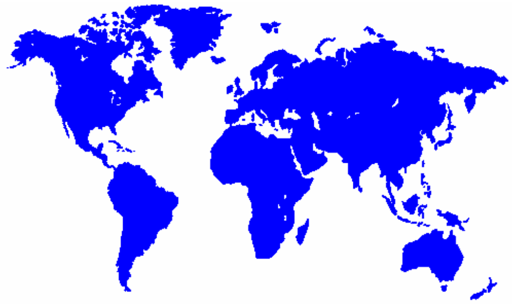

Enhancing Global Health

Patterns of Potential Human Progress

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Abstract

Health lies at the heart of all human development forecasts. At base, political, social, and economic decisions reflect the wish of individuals to live long, comfortable lives. In this spirit, we attempt to address three essential questions: 1) What health outcomes should we expect given current patterns in human development; 2) What opportunities exist for intervention and the achievement of alternate health futures; and 3) How might investments in health change economic, social, and political prospects?

This paper lays out our global health forecasting framework, the rationale behind our methodology, exploratory analyses, and a plan for moving forward. The completed project will result in the development of a publicly and freely available policy analysis tool. Users will be able to forecast health outcomes out to mid/late-century and consider the leverage points for intervention. Proposed interventions of interest include those that target health behavior (e.g. smoking), health spending, and health systems capacity.

Additionally, we will use the incorporation of country, age, sex, and cause-specific mortality rates into the International Futures (IFs) system to perform alternative scenario analysis. Specifically, we will explore expected health futures under various conditions of technological adoption, educational attainment, etc, as well as the impact of different health forecasts on variables such as fertility and economic growth. A clear picture of the feedback loops around health, population, and economic factors allows for an understanding of the costs and benefits of intervention, hopefully leading to improved policymaking and better human development outcomes.

Keywords: Global health; forecasting; health futures; human development; intervention

Table of Contents

I. Introduction
   a. Objective
   b. Overview of rationale/methods
   c. Expected outcomes
   d. Structure of paper
II. Concepts, Measures, and Drivers of Health Outcomes
   a. Overview
   b. Theories of transition
   c. Distal and proximate risk
   d. Measuring outcomes
   e. Measuring risks
   f. System capacity
III. Forecasting mortality
   a. Overview
   b. Stage 1: forecasting mortality from distal drivers
   c. Stage 2: adjusting mortality forecast using proximate risk factors
   d. Stage 3: incorporating intervention module
IV. The Larger Model
   a. Overview
   b. The international futures (IFs) system
   c. Forward linkages from health outcomes
   d. Health, population, and economic outcomes in IFs
   e. Closing the loop
V. Exploratory Forecasts
   a. Overview
   b. Mortality pyramids by broad cause for selected countries
   c. Projected life expectancies
   d. Scenario Analysis
VI. Discussion
   a. Overview
   b. Comparison to GBD
   c. Emerging issues
      i. Sex mortality ratio
      ii. Injury-related mortality
   d. Conclusion/Next steps

References

Introduction

Health lies at the heart of all human development forecasts. At base, political, social, and economic decisions reflect the wish of individuals to live long, comfortable lives. In this spirit, we attempt a global analysis that addresses three essential questions at the national level:

1) What health outcomes should we expect given current patterns in human development?
2) What opportunities exist for intervention and the achievement of alternate health futures?
3) How might investments in health change economic, social, and political prospects?

Despite much study, the relationship between human choices and health outcomes remains somewhat obscure. Analysts often assume that advances in factors such as economic growth, education, and technology will reduce disease prevalence. Indeed, much of the world's population has experienced dramatic increases in life expectancy over the last fifty-odd years. Thus, following traditional modernization theory understandings, the realization of health outcomes might seem merely a function of investment in overall socio-economic status.

Unfortunately, the mechanisms and theoretical underpinnings of the relationship between development and health outcomes remain unclear. Many international killers, such as malaria or diabetes, do not require expensive or sophisticated cures: the widespread use of bed nets could dramatically decrease malaria, while dietary restriction could prevent many cases of Type-2 diabetes. Still, even in the face of massive attempts at intervention, mortality and morbidity from both diseases persists.

In fact, thanks to work done by researchers with the World Health Organization's (WHO) Global Burden of Disease (GBD) project, we now have age, sex, and cause-specific mortality and morbidity data that belies a simplistic conception of universal progress.[1] In many countries, the battle against infectious and communicable disease seems overwhelming. More than two decades after the beginning of the HIV/AIDS epidemic, inhabitants of many African nations see their estimates of life expectancy shrinking (Walker, Walker et al. 2005). Additionally, people across the globe must now contend with the increasing burden of chronic conditions once thought to only effect those far along on their transition path; diseases such as diabetes and cancer threaten to sap the capacity of even the wealthiest countries, let alone regions still dealing with the ravages of malaria, cholera, and tuberculosis (Lopez, Mathers et al. 2006).

[1] We wish to acknowledge the tremendous generosity of Colin Mathers with the World Health Organization in providing us with the models and instructions for incorporating Global Burden of Disease relationships into IFs. Our work is greatly indebted to the groundbreaking research accomplished by Dr. Mathers and his team.

We intend to build on the important work done by GBD authors, incorporating their data and methodology into the International Futures (IFs) model in order to explore dynamics and illuminate potential policy leverage points. By imbedding mortality and morbidity patterns within the larger global system, we can add value to current health outcomes forecasting in a number of ways. These include the ability to produce long-term projections for specific countries (IFs currently forecasts out to the year 2100) and the integration of health with other social, economic, political, and environmental forces. In addition, IFs' flexible analysis system encourages users to manipulate drivers and consider the system-wide costs and benefits of intervening to achieve alternative health outcomes futures.

Expected outcomes

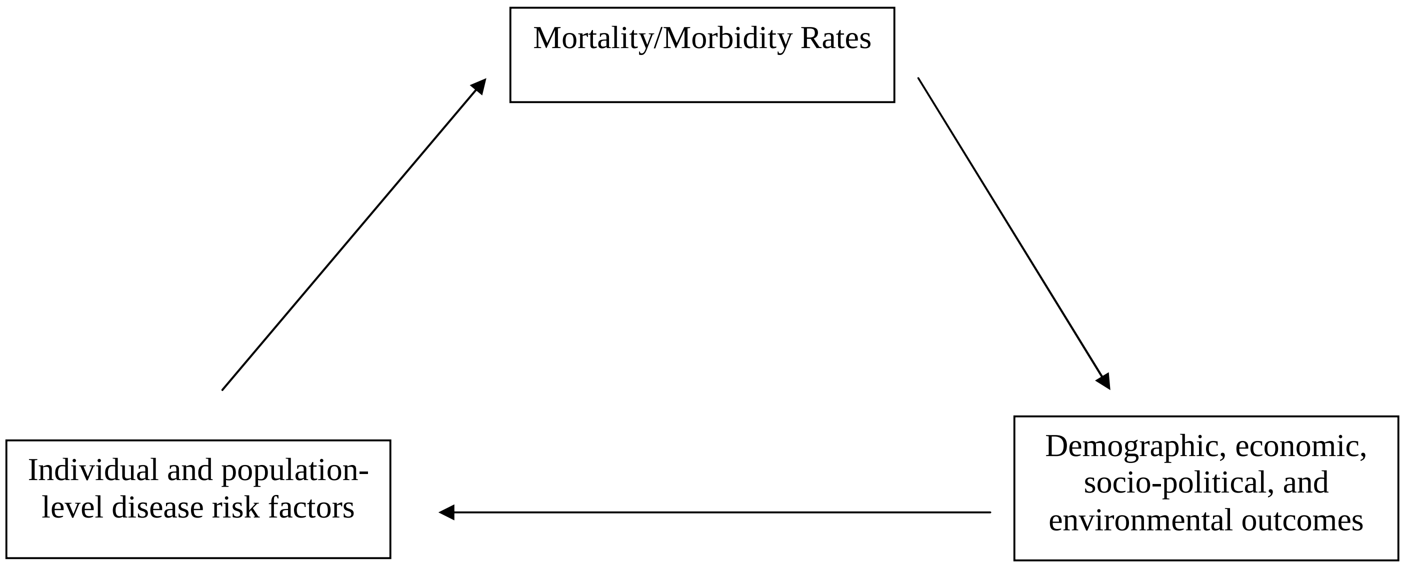
This project will result in the development of a publicly and freely available policy analysis tool. Users will be able to forecast health outcomes out to mid-century and consider the leverage points for intervention. Proposed interventions of interest include those that target health behavior (e.g. smoking), health spending, and health systems capacity.

Additionally, we will use the incorporation of country, age, sex, and cause-specific mortality rates into the IFs system to perform alternative scenario analysis. Specifically, we will explore expected health futures under various conditions of technological adoption, educational attainment, etc, as well as the impact of different health forecasts on variables such as fertility and economic growth. A clear picture of the feedback loops around health, population, and economic factors allows for an understanding of the costs and benefits of intervention, hopefully leading to improved policymaking and better human development outcomes.

Structure of paper

In this paper, we lay out our forecasting framework, the rationale behind our methodology, and a plan for moving forward. We also explore preliminary results, along with emerging issues as we compare our findings to other published work. Section II, Concepts, Measures, and Drivers of Health Outcomes, introduces theories of health transition, broad measurement issues, and the distal and proximate drivers of health outcomes. Section III explains the basic framework of our baseline mortality and morbidity forecasting. In section IV, The Larger System, we introduce the IFs system and explore the ways in which mortality and morbidity rates drive economic, social, political, and environmental outcomes. We also begin a discussion of the loops back from these broad forces to health. Section V, Preliminary Results, presents initial forecasts and begins to demonstrate the utility of forecasting health outcomes in IFs. Finally, section VI, Discussion, explores key issues and emerging limitations before detailing our next steps for continued modelling and incorporation of health outcomes into the larger IFs forecasting system.

Figure 1 –Mortality and Morbidity in the Global System



II. Concepts, Measures, and Drivers of Health Outcomes

In order to identify opportunities for intervention, we need to know who we expect to die, and fall ill, from what. Thus, this analysis begins with the projection of country-specific disease patterns and the ways in which we expect those patterns to change over time. Demographics, especially mortality, lie at the core of our analysis.

Population forecasts generally fall into one of two categories: trend extrapolation or relationship modelling (Mathers and Loncar 2006). The former looks to historical trends to inform future directions. The latter uses independent variables related to health to project outcomes. Both methods have advantages and disadvantages as far as data requirements and assumed prior knowledge. Relationship modelling best fits our purposes; we can only identify points of leverage for change if we understand causal and correlative relationships. By exploring and emphasizing associations between risk factors and health outcomes, we can provide alternative forecasts based on variable modification.

Theories of transition

In 1971 Abdel Omran published his theory of the epidemiologic transition, connecting demographic, disease, and economic processes (Omran 2005). In this seminal paper, Omran hypothesized that changing disease patterns precede and explain what demographers classically describe as the demographic transition – a shift from high to low fertility and mortality that concurs with development (Kirby and Kirby 1996).

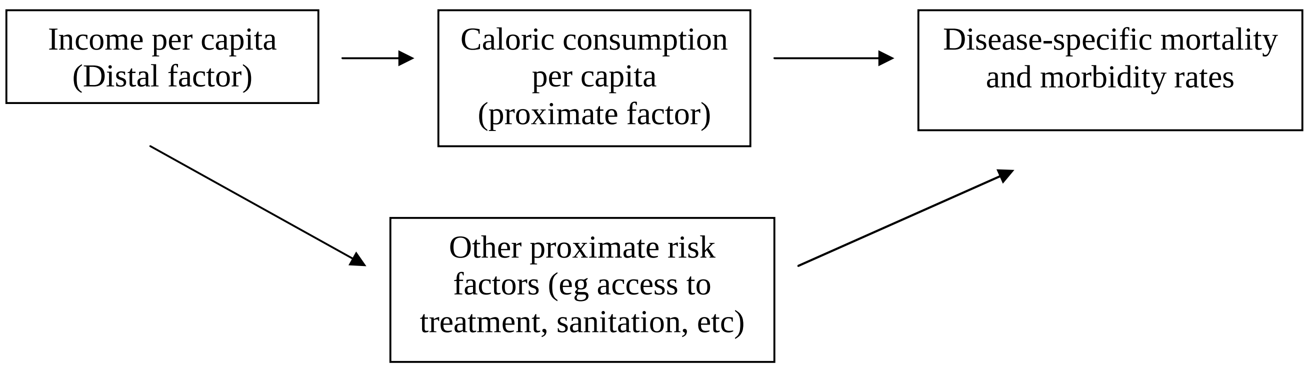
To summarize, the epidemiologic transition suggests that economic and educational progress results in better public health and thus a reduction in infectious/communicable (type I) disease. As mortality remains ultimately unavoidable, cause of death and morbidity shifts instead to chronic (type II) conditions. (Omran did not expect the type III "cause of death category," injury, to change with development). Life expectancy rises in response to lower infant and child mortality rates (type II diseases tend to strike the elderly), and the population grows rapidly. Eventually, the demographic transition results as society recognizes reduced need to "replace" itself and fertility declines, causing a general aging of the population as growth stabilizes at a slower rate.

