Harnessing Data to Advance Health Equity

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Professor, Global Health
Outline

1) IHME
2) GBD 2013 recap
3) Key results
4) County and census enumeration area methods
5) Past trends and relationships scenario for burden 2015-2040
6) Conclusion and recommendations
7) Integrated Surveillance System
Institute for Health Metrics and Evaluation

• Dedicated to providing independent, rigorous, and timely scientific measurements to accelerate progress on global health
  • Everyone deserves to live a long life in full health
  • To improve health, we need better health evidence

• Focused on answering three critical questions:
  • What are the world’s major health problems?
  • How well is society addressing these problems?
  • How do we best dedicate resources to get the maximum impact in improving population health in the future?
Key areas of research

- Global Burden of Disease
- Financing
- Impact evaluations
- Costs and efficiency of service production
- Effective coverage of interventions
- Forecasting
- Mapping
- Health Systems Solutions
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Global Burden of Disease

1. A **systematic, scientific** effort to quantify the **comparative** magnitude of **health loss** from all major diseases, injuries, and risk factors by age, sex, and population and over time.

2. 188 countries from 1990 to present. Sub-national assessments for some countries (e.g. China, Mexico, UK, US, Brazil, Japan, India, Kenya, Saudi Arabia)

3. 306 diseases and injuries, 2,337 sequelae, 79 risk factors or clusters of risk factors.

4. Updated annually; release planned for May each year.

## Risk hierarchy

<table>
<thead>
<tr>
<th>Behavioral</th>
<th>Environmental</th>
<th>Metabolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child and maternal undernutrition</td>
<td><strong>Unsafe water, sanitation and hygiene</strong></td>
<td><strong>Physiological risks</strong></td>
</tr>
<tr>
<td>Suboptimal breastfeeding</td>
<td>Unsafe water source</td>
<td><strong>High fasting plasma glucose</strong></td>
</tr>
<tr>
<td>Childhood underweight</td>
<td>Unsafe sanitation and hygiene</td>
<td><strong>High total cholesterol</strong></td>
</tr>
<tr>
<td>Iron deficiency</td>
<td>Air pollution</td>
<td><strong>High blood pressure</strong></td>
</tr>
<tr>
<td>Vitamin A deficiency</td>
<td>Ambient particulate matter pollution</td>
<td><strong>High body-mass index</strong></td>
</tr>
<tr>
<td>Zinc deficiency</td>
<td>Household air pollution from solid fuels</td>
<td><strong>Low bone mineral density</strong></td>
</tr>
<tr>
<td><strong>Tobacco smoking</strong></td>
<td>Other environmental risks</td>
<td><strong>Low glomerular filtration rate</strong></td>
</tr>
<tr>
<td>Tobacco smoking, excluding second-hand smoke</td>
<td>Ambient ozone pollution</td>
<td></td>
</tr>
<tr>
<td>Second-hand smoke</td>
<td>Residential radon</td>
<td></td>
</tr>
<tr>
<td><strong>Alcohol and drug use</strong></td>
<td>Lead exposure</td>
<td></td>
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<tr>
<td>Alcohol use</td>
<td><strong>Occupational risks</strong></td>
<td></td>
</tr>
<tr>
<td>Drug use</td>
<td>Occupational carcinogens</td>
<td></td>
</tr>
<tr>
<td><strong>Dietary risks</strong></td>
<td>Occupational asthmagens</td>
<td></td>
</tr>
<tr>
<td>Diet low in fruits</td>
<td>Occupational particulate matter, gases, and fumes</td>
<td></td>
</tr>
<tr>
<td>Diet low in vegetables</td>
<td>Occupational noise</td>
<td></td>
</tr>
<tr>
<td>Diet low in whole grains</td>
<td>Occupational risk factors for injuries</td>
<td></td>
</tr>
<tr>
<td>Diet low in nuts and seeds</td>
<td>Occupational low back pain</td>
<td></td>
</tr>
<tr>
<td>Diet low in milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet high in red meat</td>
<td></td>
<td></td>
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<tr>
<td>Diet high in processed meat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet high in sugar-sweetened beverages</td>
<td></td>
<td></td>
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<tr>
<td>Diet low in fiber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet suboptimal in calcium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet low in seafood omega-3 fatty acids</td>
<td></td>
<td></td>
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<tr>
<td>Diet low in polyunsaturated fatty acids</td>
<td></td>
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<tr>
<td>Diet high in trans fatty acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet high in sodium</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physical inactivity and low physical activity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sexual abuse and violence</strong></td>
<td></td>
<td></td>
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<tr>
<td>Childhood sexual abuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intimate partner violence</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Unsafe sex</strong></td>
<td></td>
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</tr>
</tbody>
</table>
GBD: a global study with a global network

