Incorporating inequity aversion into disease modeling

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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 **1 year** in perfect health
- Pt #2 dying at age 20 – medicine would add **1 month** in perfect health

- To whom would you rather give the medicine?

Imagine you have 2 patients but only 1 dose of medicine

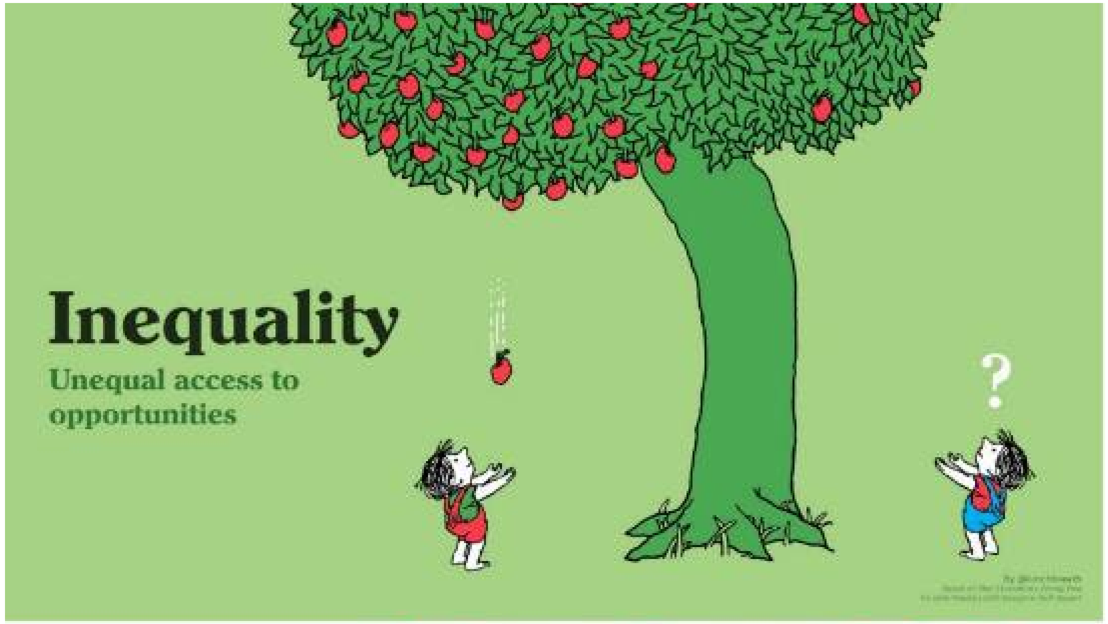
- Pt #1 dying at age 90 – medicine would add **1 year** in perfect health
- Pt #2 dying at age 20 – medicine would add **9 months** in perfect health

- 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 → measure your personal level of inequality aversion
- Surveys & decision analyses → 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?