However, many observers criticize both the epidemiologic and demographic transition theories as overly simplistic views of universal progress sometimes contradicted by the available evidence (Gaylin and Kates 1997; Carolina and Gustavo 2003). Indeed, it seems difficult to believe in the inevitability of similar kinds of change across all societies. Individuals and communities make choices, for example whether to smoke or to spend substantial resources on health care, which influence disease patterns. Moreover, mortality and morbidity appear increasingly related to access to medical technology (Caldwell 2003). While industrialization and/or development may be historically associated with certain risk patterns, the relationship is complex and mutable. For example, analysts note the concurrent prevalence of both infectious and chronic diseases in less-developed countries, belying the notion of a transition from one category of disease to the other (Ezzati, Vander Hoorn et al. 2005). Smith and Ezzati recently used GBD data to demonstrate that poor countries face a greater burden of disease across all three disease categories than their wealthier counterparts (Smith and Ezzati 2005).

Distal and proximate risk

The concept of risk underlies the arguments surrounding transition theory. Disease and demographic patterns change in concert with their causes. Omran relied mainly on broad or *distal* risk factors, such as the economy or education, that in turn impact causal or *proximate* risk factors, such as nutrition and smoking. For example, we might reasonably assume a positive association between a country's income and calories consumed (both per capita). Poor nutrition proximally causes (or at least contributes to) diseases in turn related to mortality and morbidity. However, as long the relationship between consumption and income holds, we can posit a less direct association between income and health outcomes (see Figure 2).

Figure 2 – Using distal and proximate risk factors to predict health outcomes



Advantages to looking at distal variables may include enhanced data accessibility, quantification, and the ability to capture complex relationships within a single "catch-all" variable. The power of the epidemiologic and demographic transition theories lies in their simplicity and ability to capture complex processes with very few variables. Conversely, using broad determinants to predict health outcomes obscures causal relationships, offers limited potential for intervention, and ignores potential changing associations between distal and proximate drivers. For example, even Omran admits the necessity of separate models in explaining the varying speeds of epidemiological transition observed across regions (Omran 2005).

Measuring outcomes

Most basically, a health forecast concerns measures of mortality (death) and morbidity (disability). However, despite the World Health Organization's (WHO) efforts to collect and disseminate vital registration records from member countries, good mortality data in many regions remain scarce (Murray and Lopez 1996). Defining and assessing morbidity proves even more difficult, as what counts as “healthy” may vary over time and space (Morrow and Bryant 1995).

Largely to address these data issues, in 1993 the WHO (in collaboration with the World Bank and the Harvard School of Public Health) initiated the Global Burden of Disease project (GBD). Goals included “generating a comprehensive and consistent set of estimates of mortality and morbidity by age, sex and region for the world for the first time” (Mathers CD 2003). Importantly, researchers developed explicit valuations for various disease states, allowing them to create new metrics for morbidity (Murray and Lopez 1997; Lopez and Mathers 2006). Chief among these is the disability-adjusted life year (DALY). The DALY is a summary measure of disease burden, capturing both years of life lost and years lived with disability.[2]

Figure 3, below, displays the age and causal structure of mortality for females globally in 2002 as reported by the GBD.[3] For simplicity, we combine causes into the broad disease categories discussed above (Type I, II, and III). Figure 4 incorporates morbidity by illustrating the structure of DALYs in 2002. These graphs imply that populations experience mortality and morbidity differently. Disease strikes across the age spectrum, while most deaths occur among the elderly (Type II causes) or very young (Type I causes). The DALY chart also suggests that a larger burden of disease results from Type I causes than might be expected from the mortality data, especially among infants and children under the age of four.

[2] For specific disease weights and methodology, see Mathers CD, B. C., Iburg KM, Inoue M, Ma Fat D, Shibuya K et al.. r No. 54. 2003. (2003). Global Burden of Disease in 2002: data sources, methods and results. GPE Discussion Paper, Geneva, World Health Organization. 54.

[3] Data publicly available at http://www.who.int/healthinfo/bodestimates/en/index.html.

Figure 3 – Female age and cause-specific mortality rates (2002)

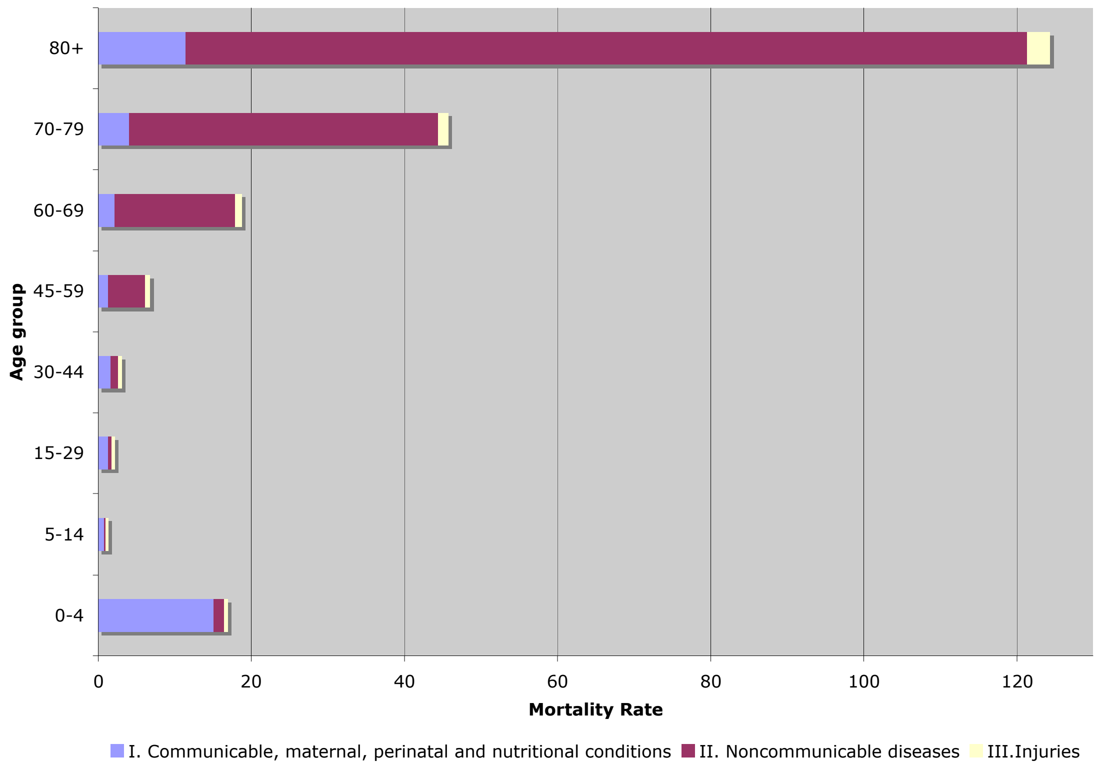
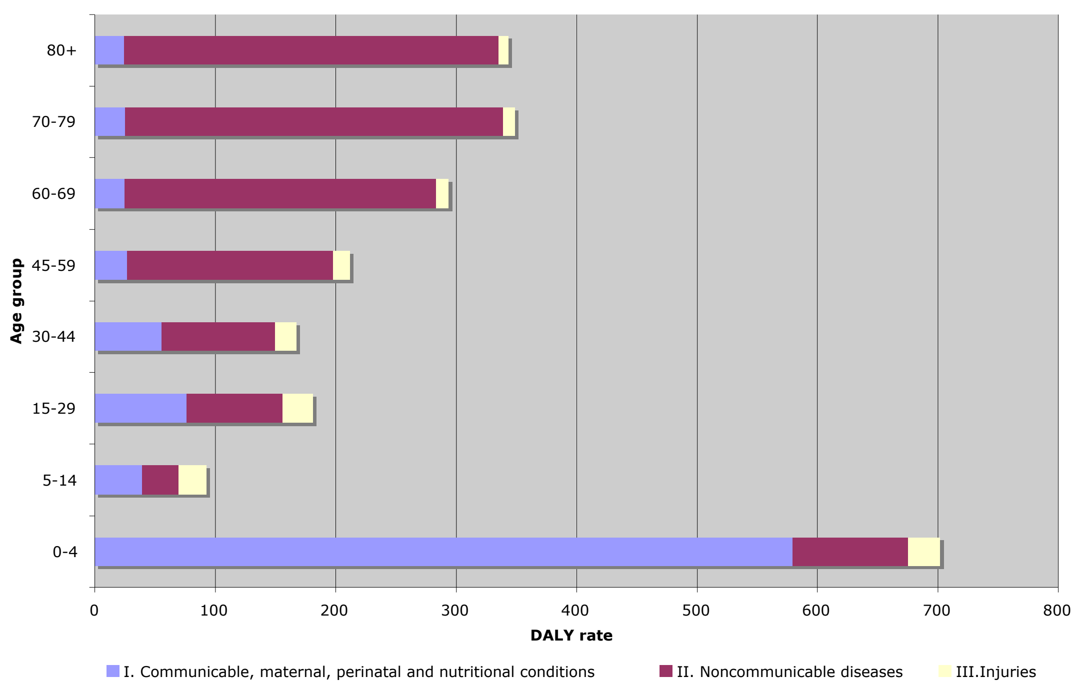


Figure 4 – Age, sex, and cause-specific DALY rates (2002)



Measuring risks

As illustrated above, a health outcomes forecast can make use of both distal and proximate risk factors. The GBD and Comparative Risk Assessment (CRA) projects outline a baseline set of well-established and quantifiable variables helpful in projections of mortality and morbidity (Ezzati, Hoorn et al. 2003; Mathers and Loncar 2006). Distal factors of interest include income per capita, adult education, and technology. Smoking, alcohol use, and malnutrition are examples of proximate risks used in the GBD/CRA analyses (Table 1).

Table 1 – Distal and Proximate Risk Factors

Distal	Proximate
Income per capita	**Childhood and maternal undernutrition**
Average years of adult education	Underweight
Technology	Iron deficiency
	Vitamin A deficiency
	Zinc deficiency
	Other risk factors related to nutrition and physical activity
	High blood pressure
	High cholesterol
	High BMI
	Low fruit and vegetable intake
	Physical inactivity
	Sexual and reproductive health
	Unsafe sex
	Lack of contraception
	Addictive substances
	Tobacco
	Alcohol
	Illicit drugs
	Environmental risks
	Unsafe water, sanitation, and hygiene
	Indoor smoke from solid fuels
	Lead
	Occupational risks
	Occupational risk factors for injuries
	Other selected risks
	Unsafe health care injections
	Childhood sexual abuse

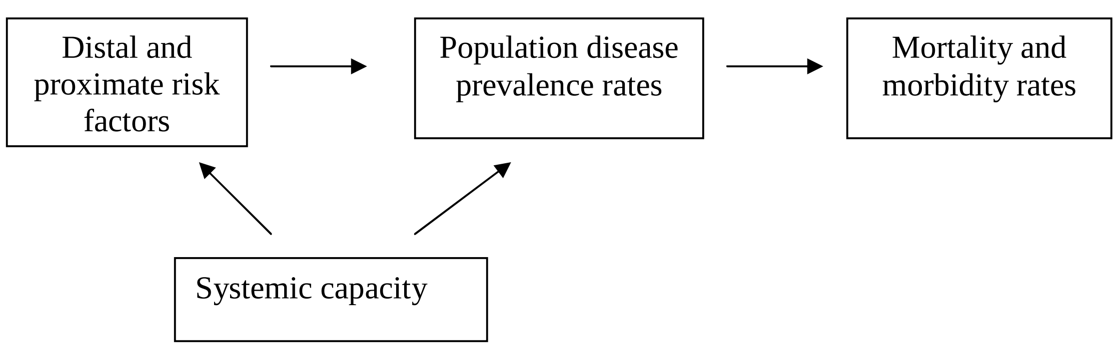
We will also include additional factors, such as the successful administration of vaccines, excluded from the WHO projects on the grounds that they did not require sophisticated calculations to discover their potential benefit. As shown in the case of smallpox, successful vaccines, if globally administered, can eliminate a disease. Scenarios in which vaccines eradicate infectious diseases such as HIV/AIDS, malaria, or tuberculosis prove interesting as they demonstrate, through forward linkages, the costs and benefits of vaccine development.

System Capacity

The identification and quantification of risk factors does not guarantee that policies to reduce risk factor prevalence will even be attempted, let alone work. The adoption and successful implementation of any intervention depends greatly on the capacity of healthcare, bureaucratic, and political systems to address disease risk or ameliorate disease prevalence (see Figure 5) (Bailey 2006; Doyle 2006). Countries face continuing fixed health care costs, and most cannot easily reallocate limited resources to adequately address even the most pressing health care problems. Moreover, the embrace of any policy depends strongly on country-specific institutions (defined here as "a set of rules, formal or informal, that actors generally follow, whether for normative, cognitive, or material reasons" (Soskice 2001)).