1,083 collaborators from 108 countries
Multiple metrics for health

1) **Traditional metrics**: Disease and injury prevalence and incidence, death numbers and rates.

2) **Years of life lost** due to premature mortality (YLLs) – count the number of years lost at each age compared to a reference life expectancy of 86 at birth.

3) **Years lived with disability** (YLDs) for a cause in an age-sex group equals the prevalence of the condition times the disability weight for that condition.

4) **Disability-adjusted life years (DALYs)** are the sum of YLLs and YLDs and are an overall metric of the burden of disease.
1. Cause of death garbage code analysis – redistribution of causes that cannot be underlying cause of death.

2. Cause of death ensemble modeling (CODEm)


4. Comorbidity microsimulation to estimate co-occurrence of multiple sequelae.

5. Joint risk factor analysis
The origins of DisMod-MR

• In the language of the statistician, DisMod-MR is a **nonlinear mixed effects model**

• In most textbooks on regression modeling, nonlinear models get only the briefest mention; the problem: too many possibilities

• In pharmacokinetics/pharmacodynamics this is called **integrative systems modeling**. It is a particular type of nonlinear modeling, using compartments
Width of Horizontal bar represents age range of estimate
Parameter value = 0.30, ages 15-94

Vertical bar represents uncertainty around estimate
Uncertainty: 0.27 – 0.32
Example estimates – Dementia
GBD approach to cause of death data

1) Map all versions of the ICD including national variants to the GBD cause list.

2) Deaths that should not be underlying cause or are unspecified in nature are mapped to garbage codes e.g. heart failure, unspecified stroke, or X59

3) For each cluster of garbage codes, a redistribution algorithm is used to re-assign deaths to likely underlying cause.

4) Selected underlying causes may be assigned to other underlying causes (mis-certification) e.g. HIV. Specialized methods are used for extracting mis-certified deaths and re-assigning them.
Three redistribution package methods

1) Proportionate redistribution – deaths re-assigned in proportion to deaths in a country-age-sex-year assigned directly to target codes.

2) Expert-based redistribution – fixed proportions of garbage deaths re-assigned to target codes based on published studies and/or expert opinion. E.g. septicemia going to maternal. Some of these algorithms are a blend of fixed proportions to groups and proportionate redistribution within a group.

3) Regression models used to estimate proportions of a garbage code assigned to each target code – these models allow for super-region, region and country variation.
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Data viz

www.healthdata.org
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Mortality models: background

- IHME has previously developed small area models for life expectancy

- We also developed a validation environment for assessing model performance

- These models borrow strength across space, across time, and from covariates to produce reliable predictions even in small counties
Risk Factors: Background

