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Future of Mortality: perspectives from IHME

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Institute for Health Metrics and Evaluation

What is the GBD?

- GBD study is a systematic, scientific effort to quantify the magnitude of all major diseases, risk factors and intermediate clinical outcomes.
- **“Rules-based evidence synthesis for global health”**
- The first GBD study began in 1991 for eight regions 106 conditions and ten risk factors, 5 age groups for the year 1990.
- The GBD 2021 estimates for each year from 1990 to the present for 371 diseases and injuries, as well as 3,499 clinical outcomes (sequelae) related to those diseases and injuries, for 204 countries and territories and for subnational units in 20 countries.


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The Global Burden of Disease Study at 30 years

Christopher J. L. Murray[1,2]

The Global Burden of Disease Study (GBD) began 30 years ago with the goal of providing timely, valid and relevant assessments of critical health outcomes. Over this period, the GBD has become progressively more granular. The latest iteration provides assessments of thousands of outcomes for diseases, injuries and risk factors in more than 200 countries and territories and at the subnational level in more than 20 countries. The GBD is now produced by an active collaboration of over 8,000 scientists and analysts from more than 150 countries. With each GBD iteration, the data, data processing and methods used for data synthesis have evolved, with the goal of enhancing transparency and comparability of measurements and communicating various sources of uncertainty. The GBD has many limitations, but it remains a dynamic, iterative and rigorous attempt to provide meaningful health measurement to a wide range of stakeholders.

The Global Burden of Disease Study (GBD) is a systematic, scientific effort to quantify the magnitude of all major diseases, risk factors and intermediate clinical outcomes in a highly standardized way, to allow for comparisons over time, across populations and between health problems. The first GBD began in 1991 and led to the first results being published in 1993, which documented for eight regions the burden of disease for 106 conditions and ten risk factors, broken down into five age groups for the year 1990. The GBD now provides estimates for each year from 1990 to the present for 371 diseases and injuries, as well as 3,499 clinical outcomes (sequelae) related to those diseases and injuries, for 204 countries and territories and for subnational units in more than 20 countries. The full time series produced in each round of the GBD is updated on an annual basis, although the coronavirus disease 2019 (COVID-19) pandemic has delayed the release of the next GBD assessment. Since serialization in 2010, 1,842 publications on the GBD have appeared in the scientific literature.

Although there are many efforts in many countries to measure outcomes relating to single diseases or risks or groups of these, the GBD stands apart because of some core principles consistently applied over the last 30 years. Beginning in 1991, when the first GBD was undertaken as background work for the *World Development Report 1993: Investing in Health*, the GBD was committed to the principles of best estimates, comprehensive accounting, comparable measurement, summary measures of fatal and non-fatal health outcomes and thoughtful and repeated assessment of face validity of findings. In this Perspective, we reflect on lessons learned from 30 years of the GBD. We begin by reviewing the core principles, and then we examine the universe of data for tracking health, the ongoing evolution of the statistical methods to support the GBD, the history of the broader GBD collaboration and some key future directions for the effort.

Core principles

Best estimates. The GBD estimates each quantity of interest for every location. Even when data are highly inconsistent or there are no data for a disease or risk, a best estimate is produced along with our best estimate of uncertainty. The logic is that decisions have to be made, and a best estimate borrowing insight from where data are available is better than no estimate, provided that there is clarity around the level of uncertainty. All too often, 'no data' has been historically equated to 'no problem', biasing prioritization and agenda-setting toward diseases, injuries and risk factors for which data have been collected and/or advocacy groups exist. This commitment to best estimates has catalyzed a continuous search for better global data (volume, veracity, variety and timeliness are all prized) as well as continuous efforts for better statistical estimation methods to deal with missing data and conflicting data that inevitably remain. It also sharply distinguishes the GBD from many government or intergovernmental efforts both in health and in other social sectors and remains the most frequently misunderstood part of the GBD.

Comprehensive accounting. This second core principle applies across diseases, injuries and risks. Comparable information on the magnitude of different health problems provides an objective framework to help establish health priorities and, importantly, can also provide important insights into what topics may be neglected. In the 1990s, the GBD finding that the burden of mental health disorders was substantial relative to infectious diseases, heart disease and cancer prompted the World Health Organization (WHO) and many countries to devote more policy attention to these neglected problems. A high-level view of the comparative magnitude of health problems has also highlighted the rapidity of the epidemiological transition in many middle-income (and former low-income) countries where the profile of burden has shifted from communicable, maternal, neonatal and nutritional deficiencies to non-communicable diseases and injuries. In more recent years, this principle has had increasing benefits as this comprehensive estimation has become a somewhat unique resource, in allowing the holistic forecasting of population health effects in an ever more rapidly changing and challenged world.