In light of the lack of evidence on a global scale, we do not know how to quantify factors related to systemic capacity. Instead, we clarify the costs and benefits associated with successfully minimizing distal and proximate risk factors. We hope that our work will inspire communities to create intervention solutions compatible with their unique institutions, values, and resources.

Figure 5, System Capacity



III. Forecasting mortality

In our proposed health forecasting model, we concentrate on projections of age-, sex-, and cause-specific mortality, by country, as our primary outcome of interest. Knowing who faces the greatest risk of premature death, and from what, allows for the possibility of targeted intervention. The centrality of demographic patterns within the larger IFs model also leads to a conception of a larger feedback loop that connects broad socioeconomic factors through mortality to political, social, economic, and environmental outcomes and back again (more in Section III below).

As noted previously, methods of population forecasting generally fall into one of two categories: trend extrapolation or relationship modelling (Mathers and Loncar 2006). The former looks to historical trends to inform future directions. The latter, which characterizes both the GBD and this analysis, uses independent variables related to health to project future outcomes. By emphasizing relationships between risk factors and health outcomes, we can explore potential policy leverage points and propose alternative forecasts.

Stage 1: Forecasting mortality from distal drivers

Varying factors, acting and interacting at different levels and intensities, determine age, sex, and cause-specific health outcomes. Broadly, these factors fall into two related categories: proximate (those closely associated with or direct causes of disease) and distal (political, social, environmental, and economic conditions associated with proximate causes). To illustrate, being overweight (proximate factor) in large part causes diabetes mellitus (Type 2 diabetes). Economic development (distal factor) related to caloric availability facilitates the population prevalence of overweight.

We use the GBD regression models developed by Mathers and Loncar to forecast mortality by age and sex for ten cause-clusters (table 2):

> Mortality(age, sex, cause)= intercept + b1*income per capita + b2*adult education + b3*technology

We project mortality related to the eleventh cause group, HIV/AIDS, separately with a structure that depends on exogenous assumptions (tied to earlier UN estimates) about when the epidemic will peak and at what infection rate. Our estimates tended to be more optimistic towards mid-century than those produced by UNAIDS (see section VI for more discussion about HIV/AIDS and IFs).

At this stage, mainly distal variables (namely income per capita, years of adult education, and year as a proxy for technology) determine mortality, although proximate variables do influence diabetes, (and some other) mortality projections (see Stage 2). Following the most recent GBD reports, we use separate regression models for low-income countries (GDP less than $3000/year). IFs forecasts years of adult education and income per capita (Hughes and Hillebrand 2006).

Table 2 – Broad cause groups

Type 1	• Communicable, maternal, perinatal, and nutritional conditions • HIV/AIDS
Type 2	• Malignant neoplasms (excluding lung cancer) • Diabetes mellitus • Cardiovascular diseases • Digestive disorders • Chronic respiratory conditions • Other Type II diseases
Type 3	• Road traffic accidents • Other unintentional injuries • Intentional injuries

Stage 2: Adjusting mortality forecast using proximate risk factors

Distal risk factors, such as income per capita, largely lie at the edges of the causal disease pathway and offer limited potential for health intervention (Mosley and Chen 2003). However, it is beyond the scope of this project to develop detailed risk specific regression models from proximate drivers that incorporate multiple time-varying covariates for all countries/regions and disease/disease clusters.

At this time, proximate drivers enter the model in only a limited fashion. The regression equations for malignant neoplasms, cardiovascular diseases, and respiratory diseases include a "smoking impact" term: "that component of observed lung cancer mortality attributable to tobacco smoking" (Mathers 2006: 2013). The GBD analyses use smoking impact, rather than smoking rate, in order to better capture the "overall health impact" of smoking, "taking into account lag times as well as important aspects of exposure such as duration, type, amount, and mode of smoking" (Mathers 2006: 2013). In our current formulation, we use the sub-regional smoking impact figures developed by the GBD, extending trends out to 2100. Additionally, following GBD methods, we project that diabetes mortality will initially decrease at three-quarters of the rate of the "other non-communicable disease" cause group. Relative risk of death associated with diabetes also rises with body mass index (BMI) (for methods, see Protocol S1, Mathers 2006).

In our next steps, we expect to consider the contribution a defined set of proximate risk factors makes to health outcomes and forecast their future prevalence. The WHO's comparative risk assessment project (CRA) provides a map for estimating the mortality and burden of disease associated with individual and/or joint risk factors. CRA authors identified and quantified the effects of 26 variables - picked for analysis because of their clear causality, data availability, and potential for modification.[4]

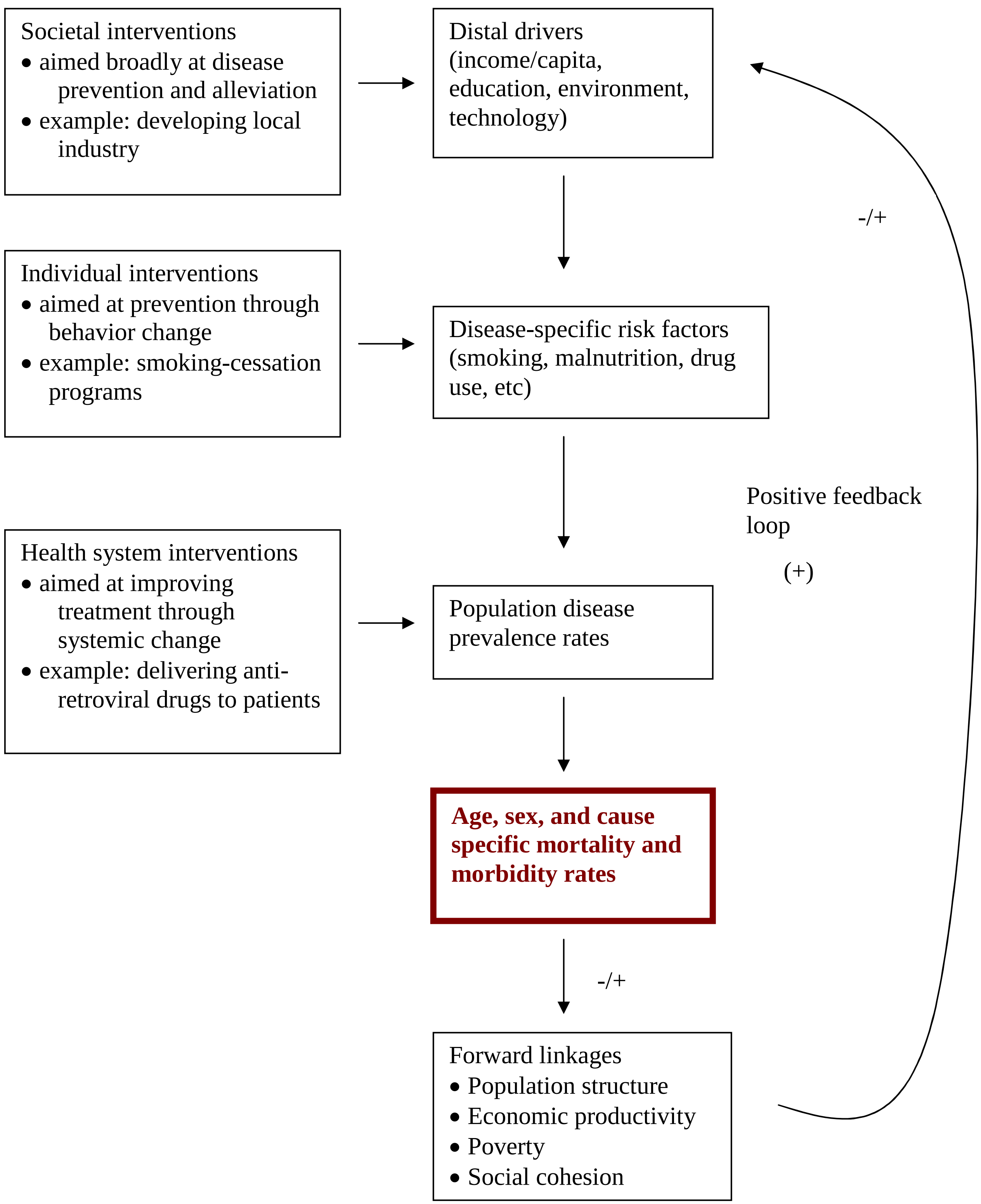
[4] The exact number of risk factors in CRA papers by Ezzati varies from 14 to 26.

IFs will forecast proximate drivers in a few different ways. Some factors, such as childhood/maternal malnutrition and environmental risks, will derive from existing IFs modules. We will also add new relationships to IFs, including cross-sectional associations between distal and proximate drivers to determine “expected” values of proximate risk factors and their comparison with both actual and possible values

Stage 3: Incorporating Intervention Module

Proximate determinants of health outcomes can be incorporated into forecasts by allowing the user to select interventions that adjust risk factors (at any time point, present or future) and thus change projected mortality and morbidity rates (see Figure 6). For example, let us suppose the user wants to forecast the mortality and population structure for South Africa in 2020. She first forecasts the 2020 mortality rate, derived as a function of distal determinants. Next, she can look at a forecast of the risk profile for South Africa in 2020 and explore how an intervention might alter that risk profile and thus the mortality forecast. For instance, an intervention that reduces unsafe water, sanitation, and hygiene to their theoretical minimums will lower the projected mortality associated with many infectious diseases. As we begin to explore in the next section, we can also expect a “domino effect” to result from revised mortality structures as these health outcomes in turn influence economic, social, political, and environmental outcomes.

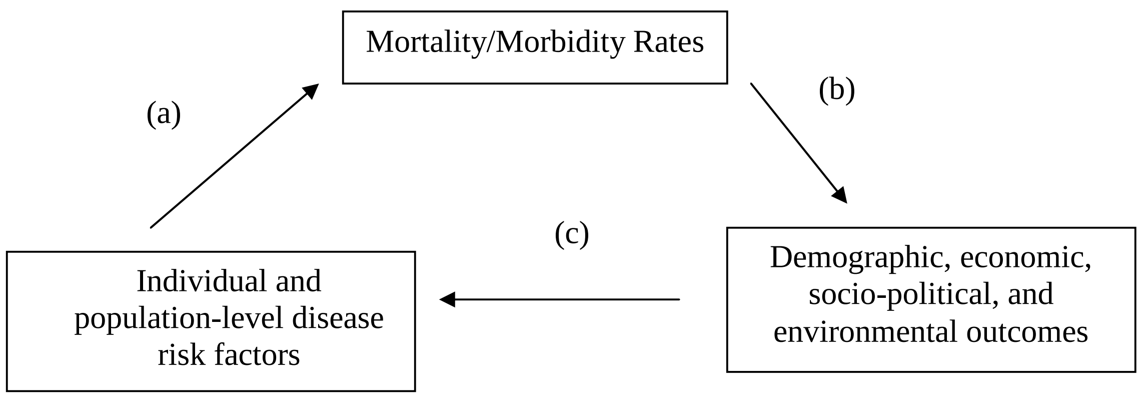
Figure 6 –Opportunities for intervention



IV. The Larger Model

Returning to our initial diagram placing mortality and morbidity within the larger global system (redrawn below as Figure 7), we can see that the previous section, and the epidemiological literature, mainly focuses on linkage (a) - forecasting health outcomes from disease risk factors. The discussion of distal and proximate drivers touches on linkage (c) – the relationship between broad demographic, economic, socio-political and environmental variables and disease risk. However, a great deal of work remains in elaborating this association, as well as linkage (b) - health to broad system variables. These are the areas in which the embedding of the health module within IFs can add the most value to current discussions around global health and global health policy.

Figure 7 – Mortality and Morbidity in the Global System



In this section, we will introduce the IFs system and explore the relationships between health outcomes and modules within IFs. These existing associations provide a guide to determining the impact of morality and morbidity rates on global system variables (linkage (b)). We also begin to think about linkage (c), the pathways through which the IFs forecasts of distal forces loop back through disease risk factors and influence population health.