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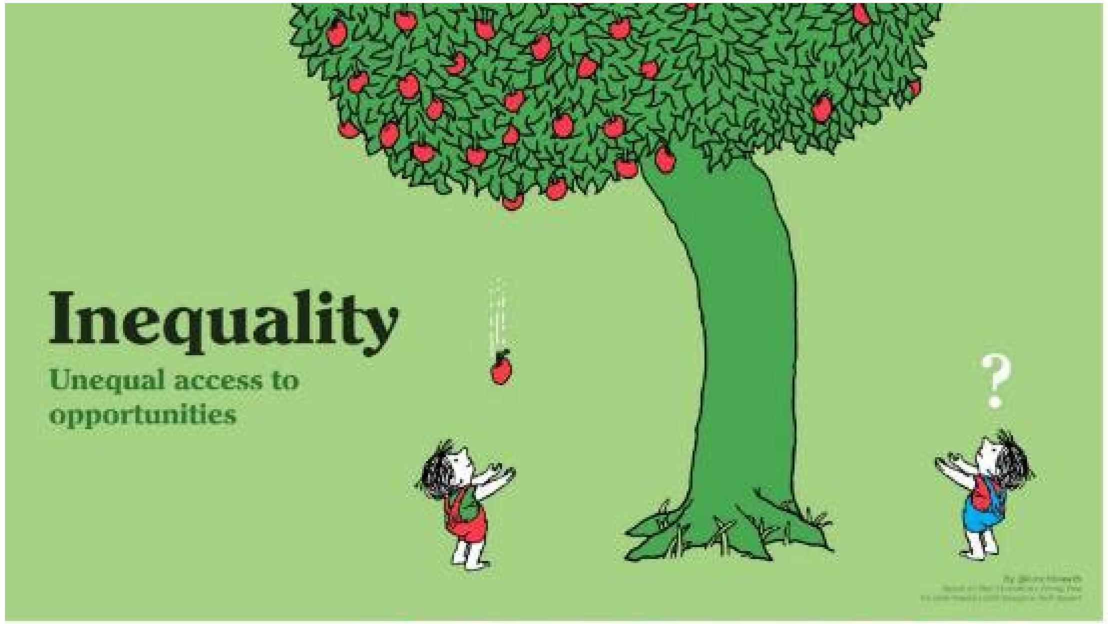
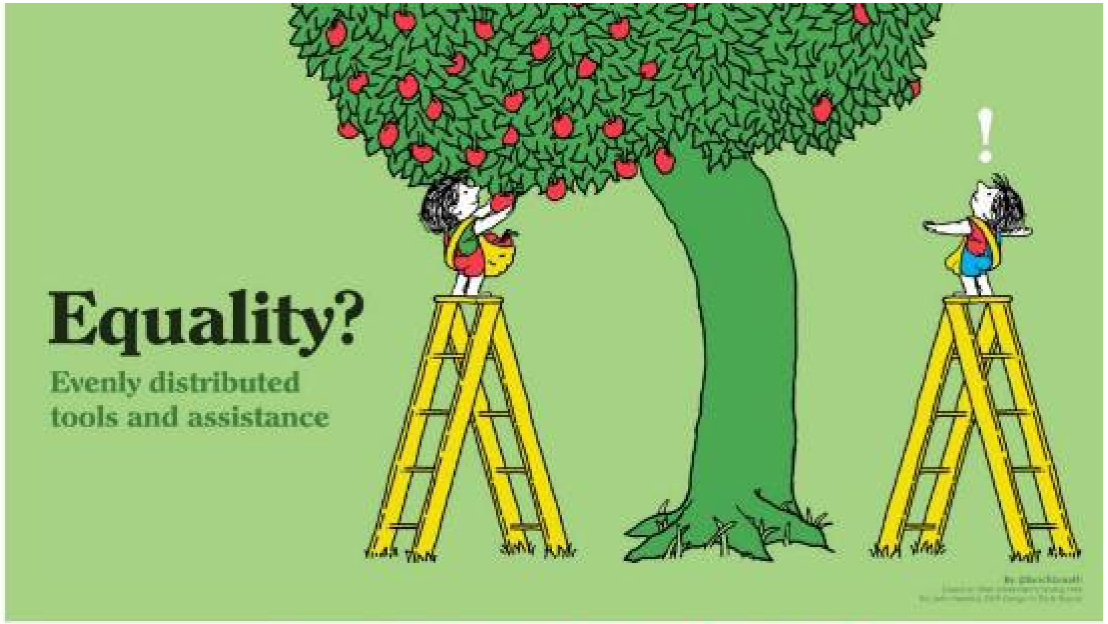