Cigarette smoking  
Age 18+, 1996-2012

Obesity  
Age 20+, 2001-2011

Any physical activity  
Age 20+, 2001-2011

Sufficient physical activity  
Age 20+, 2001-2011

Alcohol use  
Age 21+, 2002-2012

Heavy drinking  
Age 21+, 2005-2012

Binge drinking  
Age 21+, 2002-2012

Hypertension  
Age 30+, 2001, 2009

Diabetes  
Age 30+, 1996-2012

High cholesterol  
Age 30+, 1997-2011

Fair/poor health  
Age 18+, 1996-2012

Frequent mental distress  
Age 18+, 1996-2012

Frequent physical distress  
Age 18+, 1996-2012

Life expectancy  
1985-2010
Small area models: borrowing strength

- To address small number we build a model that borrows strength …

  1) Over time (i.e., by pooling data)
  2) Over space (i.e., from neighbors)
  3) From external data sources (i.e., covariates)
Small area models: model specification

\[ Y_{i,t,a,r,m,e} \sim \text{Binomial}(N_{i,t,a,r,m,e}, p_{i,t,a,r,m,e}) \]

\[
\text{logit}(p_{i,t,a,r,m,e}) = \beta_0 + \beta_1 \cdot t \\
+ \beta_{2,a} + \beta_{3,r} + \beta_{4,m} + \beta_{5,e} \\
+ \beta_6 \cdot X_{i,t} \\
+ \beta_7 \cdot \delta_i \\
+ \gamma_{0,i} + \gamma_{1,i} \cdot t
\]

\[ i \quad = \quad \text{county} \]
\[ t \quad = \quad \text{year} \]
\[ a \quad = \quad \text{age group} \]
\[ r \quad = \quad \text{race/ethnicity} \]
\[ m \quad = \quad \text{marital status} \]
\[ e \quad = \quad \text{education} \]
### Small area models: model specification

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>County racial composition (%) black, % Asian, % AIAN, % Hispanic</td>
<td>NCHS Bridged Race Population Files</td>
</tr>
<tr>
<td>Education (%) high school grads</td>
<td>1990 Census, 2000 Census, 2009-2012 American Community Survey</td>
</tr>
<tr>
<td>Poverty (%) in poverty</td>
<td>Small Area Income and Poverty Estimates (Census Bureau)</td>
</tr>
<tr>
<td>Unemployment (%) unemployed</td>
<td>Local Area Unemployment Statistics (Bureau of Labor Statistics)</td>
</tr>
<tr>
<td>Rural (%) rural households</td>
<td>1990 Census, 2000 Census, 2010 Census</td>
</tr>
<tr>
<td>MDs per capita</td>
<td>Area Health Resource File (HRSA)</td>
</tr>
<tr>
<td>Cigarette sales per capita</td>
<td>State Tobacco Activities Tracking &amp; Evaluation System (CDC)</td>
</tr>
</tbody>
</table>
Validation: methods

1. Identify a validation set: large counties where direct estimates of mortality have minimal sampling error. These direct estimates are used as the gold standard.

2. Create testing datasets by sampling down the counties in the validation set to mimic counties with 1500, 2500, 5000, 10000, or 50000 population (by sex).

3. Run models on the testing datasets and generate estimates for the validation set.

4. Compare model estimates for the validation set to the gold standard and calculate performance metrics (RMSE, mean relative error, mean absolute relative error, coverage).
Mortality models: new methods development

- We have tested newer more computationally intensive models that originally developed from the field of image processing.
- These models when used for cancer hotspot analysis usually applied to much smaller sets of geographies because of software and computational limitations.
- New software (Template Model Builder) allows us to fit these models much faster and for all census enumeration tracts or US counties at once.
- Objective validation tests show these models lead to more accurate estimates.

![Graph showing relationship between population size and mean absolute relative error.](image-url)
Model with county time and age random effects and interactions

\( D_{j,t,a} \sim \text{Poisson}(m_{j,t,a} \cdot P_{j,t,a}) \)

\[
\log(m_{j,t,a}) = \beta_{0} + \beta_{1} \cdot X_{j,t} + \gamma_{1,a,t} + \gamma_{2,j} + \gamma_{3,j} \cdot t + \gamma_{4,j} \cdot a
\]