Comparability of measurement. Comprehensive accounting requires a focus on comparability of measurement. Many authors and statistical authorities have argued that the most important comparisons are within a country; but, from the beginning of the GBD, we have seen the value of emphasizing comparability over time and across place. Decision-makers who use the GBD results are drawn to understanding why their community may have a larger or smaller burden from a condition or, even more importantly, faster or slower rates of decline or increase in a disease, injury or risk factor,

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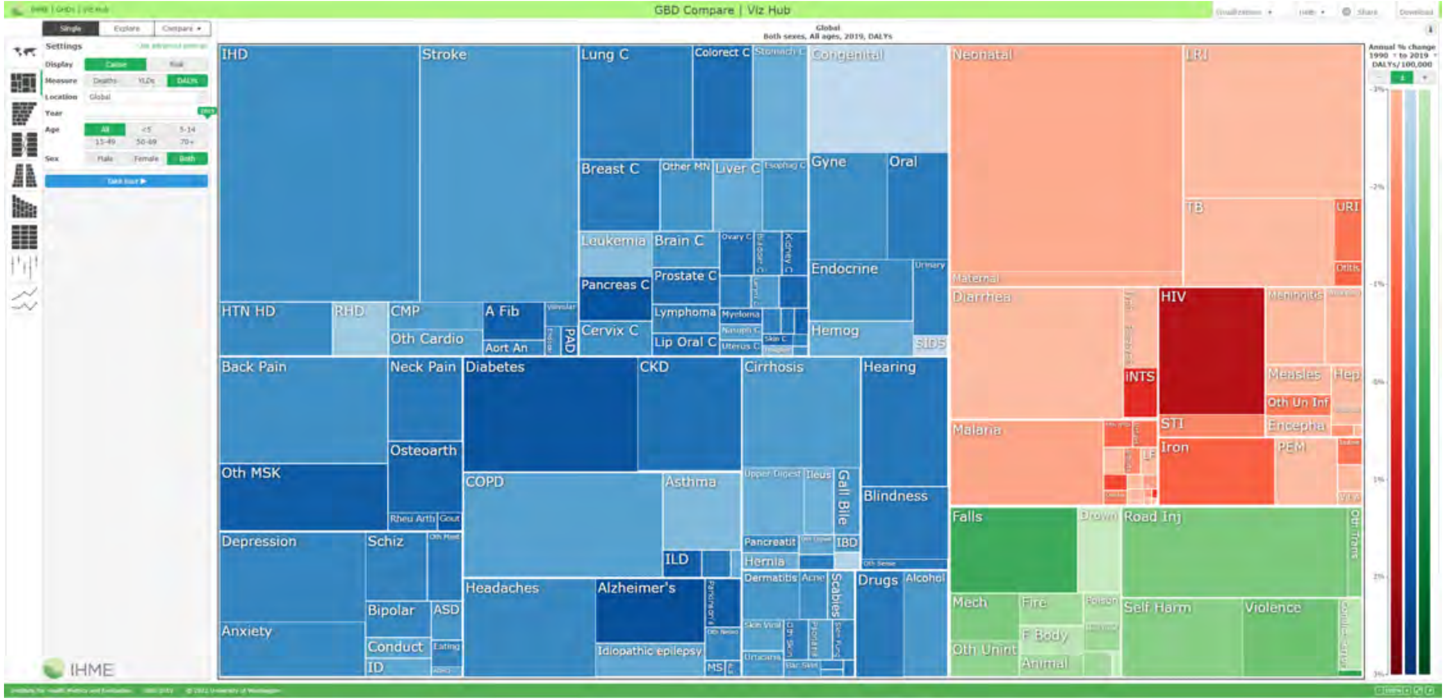
Murray CJL. The global burden of disease study at 30 years. *Nature Medicine. October 2022.*

GBD Compare: on-line tools providing access to detailed results, www.healthdata.org



Future Health Scenarios

- **1997:** Forecasting mortality and disability 1990-2020
- **2018:** Forecasting mortality, life expectancy and risk attributable burden – better/worse scenarios
- **2020:** Forecasting populations to 2100
- **2023:** Forecasting 370 causes, deaths, YLLs, YLDs, DALYs, incidence, prevalence, life expectancy, healthy life expectancy (HALE) – target scenarios with avoidable future burden 2020-2050
- **2023**: Fertility forecasting
- **2023:** India subnational forecasts