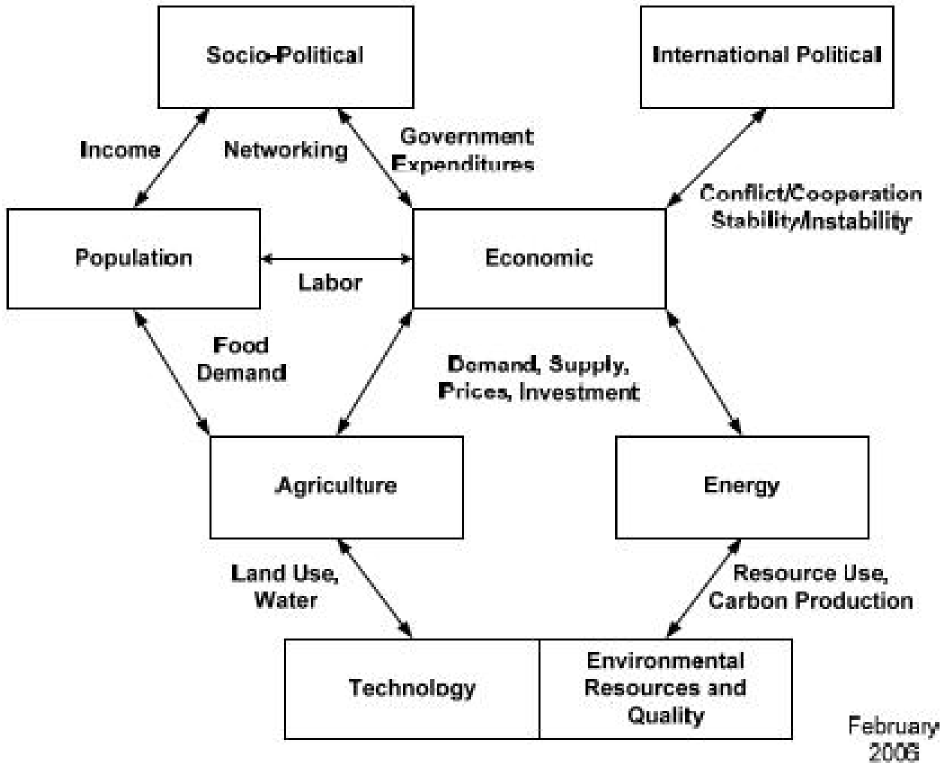
The International Futures (IFs) system[5]

International Futures is a global modelling system. The extensive data base underlying it includes data for 182 countries over as much of the period since 1960 as possible. The model itself is a recursive system that can run without intervention from its initial year (currently 2000), while the model interface facilitates interventions flexibly across time, issue, and geography.

Figure 8 shows the major conceptual blocks of the International Futures system. The elements of the technology block are, in fact, scattered throughout the model. The named linkages between blocks and the linkages themselves are illustrative, not exhaustive.

[5] Text abstracted from "Introduction to IFs" (www.du.edu/~bhughes/ifsreports.html)

Figure 8 – Modules in IFs



The population module:

- represents 22 age-sex cohorts to age 100+ in a standard cohort-component system structure
- calculates change in cohort-specific fertility of households in response to income, and income distribution
- currently calculates change in mortality rates in response to income, income distribution, and assumptions about technological change affecting mortality
- computes average life expectancy at birth, literacy rate, and overall measures of human development (HDI) and physical quality of life
- represents migration
- shows HIV/AIDS

The economic module:

- represents the economy in six sectors: agriculture, materials, energy, industry, services, and ICT (other sectors could be configured, using raw data from the GTAP project)
- computes and uses input-output matrices that change dynamically with development level
- is a general equilibrium-seeking model that does not assume exact equilibrium will exist in any given year; rather it uses inventories as buffer stocks and to provide price signals so that the model chases equilibrium over time

• contains a Cobb-Douglas production function that (following insights of Solow and Romer) endogenously represents contributions to growth in multifactor productivity from R&D, education, worker health, economic policies ("freedom"), and energy prices (the "quality" of capital)
• uses a Linear Expenditure System to represent changing consumption patterns
• utilizes a "pooled" rather than the bilateral trade approach for international trade
• has been imbedded in a social accounting matrix (SAM) envelope that ties economic production and consumption to intra-actor financial flows

The agricultural module:

• represents production, consumption and trade of crops and meat; it also carries ocean fish catch and aquaculture in less detail
• maintains land use in crop, grazing, forest, urban, and "other" categories
• represents demand for food, for livestock feed, and for industrial use of agricultural products
• is a partial equilibrium model in which food stocks buffer imbalances between production and consumption and determine price changes
• overrides the agricultural sector in the economic module unless the user chooses otherwise

The energy module:

• portrays production of six energy types: oil, gas, coal, nuclear, hydroelectric, and other renewable energy forms
• represents consumption and trade of energy in the aggregate
• represents known reserves and ultimate resources of the fossil fuels
• portrays changing capital costs of each energy type with technological change as well as with draw-downs of resources
• is a partial equilibrium model in which energy stocks buffer imbalances between production and consumption and determine price changes
• overrides the energy sector in the economic module unless the user chooses otherwise

The socio-political sub-module:

• represents fiscal policy through taxing and spending decisions
• shows six categories of government spending: military, health, education, R&D, foreign aid, and a residual category
• represents changes in social conditions of individuals (like fertility rates or literacy levels), attitudes of individuals (such as the level of materialism/postmaterialism of a society from the World Values Survey), and the social organization of people (such as the status of women)
• includes a newly developed submodel of formal education across primary, secondary, and tertiary levels
• represents the evolution of democracy
• represents the prospects for state instability or failure

The international political sub-module:

- traces changes in power balances across states and regions
- allows exploration of changes in the level of interstate threat

The environmental module:

- allows tracking of remaining resources of fossil fuels, of the area of forested land, of water usage, and of atmospheric carbon dioxide emissions
- provides a display interface for the user that builds upon the Advanced Sustainability Analysis system of the Finland Futures Research Centre (FFRC), Kaivo-oja, Luukhanen, and Malaska (2002)

The implicit technology module:

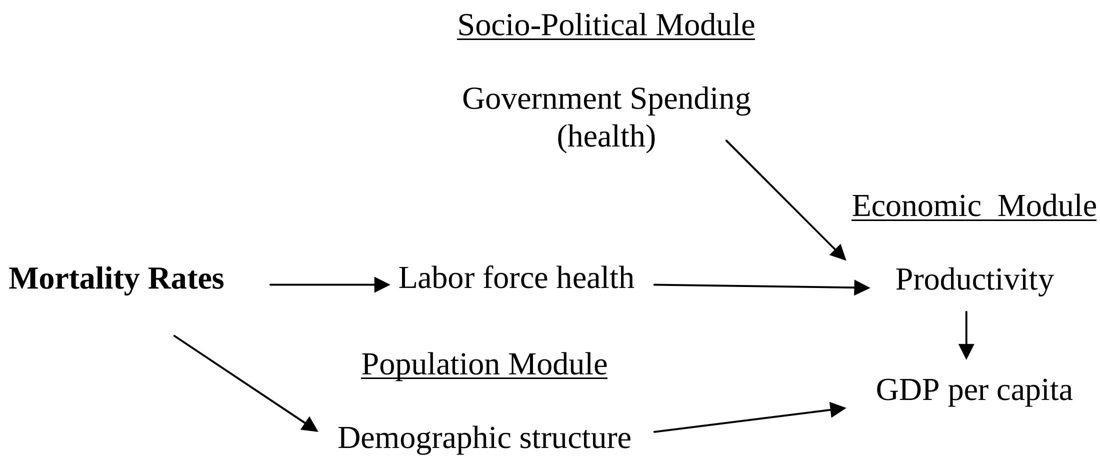
- is distributed throughout the overall model
- allows changes in assumptions about rates of technological advance in agriculture, energy, and the broader economy
- explicitly represents the extent of electronic networking of individuals in societies
- is tied to the governmental spending model with respect to R&D spending

Forward linkages from health outcomes (linkage (b))

As outlined above, IFs currently uses health outcomes to drive economic, social, political, and environmental outcomes. Most directly, mortality and morbidity relates to population structure, economic productivity, and GDP (Figure 9) (Sachs 2001; Salomon and Murray 2002; Lopez-Casasnovas, Rivera et al. 2005). In IFs, the demographic and economic modules in turn drive outcomes in other modules of the system (discussion to follow). A brief explanation of the IFs methodology around population and economics, abstracted from current IFs documentation, follows.[6]

[6] For a more indepth discussion, please see "Productivity in IFs" (www.du.edu/~bhughes/ifsreports.html)

Figure 9 – Forward linkages from health outcomes



Health, population, and economic outcomes in IFs

Although much of the discussion and analysis of growth in the IFs' manuscripts focuses on the determinants of productivity growth, it is important to note that, through a Cobb-Douglas production function, capital and labor accretion remain critical determinants of growth in both the real world and the IFs model.[7] For instance, many analyses stress the contribution of health improvements to labor force participation, not to productivity enhancement. And many factors, such as improved governance quality, can increase growth both by increasing investment and improving productivity of capital; the relative importance of the two paths is difficult to tease out and may vary by development level or even by specific country (Baldacci, Hillman, and Kojo 2003).[8] On the labor side, IFs has a full cohort-based population model that tracks the size of the labor force and dependent populations. Dependency rates depend heavily on morbidity rates (Harwood, Sayer et al. 2004).

In IFs, both outcome/stock and input/flow measures are used in analysis of the productivity impact of health, namely years of life expectancy and spending, respectively. There is some reason to question whether higher health spending should be allowed to translate immediately into productivity gains. Yet with higher health spending, some

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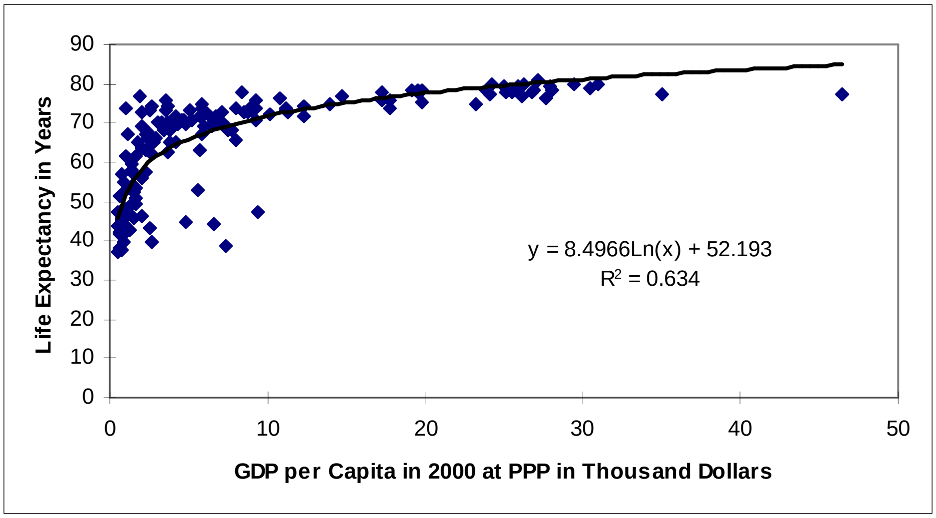
[7] The World Bank's World Development Report 98/99 (p. 19) reports on work going back to Solow that suggests that 30-40% of growth come from these other factors; some studies suggest that they determine more than half of growth, especially in developing countries.

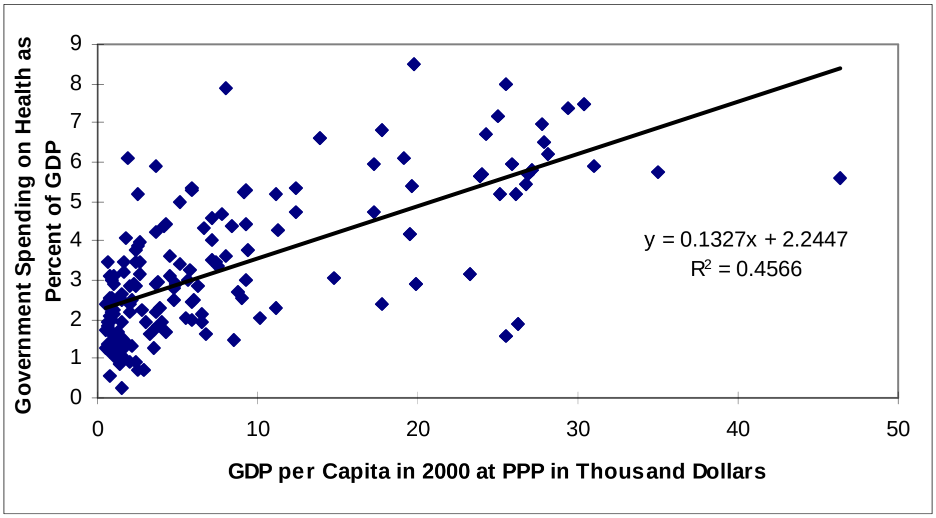
[8] They point out that the growth of GDP per capita rises by about 1% when the ratio of gross investment to GDP rises by 10 percent (p. 20). Krugman's famous article on the myth of the Asian miracle emphasized also the importance of the investment channel as opposed to the productivity channel to growth. Nonetheless, the IMF paper concludes that, with respect to fiscal policy's impact on growth, for low income countries "the factor productivity channel is some four times more effective than the investment channel." (p. 29)

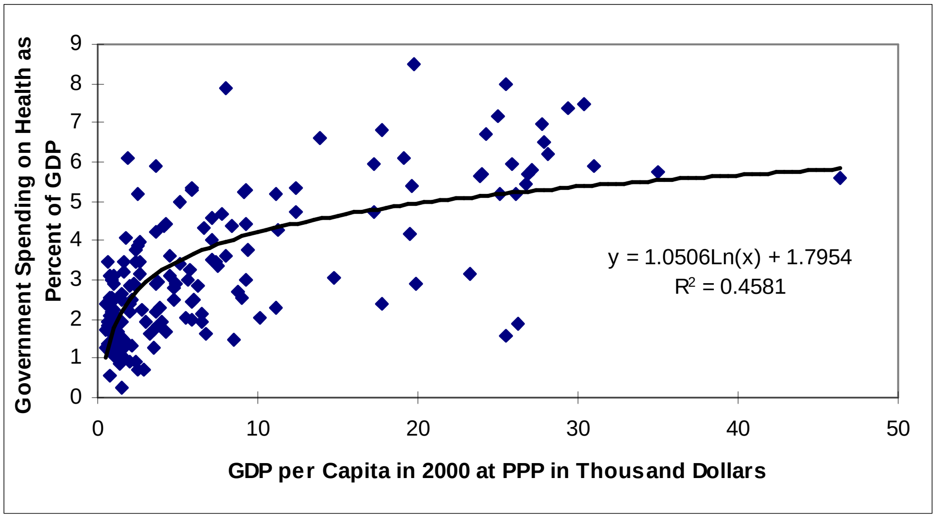
quick reduction of illness of existing workers might be expected, thus making emphasis on a lagged measure less critical. Nonetheless, we add both to the formulation.

