.88%	8.621%	8.616%	8.622%
China	9.67%	9.917%	9.916%	9.917%
DR Congo	4.73%	5.289%	5.288%	5.294%
Ethiopia	5.42%	5.870%	5.869%	5.876%
India	7.19%	7.742%	7.740%	7.742%
Indonesia	4.75%	5.266%	5.263%	5.267%
Kenya	4.25%	5.895%	5.893%	5.904%
Mozambique	7.80%	8.200%	8.197%	8.213%
Myanmar	9.81%	10.441%	10.440%	10.441%
Nigeria	5.67%	6.296%	6.294%	6.303%
Pakistan	5.88%	6.434%	6.432%	6.436%
Philippines	4.88%	5.248%	5.245%	5.248%
Russian Federation	6.31%	6.339%	6.339%	6.341%
South Africa	3.90%	2.971%	2.967%	2.979%
Thailand	6.33%	6.809%	6.807%	6.809%
Uganda	4.64%	6.418%	6.418%	6.423%
UR Tanzania	5.69%	6.182%	6.180%	6.188%
Vietnam	7.49%	7.879%	7.877%	7.879%
Zimbabwe	-5.22%	-4.594%	-4.600%	-4.578%

All values are annual growth rates of per capita values

Table 10: Partial Rank Correlation Coefficients

Economic Burden No DOTS: All Africa	
Parameter	**PRCC**
f	0.952***
x	0.753***
r	-0.655***
μ_i	-0.648***
s	0.578***
VSLY elasticity	-0.469***
v_h	0.401***
μ_h	-0.36***
e_{cpt}	0.318***
β	0.308***
μ_{ih}	-0.303***
μ	-0.3**
2012 Ts	0.221**
2011 Ts	-0.192*
μ_{in}	0.166*

Table 11: Partial Rank Correlation Coefficients

Economic Burden Sustained DOTS: All Africa	
Parameter	**PRCC**
f	0.921***
μ_i	-0.672***
x	0.595***
r	-0.588***
s	0.563***
VSLY elasticity	-0.482***
v_h	0.423***
μ_h	-0.32***
β	0.312***
μ_{ih}	-0.265**
e_{cpt}	0.257***
μ	-0.246**
e_{art}	0.184**
2015 Ts	0.177*
μ_{in}	0.172*

Table 12: Partial Rank Correlation Coefficients

Economic Burden Global Plan: All Africa	
Parameter	**PRCC**
f	0.95***
x	0.72***
r	-0.677***
μ_i	-0.672***
s	0.558***

v_h	0.452***
VSLY elasticity	-0.44***
β	0.337***
μ	-0.31***
e_{cpt}	0.304***
2010 smear + case detection	-0.259**
2008 smear + case detection	-0.246**
μ_{ih}	-0.244**
μ_h	-0.237**
2013 smear + case detection	-0.217*
2011 Ts	-0.213*
μ_{in}	0.188**

Table 13: Estimated benefit-cost ratios of some other programs evaluated by the World Bank

Table 13a. Estimated benefit-cost ratios of some investments in youth in selected countries		
Investment	Estimated benefit-cost ratio (assuming 5% annual discount rate)	Plausible ranges in estimated benefit-cost ratio
Scholarship program (Columbia)	3.31	2.77 to 25.63
Adult basic education and literacy program (Columbia)	19.9	8.14 to 1,764
School-based repoductive health program to prevent HIV/AIDS (Honduras)	0.493	0.102 to 4.59
Iron supplementation administered to secondary school children (low-income country)	32.1	25.8 to 45.2
Tobacco tax (middle-income country)	11.34	6.96 to 38.56
Source: Knowles and Berman (2003)		
Table 13b. Benefit-cost ratios for selected development bank-supported investments		
Project (year)	Benefit-cost ratio	
Hill Forest Development Project, Nepal (1983)	1.18	
Irrigation Systems Improvement Project, Philippines (1977)	1.48	
Livestock Development Project, Uruguay (1970)	1.59	
Livestock and Agricultural Development Project, Paraguay (1979)	1.62	
Cotton Processing and Marketing Project, Kenya (1979)	1.80	
Source: van der Gaag and Tan (1998)		

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