Incorporating inequity aversion into disease modeling

IDM Symposium Keynote, May 23, 2023

Anna Bershteyn, PhD
Assistant Professor of Population Health
New York University Grossman School of Medicine
Anna.Bershteyn@NYULangone.org
Overview

- Warm-up thought experiment
- Methods for defining & quantifying inequity
- Worked example: COVID-19 vaccine distribution in NYC
- Implications for IDM disease focus areas
Imagine you have 2 patients but only 1 dose of medicine

- Patient #1 is dying at age 90.
- Patient #2 is dying at age 20.
- Medicine would add 1 year of life with perfect health.
- You only have medicine to treat 1 patient.

To whom would you rather give the medicine?
  – Assume no difference in social roles, economic productivity, etc.
Imagine you have 2 patients but only 1 dose of medicine

- Pt #1 dying at age 90 – medicine would add \textbf{1 year} in perfect health
- Pt #2 dying at age 20 – medicine would add \textbf{1 month} in perfect health

- To whom would \textbf{you} rather give the medicine?
Imagine you have 2 patients but only 1 dose of medicine

- Pt #1 dying at age 90 – medicine would add 1 year in perfect health
- Pt #2 dying at age 20 – medicine would add 9 months in perfect health

To whom would you rather give the medicine?
Defining inequality aversion

• If you initially preferred giving medicine to Patient 2, you have **inequality aversion**, i.e., you dislike inequality in life expectancy.

• Continue asking questions to find your point of indifference \(\rightarrow\) measure your personal level of inequality aversion.

• Surveys & decision analyses \(\rightarrow\) measure populations’ inequality aversion.

• Inequality aversion been quantified using surveys in UK and Canada
  – UK’s > Canada’s by 2-3x
  – Few studies in US or LMIC
  – Many dependencies still to be explored, e.g., dimensions of inequality, own experiences vs. hypothetical, domestic vs. international…
But wait... what is equality?
But wait... what is equality?

Inequality
Unequal access to opportunities

Equality?
Evenly distributed tools and assistance
But wait… what is equality? Equity?

**Inequality**
Unequal access to opportunities

**Equality?**
Evenly distributed tools and assistance

**Equity**
Custom tools that identify and address inequality
But wait… what is equality? Equity? Justice?

Inequality
Unequal access to opportunities

Equality?
Evenly distributed tools and assistance

Justice
Fixing the system to offer equal access to both tools and opportunities

Equity
Custom tools that identify and address inequality
Inequality aversion does not mean discarding utilitarian values

- Equally distributed equivalents (EDEs) adjust utilitarian outcomes for how equally or unequally they are distributed
  - Examples of outcomes: life expectancy, QALYs, DALYs…
  - Examples of unequal distribution: by nationality, by sex, by SES…
- Use utilitarian modeling methods to optimize EDE-adjusted outcomes
- Customizable level of inequality aversion → “strength” of adjustment
Atkinson’s Index: one option for inequality adjustment

\[
EDE_H = \bar{H} \left[ \sum_g \left( \frac{H_g}{\bar{H}} \right)^{1-\epsilon} P_g \right]^{1/(1-\epsilon)}
\]

- \(\bar{H}\) is the mean level of health for the entire population.
- \(H_g\) is the level of health for subgroup \(g\).
- \(\epsilon\) is the Atkinson inequality aversion parameter.
  - The greater the value, the greater the aversion to inequality.
- \(P_g\) is the proportion of the population in subgroup \(g\).

- If there is no inequality aversion (\(\epsilon = 0\)), then \(EDE_H = \bar{H}\)
- If there is inequality aversion (\(\epsilon > 0\)), then \(EDE_H > \bar{H}\)
  - Extent to which one would “sacrifice” some amount of net utilitarian benefit to reduce inequality
- Empirically assessed inequality aversion
  - \(\epsilon \approx 10\) in survey of British general public
  - \(\epsilon \approx 3-6\) empirically assessed in Canadian general public
  - Not yet empirically reliably in United States general public
  - Wide-open field with many questions, e.g., domestic vs. international \(\epsilon\)?

Motivating example: COVID-19 vaccine distribution in NYC

- Vaccines became available in early 2021 with limited stocks
- Neighborhoods with high social vulnerability had highest mortality but accrued the most immunity.
Goals with vaccine roll-out: achieving efficiency vs. equity

- NYU team has been the NYC’s main COVID-19 transmission modeling partner since March 2020
  - Technical assistance for model setup from IDM: Dan Klein, Prashanth Selvaraj, Niket Thakkar
  - Main stakeholder: NYC Department of Health and Mental Hygiene (DoHMH)
  - Additional stakeholders: City hall, DoE, Medical examiners’ office, local hospitals
  - Meeting up to daily to inform real-time policy decisions

- Early 2021 policy challenge: cannot vaccinate instantaneously across all neighborhoods

- NYC health department had two goals with vaccine roll-out
  1. Minimize COVID-19 deaths → Maximize health benefits
  2. Minimize inequality in death rate across neighborhoods → Maximize health equity

- Key question: How to balance the desire for efficiency vs. equity?
  - The hardest-hit neighborhoods accrued more immunity → fewer people susceptible to infection
NYC COVID modeling methods: augmented SEIR model