The figure below shows life expectancy at birth as a function of GDP per capita. The outlier at $7,300 and 38 years is Botswana. Clearly this reflects increased mortality from AIDS in recent years. Botswana is often cited as an exemplar of good governance in Africa, but its position on this graph would suggest that substantial set-backs in productivity could be coming.



The two graphs below look at government spending on health as a function of GDP per capita. The relationships tend to be somewhat steeper than those for educational spending. The saturating logarithmic formulation is more theoretically satisfying.





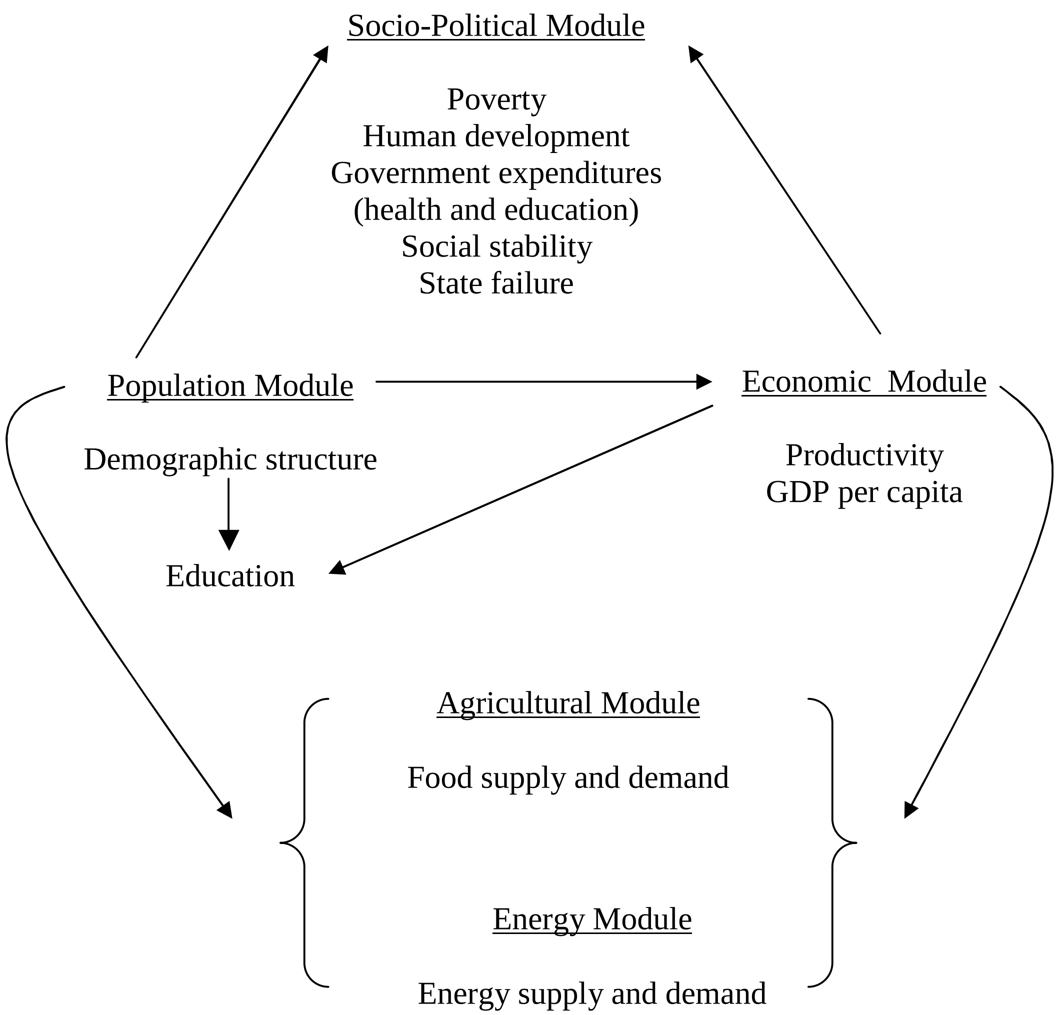
In setting parameters around health in the IFs model, life expectancy and health spending were treated as a pair. The literature suggests that 1 standard deviation in life expectancy (about 13 years) can yield about 1.4% growth (another study says 1-4%). The IFs parameterization is quite conservative. The literature suggests that 1% of extra spending might yield 0.5% in growth; the parameter is again very conservative.

Beyond the population and economic modules

Figure 10, below, illustrates the paths through which the population and economic modules in turn drive other system outcomes. While neither detailed nor exhaustive, the simple diagram demonstrates the potential "domino effect" of changes in mortality and morbidity rates. For a more complete discussion of the forward linkages from the population and economic modules, please refer to IFs documentation (www.ifs.du.edu).

We also recognize the possibility of more direct links from health outcomes to factors in other IFs modules. For example, as suggested previously, disease rates and government health care spending often rise or fall at least approximately in tandem. Morbidity, in particular, increases health care costs (Lopez-Casasnovas, Rivera et al. 2005). The prevalence of infectious diseases, such as HIV/AIDS, which threaten populations beyond political borders, may trigger increases in foreign aid or debt relief (represented in IFs' international political module). We plan to add these relationships as the project progresses.

Figure 10 – Forward linkages from the population and economic modules



Closing the loop (linkage (c))

After elaborating the forward linkages from health outcomes to global system variables within IFs, an obvious question arises – how do these distal factors feed back and influence the more proximate drivers of mortality and morbidity? Some of the mechanisms seem almost straightforward. For example, a country's food supply and demand clearly impacts rates of malnutrition (itself a proximate disease driver). However, socio-political factors such as state stability and regime type largely determine food distribution and food policy – and thus also influence country-specific malnutrition rates; detailing these kinds of complex relationships remains a central goal of this project.

A sizable literature exists surrounding the associations between health and issues such as education, government spending, political regime type, state failure, national security, and environmental quality (Frey and Al-Roumi 1999; Council 2000; Ingram 2005; Andoh, Umezaki et al. 2006; Kugler and Swaminathan 2006; Raphael 2006; Safaei 2006; Tsai 2006). However, to our knowledge, no encompassing, global-level study expressly relates such variables to the proximate drivers of country, age, sex, and cause specific mortality/morbidity. Incorporating the GBD methodology into the IFs system uniquely positions us to attempt this task. By including distal determinants (eg democracy or climate) left out of the GBD analysis, we hope to provide both a more accurate forecast and provide additional opportunities for policy and intervention.

V. Exploratory Forecasts

In earlier versions of IFs, the model incorporated a representation of aggregate mortality/life expectancy which was fully imbedded into the demographic and economic modules. GDP per capita, technological change, and health spending drove the mortality forecasts; mortality in turn affected economic productivity (as described in section IV). As noted previously, and discussed in more detail in the next section, IFs projected mortality associated with HIV/AIDS separately, using exogenous assumptions about when the epidemic would peak and at what infection rate. Our base case estimates of HIV/AIDS-related mortality tended to be more optimistic towards mid-century than those produced by UNAIDS.

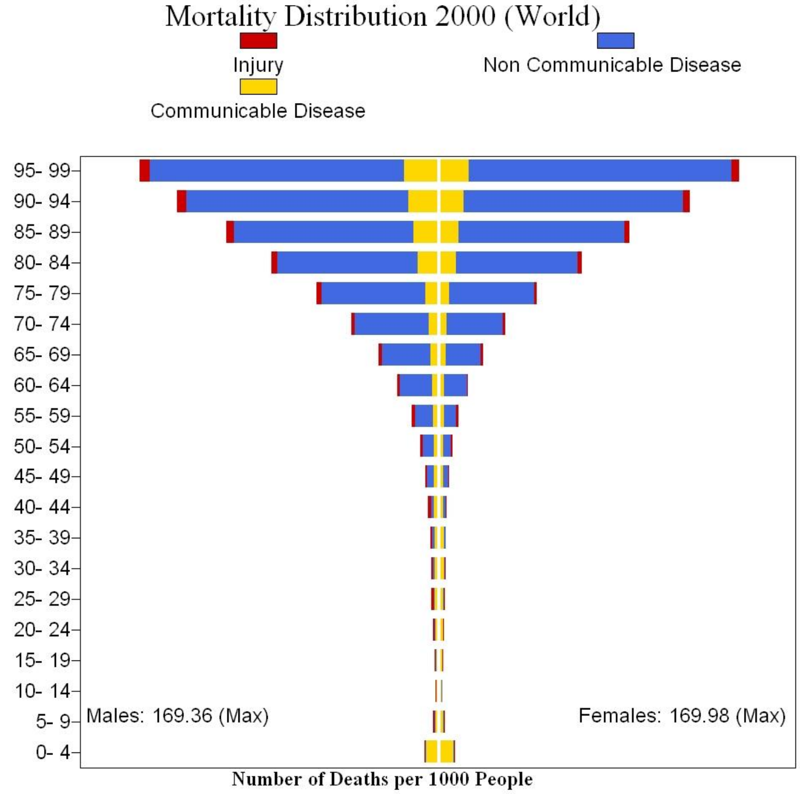
As reviewed in this working document, we are currently replacing that overall mortality representation with a new health module based on the GBD analysis. Following their methodology, we project sex and age-group specific mortality for eleven cause clusters (see table 3). At this point, we are only at the first stage of development: forecasting mortality from distal drivers (mainly income per capita and adult education). We are still using our original and separate formulations for HIV/AIDS-related mortality, although we now use an “intermediate” scenario with assumptions about peak year and infection rates that bring our forecast closer to UN estimates. Our formulations at this stage incorporate proximate drivers in only a limited way – namely, we include smoking impact and BMI as elements to help forecast non-communicable diseases. Yet BMI is now being held constant, so that it is distal drivers that shape the current forecasts.

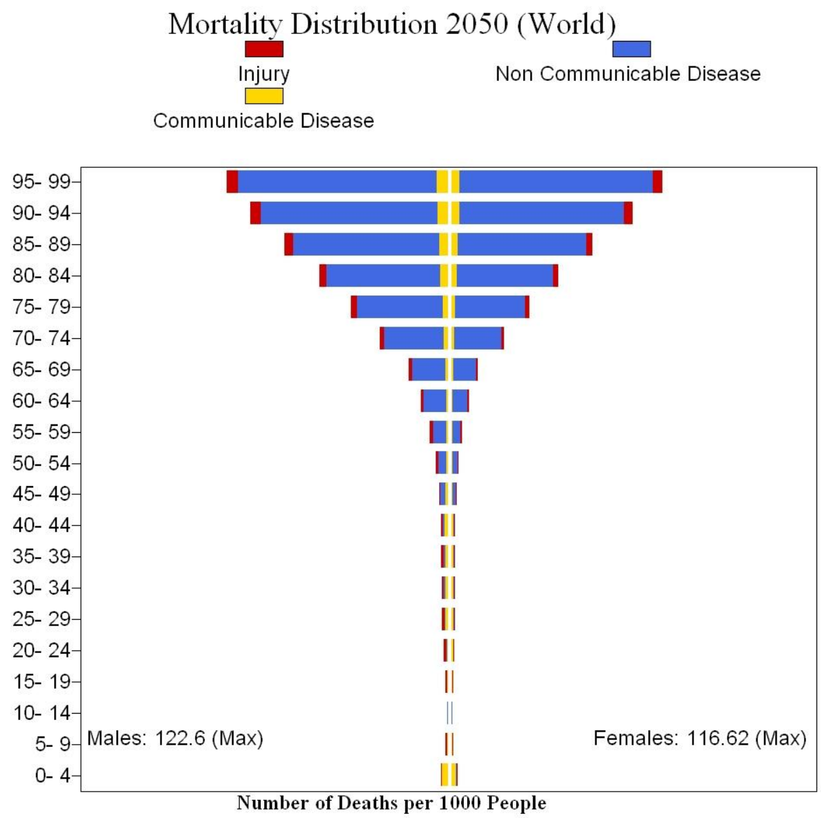
Therefore, we present preliminary figures less to definitely forecast health outcomes than to analyze our first-stage implementation of the regression models created by GBD researchers. The GBD was not designed to serve as a long-term forecasting tool; their projections represent a small piece of the overall project and forecast out less than 30 years. Using IFs, the user can forecast mortality out to the year 2100. While accuracy necessarily falls with extended projections, we display results to 2100 for a number of reasons. These include the recognition that looking at the very long-term time horizon helps us to better understand the implications of current trends; anomalies not especially clear in 2030 or 2050 will become much more obvious in the longer term.