THE LANCET

Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study

1997

Christopher J L Murray, Alan D Lopez

Summary

Background Plausible projections of future mortality and disability are a useful aid in decisions on priorities for health research, capital investment, and training. Rates and patterns of ill health are determined by factors such as socioeconomic development, educational attainment, technological developments, and their dispersion among populations, as well as exposure to hazards such as tobacco. As part of the Global Burden of Disease Study (GBD), we developed three scenarios of future mortality and disability for different age-sex groups, causes, and regions.

depression, road-traffic accidents, cerebrovascular disease, chronic obstructive pulmonary disease, lower respiratory infections, tuberculosis, war injuries, diarrhoeal diseases, and HIV. Tobacco-attributable mortality is projected to increase from 3·0 million deaths in 1990 to 8·4 million deaths in 2020.

Interpretation Health trends in the next 25 years will be determined mainly by the ageing of the world's population, the decline in age-specific mortality rates from communicable, maternal, perinatal, and nutritional disorders, the spread of HIV, and the increase in tobacco-related mortality and disability. Projections, by their nature,

Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: referenc and alternative scenarios for 2016–40 for 195 countries and territories

2018

Kyle J Foreman, Neal Marquez, Andrew Dolgert, Kai Fukutaki, Nancy Fullman, Madeline McGaughey, Martin A Pletcher, Amanda E Smith, Kendrick Tang, Chun-Wei Yuan, Jonathan C Brown, Joseph Friedman, Jiawei He, Kyle R Heuton, Mollie Holmberg, Disha J Patel, Patrick Reidy, Austin Carter, Kelly Cercy, Abigail Chapin, Dirk Douwes-Schultz, Tahvi Frank, Falko Goettsch, Patrick Y Liu, Vishnu Nandakumar, Marissa B Reitsma, Vince Reuter, Nafis Sadat, Reed J D Sorensen, Vinay Srinivasan, Rachel L Updike, Hunter York, Alan D Lopez, Rafael Lozano, Stephen S Lim, Ali H Mokdad, Stein Emil Vollset, Christopher J L Murray

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Summary

Background Understanding potential trajectories in health and drivers of health is crucial to guiding long-term investments and policy implementation. Past work on forecasting has provided an incomplete landscape of future health scenarios, highlighting a need for a more robust modelling platform from which policy options and potential

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Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study

2020

Stein Emil Vollset, Emily Goren, Chun-Wei Yuan, Jackie Cao, Amanda E Smith, Thomas Hsiao, Catherine Bisignano, Gulrez S Azhar, Emma Castro, Julian Chalek, Andrew J Dolgert, Tahvi Frank, Kai Fukutaki, Simon I Hay, Rafael Lozano, Ali H Mokdad, Vishnu Nandakumar, Maxwell Pierce, Martin Pletcher, Toshana Robalik, Krista M Steuben, Han Yong Wunrow, Bianca S Zlavog, Christopher J L Murray

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Summary

Background Understanding potential patterns in future population levels is crucial for anticipating and planning for changing age structures, resource and health-care needs, and environmental and economic landscapes. Future fertility patterns are a key input to estimation of future population size, but they are surrounded by substantial uncertainty and diverging methodologies of estimation and forecasting, leading to important differences in global population projections. Changing population size and age structure might have profound economic, social, and geopolitical impacts in many countries. In this study, we developed novel methods for forecasting mortality, fertility, migration, and population. We also assessed potential economic and geopolitical effects of future demographic shifts.