- Susceptible-Exposed-Infectious-Recovered (SEIR) model widely used for respiratory infections
- Included community transmission ($\beta$SI) and secondary transmission within households
- Neglected re-infections and vaccine waning, which were less common pre-Omicron
- Stratified by NYC neighborhood (no inter-neighbourhood transmission)
- Included effects of social distancing & contact tracing
- Fit to NYC Department of Health and Mental Hygiene (DoHMH) public and internal data including daily cases, hospitalizations, ICU occupancy, and deaths

\[\text{Susceptible (S)} \rightarrow \text{Exposed (E)} \rightarrow \text{Infectious (I)} \rightarrow \text{Recovered (R)}\]
NYC COVID modeling assumptions & scenarios

**Assumptions**

- **Baseline assumption of 95% efficacy**
  - Efficacy begins on D11
  - Same efficacy against COVID-19 disease as against acquisition/transmission
- **Vaccine rollout 50,000 per day**
- **Willingness to receive vaccine**
  - 90% of healthcare workers (HCW)
  - 70% of non-HCW
  - Vaccine hesitancy assumed to be similar across neighborhoods

**Vaccination scenarios**

- **NYC neighborhoods categorized into two groups based on cumulative deaths until Dec 14th, 2020**
  - Higher prior exposure
  - Lower prior exposure
- **Vaccine distribution strategies**
  - **No prioritization**: Vaccinate at uniform rate across neighborhoods
  - **Exposure-based prioritization**: First vaccinate neighborhoods with highest case and death counts
- **Health outcomes**
  - Cumulative infections and deaths
  - EDE-adjusted cumulative infections and deaths at different levels of inequality aversion
Model results: NYC cumulative infections by vaccine distribution strategy

- No Vaccination
  - All neighborhoods: 1.77M
  - Neighborhoods with higher prior exposure: 1.03M
  - Neighborhoods with lower prior exposure: 0.74M

- No prioritization
  - All neighborhoods: 1.10M
  - Neighborhoods with higher prior exposure: 0.59M
  - Neighborhoods with lower prior exposure: 0.51M

- Exposure-based prioritization
  - All neighborhoods: 1.42M
  - Neighborhoods with higher prior exposure: 0.97M
  - Neighborhoods with lower prior exposure: 0.45M

*Values indicate cumulative infections since Dec 15th, 2020*
Model results: NYC cumulative deaths by vaccine distribution strategy

No Vaccination

No prioritization

Exposure-based prioritization

*Values indicate cumulative deaths since Dec 15th, 2020
Model results: NYC cumulative deaths adjusted for inequality aversion

- At $\varepsilon = 0$, “no prioritization” is preferable with the lowest cumulative deaths.
- At $\varepsilon \sim 2$, “exposure-based prioritization” becomes preferable.
- At $\varepsilon \sim 10$, “exposure-based prioritization” is strongly preferable.

![Bar chart showing inequality-adjusted cumulative deaths per 100k NYC residents until August 31, 2021.](chart.png)
Summary of motivating example

• Without inequality aversion, no prioritization of vaccination would have averted the greatest number of deaths and infections in NYC after vaccine roll-out.

• At moderate inequality aversion ($\varepsilon \sim 2$), exposure-based prioritization of vaccine distribution became preferrable.

• **Conclusion**: Societies with moderate or greater inequality aversion may consider vaccine prioritization based on prior disease burden to reduce health inequity.

• **Limitations**: This simple early model (pre-Omicron) did not account for re-infections or waning vaccine efficacy, which have increased in the Omicron era. Re-infection would have made exposure-based prioritization more effective.
Discussion: implications for IDM focus disease areas

• Some disease areas could have a genuine tension between equity vs. efficiency
  – **HIV**: drastically shortens LE, but cost to avert 1 DALY >> marginal productivity of healthcare systems

• Other disease areas are less likely to face a tension between efficiency and equity
  – **TB** concentrates in the most disadvantaged populations

• Still other disease areas have faced challenges conceptualizing equity/equality
  – **Malaria** “equal” distribution of bednets is not necessarily more equitable or efficient

• Implications for this audience:
  – EDEs can avoid false dichotomies and quantitatively balance efficiency vs. equity
  – Future modeling research could apply EDE adjustment to utilitarian modeling outcomes
  – Future surveys could measure $\varepsilon$ in different groups, domestic vs. global applications…
Acknowledgements

• NYU Grossman School of Medicine, Department of Population Health
  Hae-Young Kim
  R. Scott Braithwaite
  Jessica McGillen
  Yao-Rui Yeo

• Institute of Disease Modeling
  Daniel Klein
  Niket Thakkar
  Prashanth Selvaraj

• NYC Department of Health and Mental Hygiene
  Jaimie Shaff
  Julia Sisti
  Charles Ko
  Radhika Wikramanayake
  Sharon Greene
  Donald Olson
  Remle Newton-Dame

• NYC Office of Mayor
• Centers for Disease Control and Prevention
  Demetre Daskalakis
NYU Team

Hae-Young Kim, PhD
Assistant Professor

Masabho Milali, PhD
Research Scientist

Daniel T Citron, PhD
Research Scientist

David Kaftan
Research Scientist

Ingarda Platais
Project Manager

Frey Assefa
Data Analyst

Shiying You
PhD Candidate

Afia Osei-Mtansah
PhD Candidate

Julia Lam
Research Coordinator

Collaborators around
the world!