We will also suggest, in this section, some of the utility in using IFs to forecast health outcomes. Even now, users can visually explore results by looking at mortality pyramids that show mortality rates for age and sex distributed by cause group. Additionally, the user can alter causal variables, either directly or through scenario development, and examine the impact of changes on mortality forecasts.

Figure 11 displays global mortality pyramids, by broad cause, for the years 2000 and 2100:

Figure 11 – Mortality Distribution, World 2000-2050

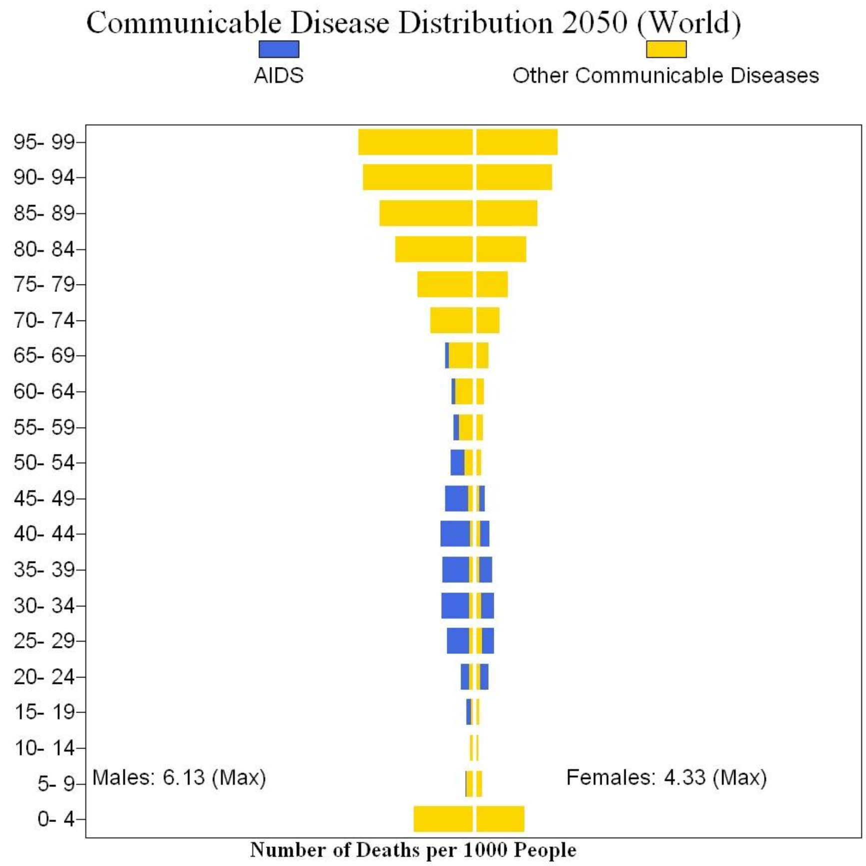


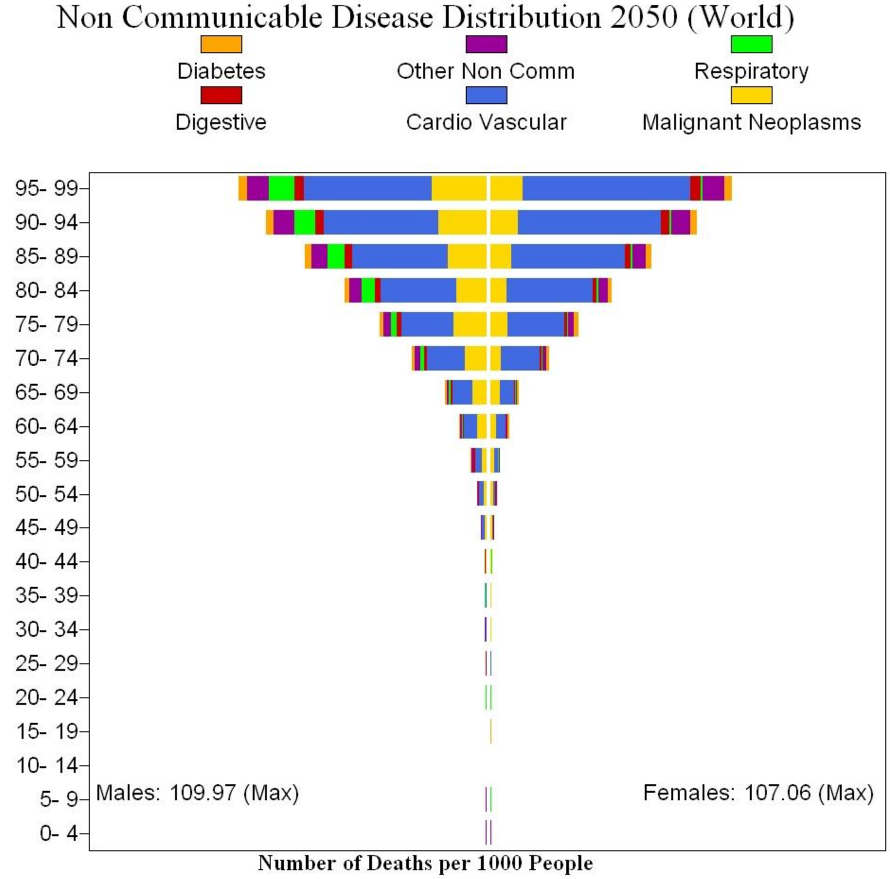


As shown in the above figures, in our current formulation we project that both overall mortality and, proportionally, mortality from Type I diseases (labelled here as "communicable disease") will decrease by the year 2050. Conversely, we forecast increases in injury mortality, especially for males between the ages of 15 and 44. The number of deaths per 1000 people is expected to decrease for all age groups over time, from a maximum of 169.98 deaths per 1000 (females aged 95-99 in the year 2000) to 122.6 deaths per 1000 (males aged 95-99 in the year 2050). This last observation also highlights the more rapid drop in mortality over time for females than for males.

The user can also drill down into specific disease categories. For example, Figure 12 presents global mortality pyramids, as in Figure 11, but for Type I and Type II disease subtypes (2050):

Figure 12 – Mortality Distribution, Subtypes, World 2050

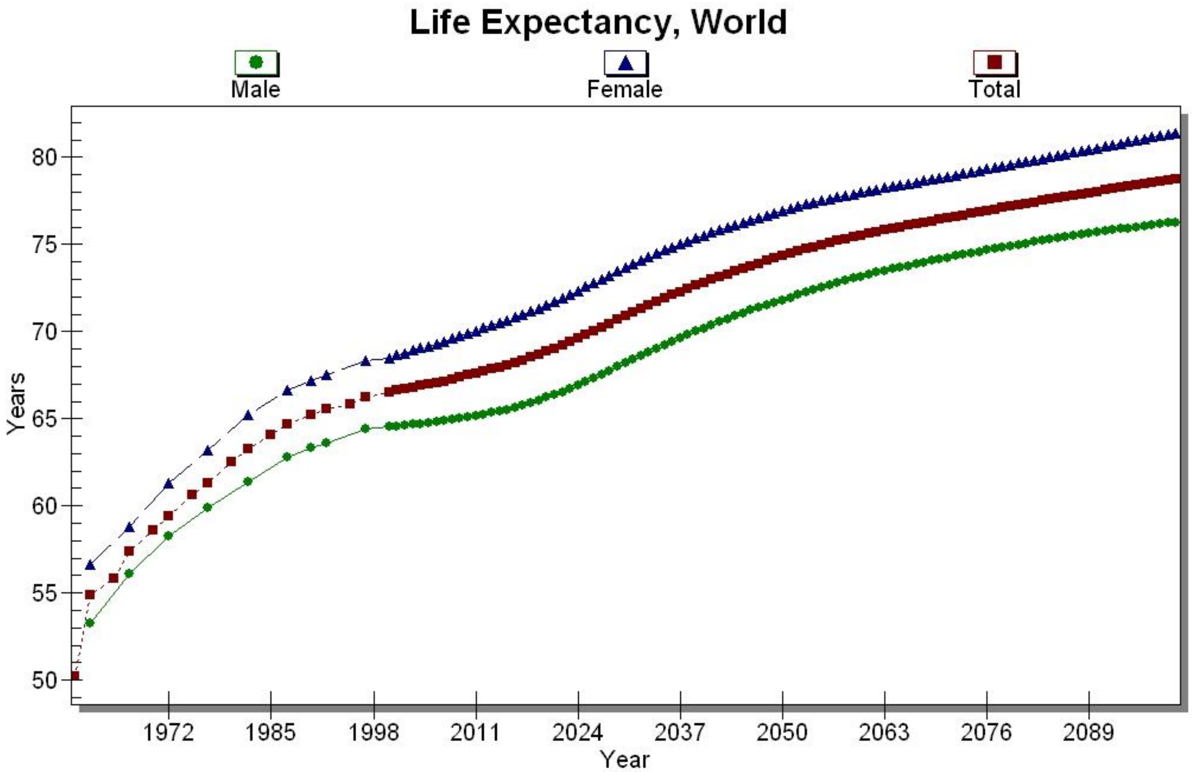




While Figure 12 reflects the overall decrease in communicable disease mortality over time, it also provides a greater degree of detail about the specific kinds of communicable disease we might expect to face. By 2050, we expect that HIV/AIDS will cause the majority of communicable disease mortality experienced by people under the age of 60. Looking at the pyramid of non-communicable disease subtypes, a few notable findings emerge. Unlike for communicable disease, males and females display nearly identical overall rates of Type II disease-related mortality in this 2050 forecast. However we can also see differences when we examine mortality by specific cause group. Males appear to experience greater rates of respiratory-related mortality, perhaps related to higher projected smoking rates. Interestingly, mortality associated with cardiovascular disease appears higher for females than males by 2050, a projection that warrants further investigation.

IFs uses age- and sex-specific mortality rates to forecast life expectancy by country or group of countries. Figure 13 displays world life expectancy (male, female, and overall) out to the year 2100:

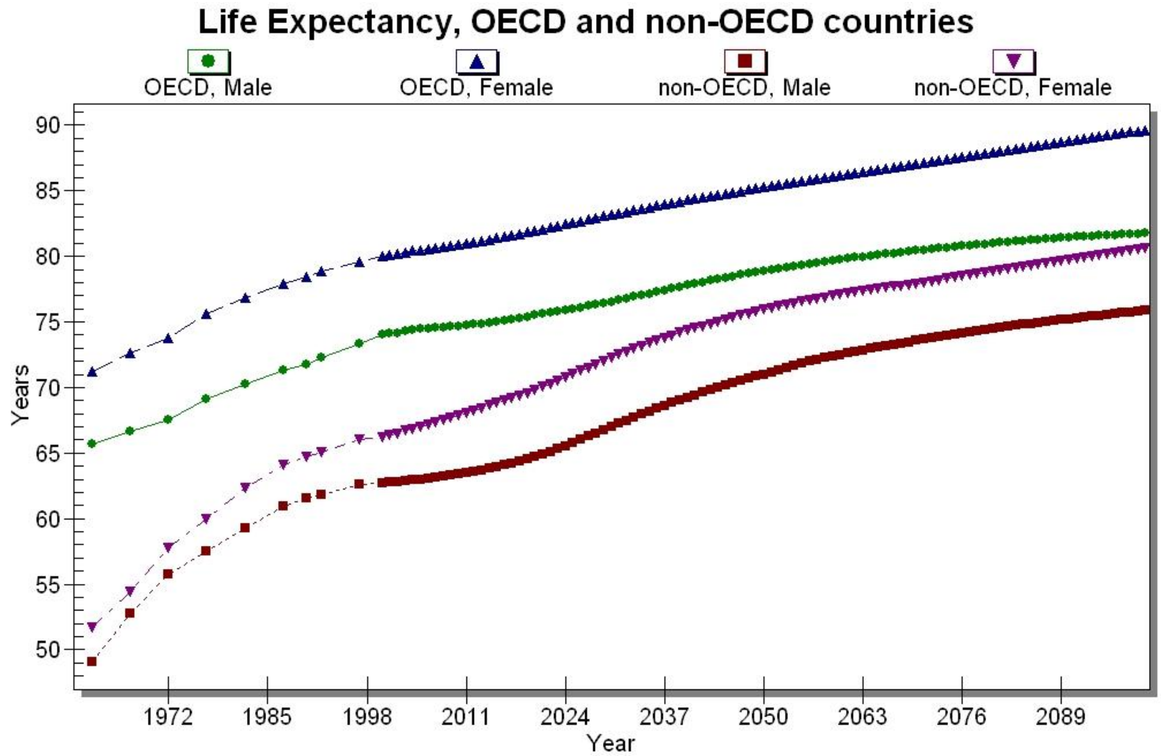
Figure 13 – World Life Expectancy



As we might expect from looking at the mortality pyramids, IFs forecasts that life expectancy will rise fairly steeply over the next century (following the trend of the last forty years, shown as a dashed line above). Female life expectancy seems to increase slightly more rapidly than male life expectancy, most likely due to the forecasted decrease in Type I disease-related mortality.