\( \gamma_{1,a,t} \sim \text{LCAR:LCAR}(\sigma_{1}^2, \rho_{1,A}, \rho_{1,T}) \)
\( \gamma_{2,j} \sim \text{LCAR}(\sigma_{2}^2, \rho_{2}) \)
\( \gamma_{3,j} \sim \text{LCAR}(\sigma_{3}^2, \rho_{3}) \)
\( \gamma_{4,j} \sim \text{LCAR}(\sigma_{4}^2, \rho_{4}) \)

\( \frac{1}{\sigma_{i}^2} \sim \text{Gamma}(1,1000) \) for \( i \in 1,2,3,4 \)
\( \text{logit}(\rho_{i}) \sim \text{Normal}(0, 1.5) \) for \( i \in A, T, 2, 3, 4 \)

\( j = \text{county}, t = \text{year}, a = \text{age group} \)

\( D_{j,t,a} = \text{deaths} \)
\( P_{j,t,a} = \text{population} \)
\( m_{j,t,a} = \text{mortality rate} \)
\( \beta_{0} = \text{global intercept} \)
\( \beta_{1} = \text{covariate effects} \)
\( X_{j,t} = \text{covariates} \)
\( \gamma_{1,a,t} = \text{age-time effects} \)
\( \gamma_{2,j} = \text{county effects} \)
\( \gamma_{3,j} = \text{county-time effects} \)
\( \gamma_{4,j} = \text{county-age effects} \)
\( \sigma_{i}^2 = \text{variance parameters} \)
\( \rho_{i} = \text{spatial correlation parameters} \)
Leroux Conditional Auto-Regressive

LCAR(\sigma^2 ,\rho) implies:

\gamma_j | \gamma_{\neq j} \sim \text{Normal}\left(\rho \cdot \sum_{k \sim j} \gamma_k / n_{\downarrow j} \cdot \rho + 1 - \rho , \sigma^2 / n_{\downarrow j} \cdot \rho + 1 - \rho \right)

where:

- \( n_{\downarrow j} \) = the number of neighbors to area \( j \)
- \( k \sim j \) = the set of areas which are neighbors to area \( j \)
- \( \rho \) = a spatial correlation parameter
- \( \sigma^2 \) = a variance parameter
Application to US counties: 1980-2013

1) Data at the county level adjusted for garbage codes and ICD9 and ICD10 mapping using GBD methods.

2) LCAR models used to estimate age-sex-specific death rates for each GBD cause – causes with less than 100 deaths over the period excluded.

3) All-cause mortality also estimated by age and sex – cause-specific estimates for each county-age-sex raked to estimates of all-cause mortality.
Change in HIV/AIDS among both sexes, age-standardized, 1980 - 2013
Diabetes mellitus among females, age-standardized, 2013

King County, Washington, 2013

<table>
<thead>
<tr>
<th></th>
<th>King County</th>
<th>Washington</th>
<th>National average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaths per 100,000 population</td>
<td>8.21</td>
<td>10.68</td>
<td>10.45</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>8.02 Lower bound</td>
<td>10.57 Lower bound</td>
<td>10.42 Lower bound</td>
</tr>
<tr>
<td></td>
<td>8.41 Upper bound</td>
<td>10.79 Upper bound</td>
<td>10.48 Upper bound</td>
</tr>
</tbody>
</table>

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Life expectancy among females at birth, 2013
Diabetes mellitus among females, age-standardized, 2013
County performance benchmarking

1) For a cause, age-standardized rates can be thought of as a function of income per capita, race, time and performance. Where performance is the variation across counties controlling for income, race and secular trends.

2) Quantifying how much each cause would be reduced and health improved overall for a county if the worst ‘performers’ moved to the level of the best or an explicit performance benchmark provides some indication of health improvements that are possible given observed variation.

3) Assumption is that level of performance achieved in one county can be replicated in another through risk factor modification, healthcare intervention and other social sector interventions. Method to identify factors (mixed methods case studies?) needs elaboration.
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Three goals for forecasting platform

1) Generate and regularly update probabilistic past trends and relationships scenario (baseline) for mortality, morbidity and population from now to 25 years in the future by age, sex, cause and GBD geographies.