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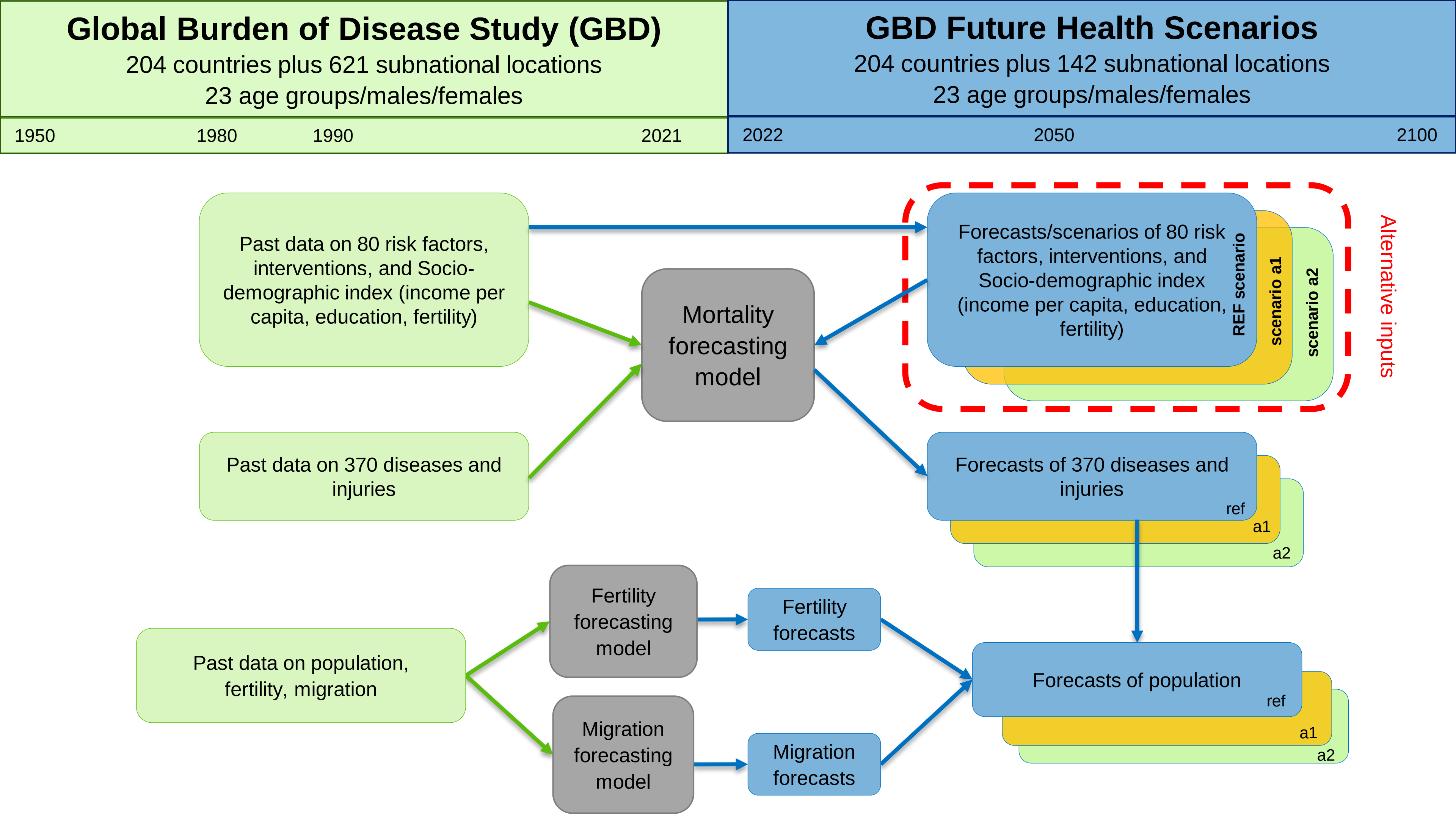
Explicit vs implicit drivers in forecast models

- Debate between demographers and other groups on using explicit vs. implicit drivers in forecast models.
- Demographers prefer to use models where time is the only covariate which assumes that past correlations of real drivers of change maintain the same correlation in the future.
- Demographic forecasts also are for all-cause mortality and not cause-specific mortality.
- Alternatively, models can incorporate known relations such as tobacco and lung cancer. **HOWEVER** forecasts of the drivers are required.
- Driver forecasts often include only time as the only covariate.
- Explicit driver models allow for alternative scenario construction by modifying the trajectory of the explicit drivers.


Global Burden of Disease Study (GBD)
204 countries plus 621 subnational locations
23 age groups/males/females
1950
1980
1990
2021
GBD Future Health Scenarios
204 countries plus 142 subnational locations
23 age groups/males/females
2022
2050
2100
Past data on 80 risk factors, interventions, and Socio-demographic index (income per capita, education, fertility)
Mortality forecasting model
Forecasts/scenarios of 80 risk factors, interventions, and Socio-demographic index (income per capita, education, fertility)
REF scenario
scenario a1
scenario a2
Alternative inputs
Past data on 370 diseases and injuries
Forecasts of 370 diseases and injuries
ref
a1
a2
Fertility forecasting model
Fertility forecasts
Past data on population, fertility, migration
Migration forecasting model
Migration forecasts
Forecasts of population
ref
a1
a2