We can further explore whether all country groups should expect to experience this increase in life expectancy equally. Figure 14 presents male and female life expectancy from OECD and non-OECD countries separately:

Figure 14 – Life Expectancy by Country Group



In Figure 14, we can see that forecasted life expectancy varies notably depending on a country's current economic grouping. Life expectancy for both sexes is lower in non-OECD countries, although female life expectancy in non-OECD countries may catch up with male life expectancy in OECD countries by the end of the century. Moreover, while males and females follow somewhat similar paths out to mid-century, our current forecast projects significant divergences, especially in wealthier countries, by the end of the century. We discuss this issue briefly in the next section (discussion), but we will certainly want to consider more seriously whether these long-term trends fit with current expectations.

Adding Scenarios

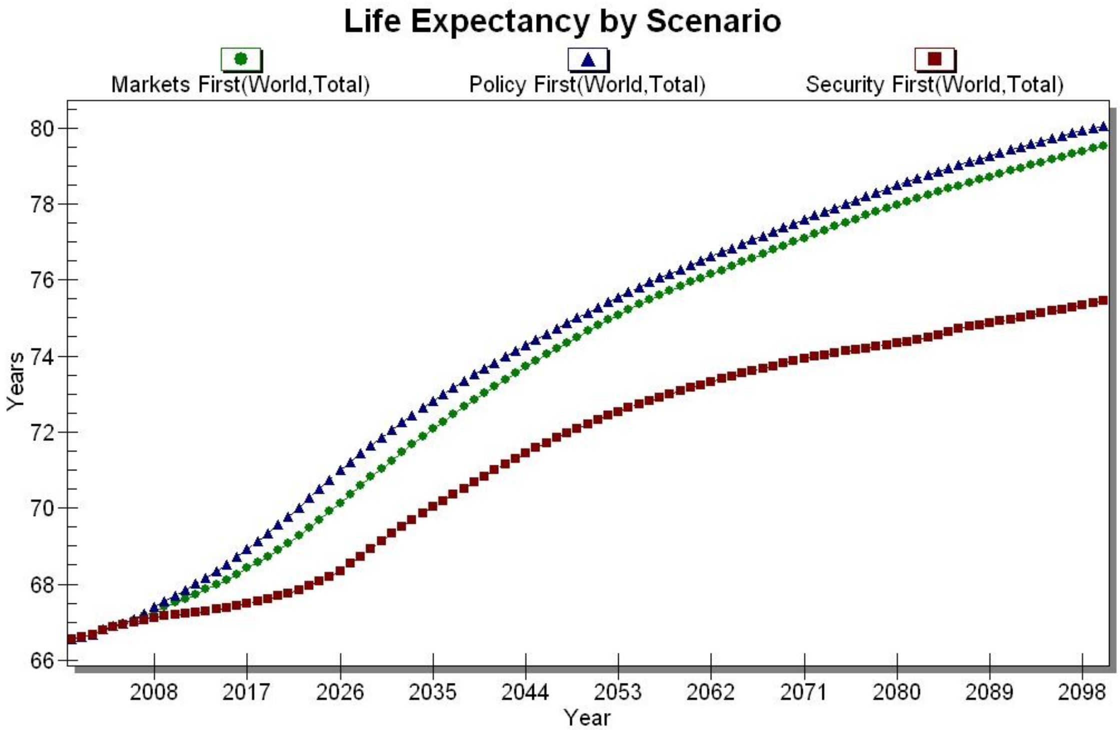
As a small demonstration of the utility of a global model in which causal variables are endogenized, we present forecasts of life expectancy under three distinct UN GEO-3 scenarios: "markets first," "policy first," and "security first" (table 3). At this stage in our model formulation, few causal variables influence mortality projections (namely, income per capita, adult education, smoking impact, and BMI). Therefore, we cannot yet examine some potentially interesting implications of these scenarios that might result from the changes in variables such as governance or foreign direct investment. However, as each of these scenarios impact our main distal variables - income per capita and adult education - they present an opportunity to begin thinking about the ways in which policy can result in different forecasts of health outcomes.

Table 3 – UN GEO-3 Scenarios

Scenario Name	Description
Markets First	"Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities to afford to ensure against -- or pay to fix -- social and environmental problems" (UN GEO-3, 329).
Policy First	"Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting environment and development are integrated into unified blueprints and their status in law is upgraded, though fresh provisions to allow for regional and local variants" (UN GEO-3, 334).
Security First	"This scenario assumes a world of striking disparities where inequality and conflict prevail. Socio-economic and environmental stresses give way to waves of protest and counteraction. As such troubles become increasingly prevalent, the more powerful and wealthy groups focus on self-protection, creating enclaves akin to the present day 'gated communities.' Such islands of advantage provide a degree of enhanced security and economic benefits for dependent communities in their immediate surroundings but they exclude the disadvantaged mass of outsiders. Welfare and regulatory services fall into disuse, but market forces continue to operate outside the walls" (UN GEO-3, 339).

Figure 15 presents life expectancy under each of the three UN GEO-3 scenarios:

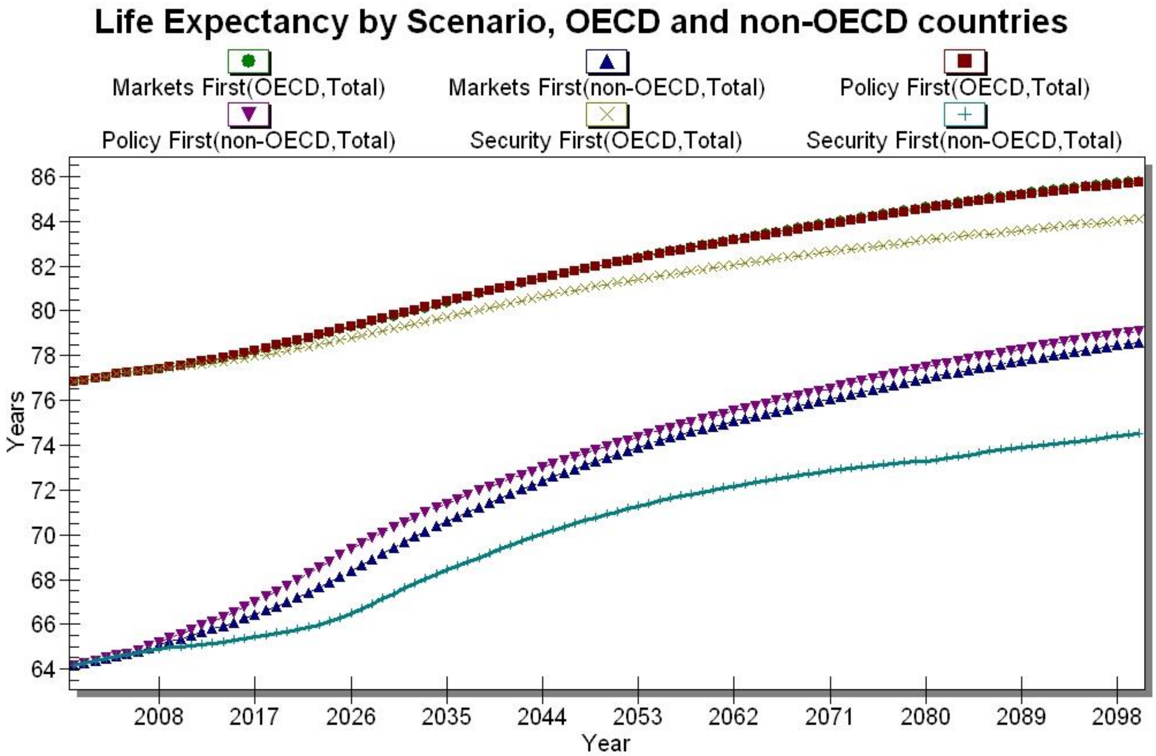
Figure 15 – Life Expectancy by Scenario



At a global level, our current forecast suggests the highest life expectancy in a "policy first" scenario, probably reflecting an emphasis in this scenario on increased educational spending. However, we achieve life expectancies similar to the policy first scenario under the "markets first" scenario, possibly due to increased productivity and thus income per capita. Alternately, the outlook for life expectancy is much worse in the "security first" scenario. This most likely reflects lower projections of income per capita and educational spending under this scenario.

We can further examine whether the scenarios impact countries differently depending on their relative wealth. Figure 16 presents life expectancy under the three scenarios for OECD and non-OECD countries:

Figure 16 – Life Expectancy by Scenario and Country Group



We can see that the "security first" scenario appears particularly harmful for non-OECD country life expectancy. For OECD countries, the three scenarios do not even begin to diverge until about 2020, with the impacts on life expectancy of the "policy first" and "markets first" scenarios indistinguishable. However, for non-OECD countries, the "policy first" scenario results in the highest forecast of life expectancy across the century while the "security first" assumptions result in stagnating projections of life expectancy.

VI. Discussion

As noted in the previous section, we need to stress that the results presented represent an opportunity for us to evaluate this first stage of our model implementation; they should not be mistaken for authoritative forecasts of health outcomes. Instead, our findings alert us to potential issues in our implementation that may require addressing before moving forward. They also suggest some interesting trends that we need to consider as we continue to develop the larger model.

Comparison to GBD results

GBD authors do not publish or make publicly available their projections of country-, cause-, age-, and sex-specific mortality. Thus, it is difficult to directly compare results. However, they do publish aggregate results that allow us to consider areas of divergence. For example, a 2006 paper graphs regional life expectancies for 2002 and 2030 (Mathers 2006: 2016):

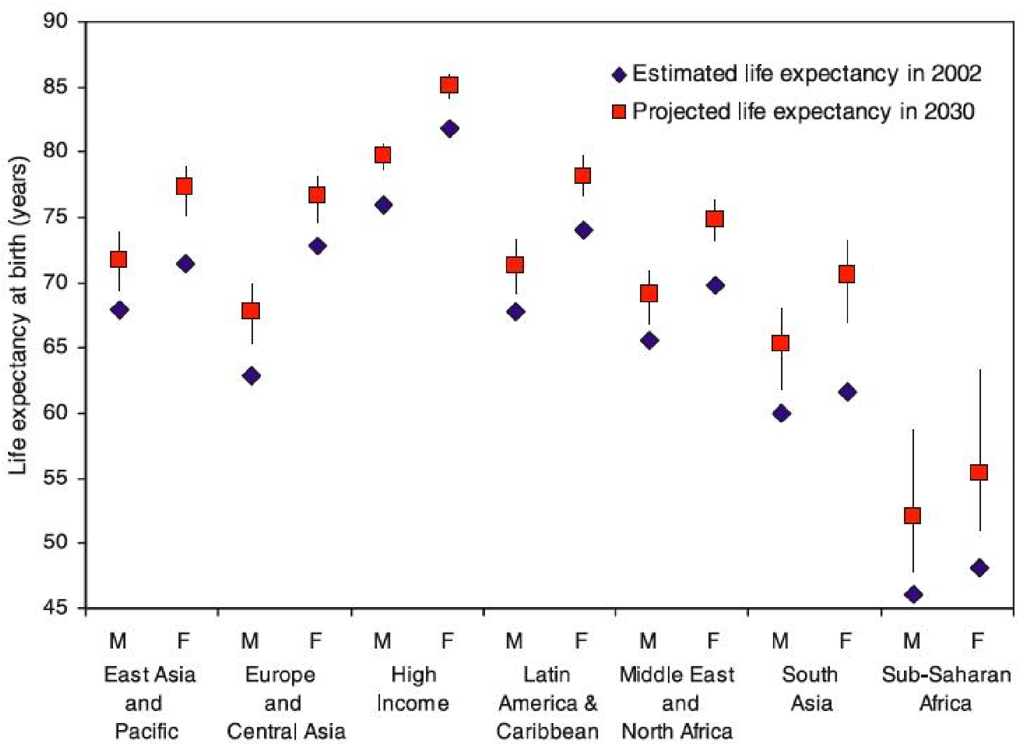


Figure 1. Projected Life Expectancy at Birth in 2030 by World Bank Region and Sex: Baseline, Optimistic, and Pessimistic Scenarios Compared with 2002 Estimates
doi: 10.1371/journal.pmed.0030442.g001

Table 4 – Comparison of Life Expectancy Forecasts

Region	GBD Life Expectancy 2030, Estimated*		IFs Life Expectancy 2030, HIV base case scenario		IFs Life Expectancy 2030, HIV intermediate scenario	
	Male	Female	Male	Female	Male	Female
East Asia & Pacific	72	77	72	77	70	75
Europe & Central Asia	68	77	70	78	68	77
High-Income Economies	79	85	78	84	77	84
Latin America & Caribbean	71	78	71	78	72	78
Middle East & North Africa	69	76	70	75	69	73
South Asia	65	70	68	74	65	69
Sub-Saharan Africa	53	56	66	73	61	66

*Life expectancy figures estimated from graph presented on page 35

Comparing output from IFs, we see that our life expectancy estimates, using either HIV/AIDS scenario, compare relatively favourably to those produced by the GBD analysis. One glaring exception does deserve attention: we forecast much higher life expectancy by 2030 in sub-Saharan Africa. We expect that this discrepancy mainly stems from our projections of AIDS-related mortality. As such, we need to re-examine both our HIV/AIDS forecast and our incorporation of the regression models for low-income countries. We currently project HIV/AIDS-related mortality using country or region-specific assumptions about infection rates and the peak year of infection, with the IFs base case being more optimistic than the intermediate scenario on both of these assumptions (Eberstadt 2002).[9] The GBD estimates incorporate more recent and sophisticated UNAIDS/WHO forecasts that include expectations about disease transmission and treatment (Mathers 2006: 2015).