2) Create a comprehensive framework to assess alternative trajectories for independent drivers in the forecast models to quantify specific scenarios of interest to relevant stakeholders.

3) For select causes (conditional on funding) build more detailed ODE or microsimulation models or incorporate existing models to answer more detail what if scenarios such as the development of new diagnostics, drugs, or vaccines or the adoption of new policies or programs.
Picking a good forecast model

1. Good out-of-sample predictive validity

2. Change in independent drivers leads to change in mortality or morbidity consistent with known evidence

3. Forecasts respect known empirical regularities in mortality
   a) Gompertz law – smooth relationship of log death rates versus age
   b) Taylor’s law – linear relationship between variance over time in log death rates with expected value of death rates

4. Forecasts for spatially related geographies do not diverge in unexplainable ways in the future.
Models for underlying mortality

1) Intercept shift model

1.1.2 Functional form

\[ \mu_{lat}^{[U]} = (\beta_{LDI} \times \log(LDI_{pclt})) + (\beta_{EDU} \times edu_{lat}) + \pi_{la}^{[U]} \]

2) Secular trend intercept shift model

1.1.2 Functional form

\[ \mu_{lat}^{[U]} = (\beta_{year} \times t) + (\beta_{LDI} \times \log(LDI_{pclt})) + (\beta_{EDU} \times edu_{lat}) + \pi_{la}^{[U]} \]

3) Piecewise model

1.2 Model

if \( t < knot_r \):

\[ \mu_{cat} = \alpha_{ca} + \beta_a X_{cat} + (\theta_{ca}^{[1]} \times t) \]

else if \( t \geq knot_r \):

\[ \mu_{cat} = \alpha_{ca} + \beta_a X_{lat} + (\theta_{ca}^{[1]} \times knot_r) + (\theta_{ca}^{[2]} \times (t - knot_r)) \]
Models for underlying mortality

1) Anchor model

1.1.2 Functional form

\[ \mu_{lat}^{[U]} = (\kappa \cdot \mu_{lat-1}^{[U]} + (\beta_{LDI} \cdot \Delta \log(LDI_{pcU})) + (\beta_{EDU} \cdot \Delta edu_{lat}) + \pi_{la}^{[U]} \]

2) Modified Girosi-King model – many options with different hyper-parameters

\[ \hat{y}_{lat}^{[U]} = \mu_{lat}^{[U]} + \sum_{j}^{T^*} y_{la,j}^{[U]} / T^* \]

\[ \mu_{lat}^{[U]} = \beta_a \hat{X}_{lat} + \theta_{lat} \]

\[ \hat{X}_{lat} = X_{lat} - \sum_{j}^{T} X_{la,j} / T \]
Global probability of premature death in women ages 30 to 70 due to cardiovascular disease

**Forecast Scenarios**
- Orange: Forecast if risk factors continue current trend
- Red: Halft the rise in fasting plasma glucose
- Blue: Halft the rise in elevated BMI
- Pink: Prevalence of elevated systolic blood pressure by 25%
- Green: Prevalence of smoking by 30%
- Green: Forecast if all risk factor targets are achieved in 2025

Probability of premature mortality due to cardiovascular diseases

Year

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US IHD, males – intercept shift

USA, Underlying OoS RMSE: 0.12533

USA, Total OoS RMSE: 0.12335

Institute for Health Metrics and Evaluation
US IHD, males – anchor model

USA, Underlying OoS RMSE: 0.163266

USA, Total OoS RMSE: 0.149072

IHME | University of Washington

Institute for Health Metrics and Evaluation
US males drop to 43rd of 188 countries in 2040 and females 54th in 2040.
Comprehensive past trends and relationships scenario of GBD 2015-2040 available in 2016
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What are the drivers of these trends?