Modeling future mortality - 3 components

- We forecast the GBD as follows:

1. Remove effect of risk factors and interventions - gives us risk-deleted or underlying cause-specific mortality (scalars in model = multipliers of mortality rate) 1
2. Model cause-sex-specific underlying mortality with Sociodemographic index (SDI) and time as explanatory variables (mixed effects linear model with priors; age-location & age-time random effects) 2
3. What is not explained with risk factors/interventions and SDI/time is modelled with time-series (ARIMA) models 3

Input needed: past cause-specific mortality, past and future drivers of mortality (risk factors, vaccines, SDI (GDP per capita, educational level, fertility under 25 years)

Drivers of health – all are forecasted

Sociodemographic index:	Occupational exposure to benzene	Short gestation for birth weight	Diet low in calcium	Number of motor vehicles per capita
Mean years of education	Occupational exposure to beryllium	Low birth weight for gestation	Diet low in seafood omega-3 fatty acids	Hypertensive heart disease/CKD
Income per capita	Occupational exposure to cadmium	Iron deficiency	Diet low in polyunsaturated fatty acids	Systolic blood pressure SEV
Total ferility under 25 years	Occupational exposure to chromium	Vitamin A deficiency	Diet high in trans fatty acids	Diabetes mellitus
Vaccines:	Occupational diesel engine exhaust	Zinc deficiency	Diet high in sodium	Fasting plasma glucose SEV
Measles (mcv1)	Occupational exposure to formaldehyde	Tobacco, alcohol, drug use:	Other behavioral risk factors:	Alcohol-related liver cirrhosis/CMP
Diphteria-tetanus-pertussis (dtp3)	Occupational exposure to nickel	Smoking	Intimate partner violence	Alcohol SEV
Hemophilus influenzae B (hib3)	Occup. polycyclic aromatic hydrocarbons	Chewing tobacco	Childhood sexual abuse	Preterm birth complication deaths
Pneumococcal conjugate (pcv3)	Occupational exposure to silica	Secondhand smoke	Bullying victimization	Low birth weight for gestation SEV
Rotavirus	Occupational exposure to sulfuric acid	Alcohol use	Unsafe sex	Protein energy malnutrition (PEM)
Water, sanitation, handwashing	Occupat. exposure to trichloroethylene	Drug use	Low physical activity	Child underweight SEV
Unsafe water source	Occupational asthmagens	Diet risk factors:	Metabolic risk factors:	Anemia
Unsafe sanitation	Occup. particulate matter, gases & fumes	Diet low in fruits	High fasting plasma glucose	Iron deficiency SEV
No access to handwashing facility	Occupational noise	Diet low in vegetables	High LDL cholesterol	Selcted pneumonia deaths
Air pollution, other environmental risks:	Occupational injuries	Diet low in legumes	High systolic blood pressure	Occupational exposure to silica SEV
Ambient particulate matter pollution	Occupational ergonomic factors	Diet low in whole grains	High body-mass index	HIV/AIDS drivers:
Household air pollution from solid fuels	Child and maternal malnutrition:	Diet low in nuts and seeds	Low bone mineral density	ART Price
Ambient ozone pollution	Non-exclusive breastfeeding	Diet low in milk	Impaired kidney function	Income per capita
Residential radon	Discontinued breastfeeding	Diet high in red meat	Cause-specific covariates	HIV-specific DAH/GHE
Lead exposure	Child underweight	Diet high in processed meat	Maternal (maternal HIV)	Child ART/cotrimoxazole coverage
Occupational exposure to asbestos	Child wasting	Diet high in sugar-sweetened beverages	Age specific fertility rate (+ HIV mortality)	PMTCT coverage
Occupational exposure to arsenic	Child stunting	Diet low in fiber	Road injuries	SEV = summary exposure value

From GBD 2019 non-optimal temperature (high and low temperature) is added as an environmental risk factor (Burkhart, Brauer, Aravkin et al. Lancet 2021)

Forecast skill

- 2018 Lancet paper on age-specific and cause-specific mortality forecasts reported out of sample predictive validity in terms of RMSE by cause over the last 15 years of observation with these data held out of model construction.
- IHME is switching to using forecast skill to quantify model performance: specifically, skill computed as 1-(winsorized RMSE)/(winsorized RMSE for a baseline model). The baseline model is assuming age-specific death rates (and disability rates remain constant).
- Skill metrics will be reported in our next publication later this year.

US and states 1990-2100: life expectancy