Table 5 compares our region-specific forecasts of AIDS-related deaths in 2030 to those produced for the GBD analysis:

[9] For more on the current formulation of HIV/AIDS in IFs, see: “The IFs Base Case in Context,” pp. 13-14, in the Reports section of the IFs website (www.du.edu/~bhughes/ifsreports.html).

Table 5 – Comparison of AIDS-Related Mortality Forecasts

Region	Year	AIDS-related mortality (million people, GBD Baseline Scenario)	AIDS-related mortality (million people, IFs Baseline Scenario)	AIDS-related mortality (million people, IFs Intermediate Scenario)
East Asia and Pacific	2002	0.148	0.170	0.172
	2015	0.517	0.409	1.136
	2030	0.854	0.281	1.856
Europe and Central Asia	2002	0.033	0.018	0.021
	2015	0.181	0.021	0.317
	2030	0.218	0.011	0.273
High Income	2002	0.020	0.034	0.037
	2015	0.022	0.046	0.201
	2030	0.023	0.034	0.198
Latin America and Caribbean	2002	0.091	0.094	0.095
	2015	0.182	0.132	0.192
	2030	0.245	0.079	0.17
Middle East and North Africa	2002	0.002	0.008	0.01
	2015	0.050	0.014	0.286
	2030	0.116	0.009	0.295
South Asia	2002	0.342	0.403	0.405
	2015	0.773	1.054	1.454
	2030	1.279	1.013	2.643
Sub-Saharan Africa	2002	2.216	2.379	2.395
	2015	2.596	3.195	3.832
	2030	3.767	1.942	2.931

From table 5, we recognize that our intermediate scenario seems to result in estimates that more closely mirror those used in the GBD analyses. However, our projections still differ markedly for many regions, most notably sub-Saharan Africa. These figures present strong evidence that we need to rethink out forecast of AIDS-related mortality. As a next step, we will explore integrating the more recent UNAIDS forecasting methodology into IFs.

Interestingly, our overall life expectancy forecasts for 2050 appear very similar to those prepared by the UN for 2006 revision of the World Populations Prospects report (2007). The report projects that world life expectancy will reach 75.4 by 2045-2050, compared to our estimate of 74.04 years (2050). The UN further forecasts that life expectancy will reach 82.4 in more developed regions and 74.3 in less developed regions. Our projections are only slightly lower, at 81.7 (OECD, 2050) and 72.8 (non-OECD, 2050). UN, like IFs, may posit that the HIV/AIDS epidemic will be largely complete in 2050.

Other issues/emerging trends

As we extend the GBD regression models out to the year 2100, we notice a few trends that require, at the very least, further thought and exploration. These include: continued divergence of male and female mortality, with female life expectancy significantly higher than that of their male counterparts by the year 2100, and considerable proportional increases in injury as a cause of mortality, especially among young males.

Sex mortality ratios

As displayed most strikingly in Figure 14 (life expectancy by sex and country group), the gap between male and female mortality appears to widen throughout the coming century – especially in the OECD country group. We want to think about whether this outcome, which follows trends observed throughout the previous century, will continue to make sense in the future.

Indeed, we currently observe, in almost every country across the globe, a gap between male and female life expectancy. In the past century, the difference was largest for high income countries and less pronounced in developing regions which experienced high maternal mortality (Jones 2001). However, by the end of the 20th century, researchers noted that sex mortality ratios began to narrow in many developed countries (Waldron 1993; Trovato and Lalu 2007). In developed countries, where child and young adult mortality rates are already very low, increases in life expectancy derive mainly from greater survival at older ages (Guralnik, Balfour et al. 2000). Thus, many analysts attribute the narrowing of the life expectancy gap to increasing male survival in middle and late life as men make healthy “lifestyle choices” such as refraining from smoking, following a healthy diet, exercising, and avoiding trauma (Simon 2004).

In lower income countries, we expect female mortality to decrease rapidly as maternal and communicable disease-related mortality rates decline. Therefore, we should see a widening gap in male/female life expectancy even at constant rates of Type II and III mortality. If males in these countries follow past trends, and engage in relatively riskier behaviour than females, we very likely will see that gap widen even further. We cannot know whether historical patterns will repeat themselves, as our understandings about what constitutes “risky behaviour,” such as smoking, are very different today than they were in the last century.

We need to explore why we do not show a narrowing of the male/female life expectancy ratio for high income countries, as indicated in the literature. Injury mortality perhaps confounds our analysis at this stage, as our current forecast projects that male injury rates will remain high or increase with time (discussed below). While good macro level data is scarce, some evidence actually suggests a drop in male mortality associated with accidents and violence in developed countries (Trovalo and Lalu 2007). We will also consider further the issue of a possible mortality gap between male and female life expectancy in lower income regions.

Forecasting injury-related mortality

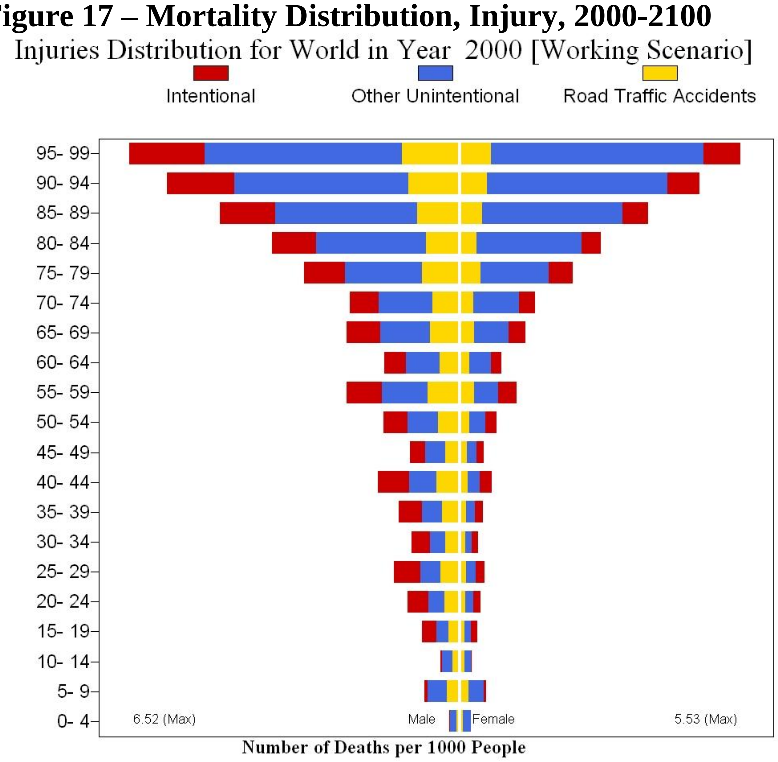
Researchers with the GBD recognize that their regression models do not adequately fit observed trends in injury-related mortality. In fact, for many age/sex groups, analysts simply assume constant mortality rates rather than use equations with R^2 values of less than 10% (Mathers 2006). Thus, it seems prudent to examine our injury forecasts with a critical eye as we attempt to understand anomalous long-term projections.

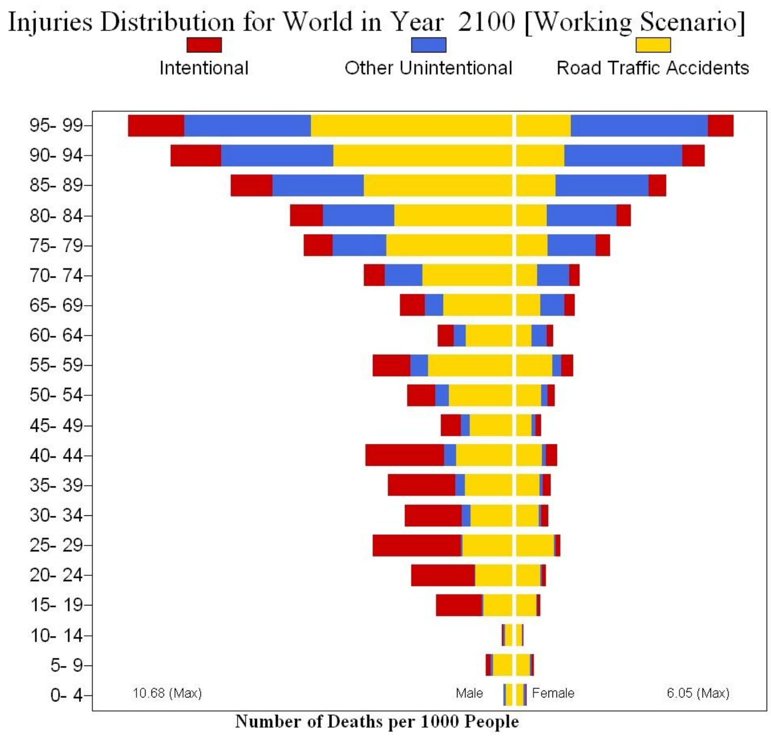
We especially want to revisit the issue of road traffic accident deaths. In the GBD analysis:

> "[t]he projected 40% increase in global deaths due to injury between 2002 and 2030 are predominantly due to the increasing numbers of road traffic accident deaths, together with increases in population numbers more than offsetting small declines in age-specific death rates for other causes of injury. Road traffic accident deaths are projected to increase from 1.2 million in 2002 to 2.1 million in 2030, primarily due to increased motor vehicle fatalities associated with economic growth in low- and middle-income countries" (Mathers 2006: 2017-2018).

Obviously, this rapid increase in traffic-related mortality becomes only more pronounced as we expand our time horizon to 2100, as displayed in Figure 17:

Figure 17 – Mortality Distribution, Injury, 2000-2100





As shown, road accidents increase dramatically – both proportionally and absolutely – especially for males. Note that the scale in the bottom half of Figure 17 is considerably large than in the top half. (Intentional injuries for males also increase significantly, another issue we will want to consider further). Should we expect such a rapid escalation in road traffic accident-related mortality as income rises? The guidance on this issue remains far from clear. In many countries, an S-shaped curve has been used to fit the relationship of income per capita and automobile ownership (Dargay, Gately et al. 2007). Yet that still does not tell us the association between automobile ownership and road traffic accidents. "Smeed's law," although controversial, suggests that road deaths per vehicle actually decrease as the number of registered vehicles in a country increases (Adams 1987). Thus saturating ownership rates may correspond to even more rapidly saturating injury rates.

We certainly want to modify our current injury forecasts to some extent, recognizing that our models do not adequately estimate injury-related mortality in the long-term. The well-established relationship between income per capita and automobile ownership provides a starting point, at least for projecting deaths associated with road traffic accidents. In the absence of persuasive evidence, we can also allow the user to make assumptions about injury-related mortality and adjust the forecast accordingly. We will consider all of our options further as we continue the process of refining our model within IFs.

Conclusion/Next steps

This paper represents an attempt to document our process thus far, including both our conceptual methodology and some of the implementation issues we find ourselves addressing as we begin to incorporate a health outcomes model into the larger structure of IFs. Despite what seems like a great deal of time and effort, we recognize that, at this point, we are only at the first stage of model development.

Once we resolve the issues stemming from our initial implementation of the GBD regression models, we plan to proceed to the next stages of our forecasting plan. These include adding proximate drivers, in order to better adjust our estimates of mortality. The addition of proximate drivers also provides additional opportunities for analysis around interventions that may help to reduce cause-specific mortality rates. We will begin as well to consider social and political drivers, such as governance, that almost certainly influence health outcomes. Importantly, we will attempt to delineate the pathways around health outcomes (figure 1), considering both backwards and forward linkages in a globally integrated system.

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