Socio-economic inequalities
Lack of financial access to health care
Poor quality of care
Preventable causes of death
Focus on Preventable Risks

1. Reducing socio-economic inequalities, expanding insurance, improving quality are all important goals and can improve health and reduce disparities.

2. Focusing on preventable risks is likely to be more cost-effective: bigger potential benefits, neglected in many communities and less costly than other strategies.
Fund Local Innovative Strategies to Reduce Risks

1. Given the diversity of risks and communities/workplace, no simple menu of effective programs for risk reduction.
2. Local experimentation to figure out what works in a given community is likely to be necessary.
3. Fund innovative strategies and document through independent evaluation whether they work or do not.
Use the Power of Incentives

1. Reward programs that demonstrate measured changes in risks in the community they are serving by extending or increasing funding.

2. Stop funding programs that do not demonstrate progress on risk reduction.
Engage Medical Providers in Accountable Care

1. Many leading risks (tobacco, blood pressure, blood sugar, cholesterol, alcohol intake, physical inactivity, components of diet) there is an important role for primary health care.

2. Need to broaden the notion of accountability beyond providing high quality care to encompass achieving risk reduction in partnership with patients.

3. Forging a connection between healthcare provision and progress for individuals and communities in health outcomes will be critical for the future.
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Integrated Surveillance Systems for Health

• Capture data through multiple systems:
  o Complete vital registration
  o Annual community sampling to collect key types of missing information
  o Communicable disease reporting and laboratory confirmation
  o Health service encounter data: primary care, ambulatory specialists services, community outreach, emergency services, inpatient admissions, pharmacy use.
  o Census or sample of provider resources and activities
Integrated Surveillance Systems for Health (Con’t)

• Unique identifiers and record linkages:
  o Trace the experience of an individual over time
  o Connect socio-demographic, behavioral risk, biometric, intervention delivery and outcome data
  o Use of unique identifiers for data linkage must be supported by the applicable legal framework

• Optimal design of variables captured at each point:
  o Most data collection platforms are stand-alone
  o Across multiple platforms, individuals may report the same information multiple times (e.g., socio-demographic data)
  o Linking digital data capture with unique identifiers can optimize the process of data collection
Getting the most from each data collection platform

• **Vital registration:** strengthen data-capture and collection systems and make sure legal and other incentives work in different community contexts

• **Health service encounter data:**
  - If legally permissible, link unique identifiers and service encounters
  - Consider frequency of data collection for different variables
  - Assess national burden of disease to establish intervention priorities
  - Pay close attention to the impact of financial incentives on data collection practices
Getting the most from each data collection platform (Con’t)

• **Communicable disease reporting:**
  - Requires special attention in terms of timeliness of assessment and reporting and laboratory confirmation
  - Digital data capture with unique identifiers can serve the purpose of communicable disease surveillance (assuming laboratory confirmation is included in data capture)

• **Annual community sampling:**
  - Community sampling can better target individuals who are not in regular contact with the health system by linking health service encounters or vital registration data of individuals who do have regular contact with the health system
  - Substantial need for standardized modules for community samples for different topic areas
Getting the most from each data collection platform (Con’t)

• **Provider surveys or censuses:**
  - Provider information is not naturally captured in individual encounter data systems
  - Provider surveys or censuses ideally link provider information with health service encounter and community surveys
  - Engagement of private sector providers requires additional consideration of the legal and incentive environment
Evolution towards an integrated surveillance system

• Integrated surveillance systems are possible with current technologies
• Legacy systems and legal / political hurdles may slow the integration of surveillance systems in some countries
Key Challenges

Adequate funding
Political will
Business model
Examples from IHME

Monitoring Disparities in Chronic Conditions
  o A national integrated surveillance system to monitor disparities in non-communicable diseases
Main Components

- Medical Records
- Population Profiles
- Administrative Records
- Survey

Institute for Health Metrics and Evaluation
US Surveillance

NHANES
NHIS
BRFSS
NIS
Etc. . . .
Thank you!

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