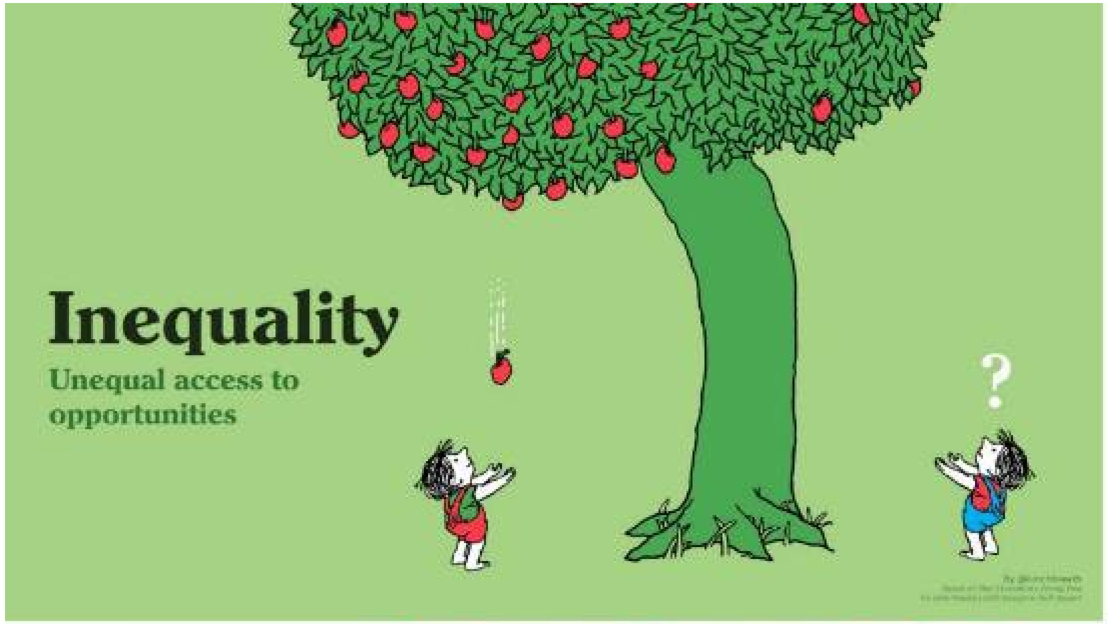
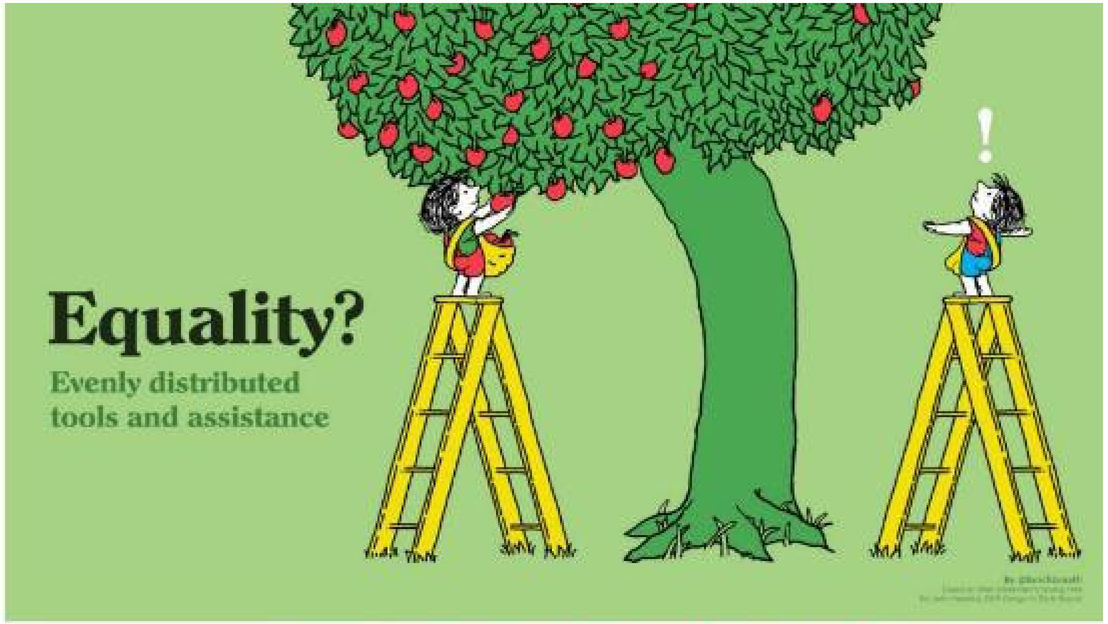
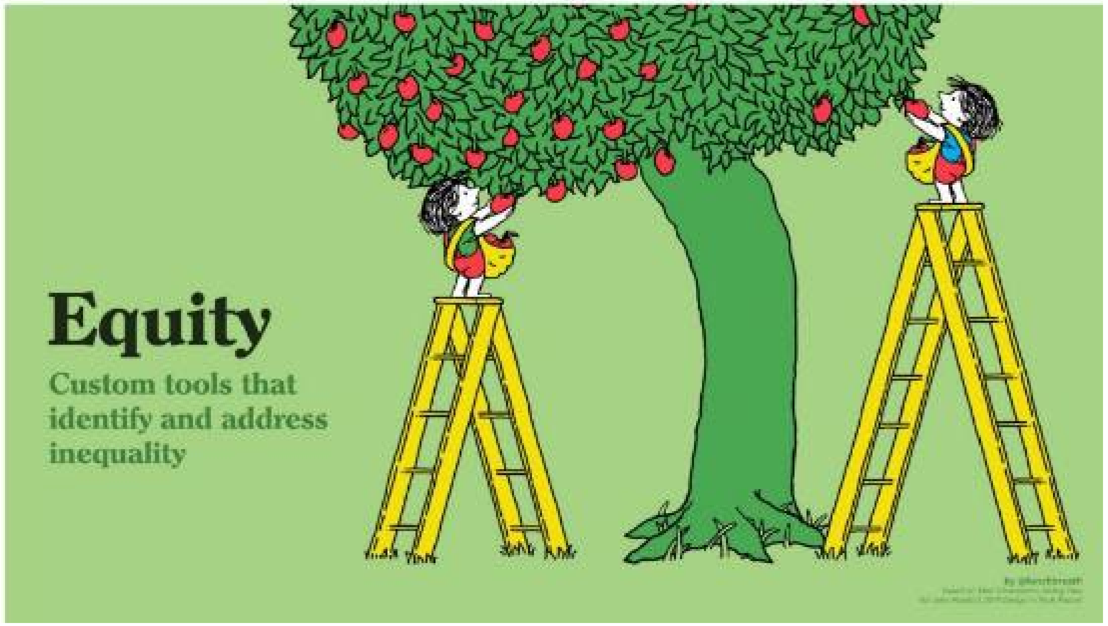




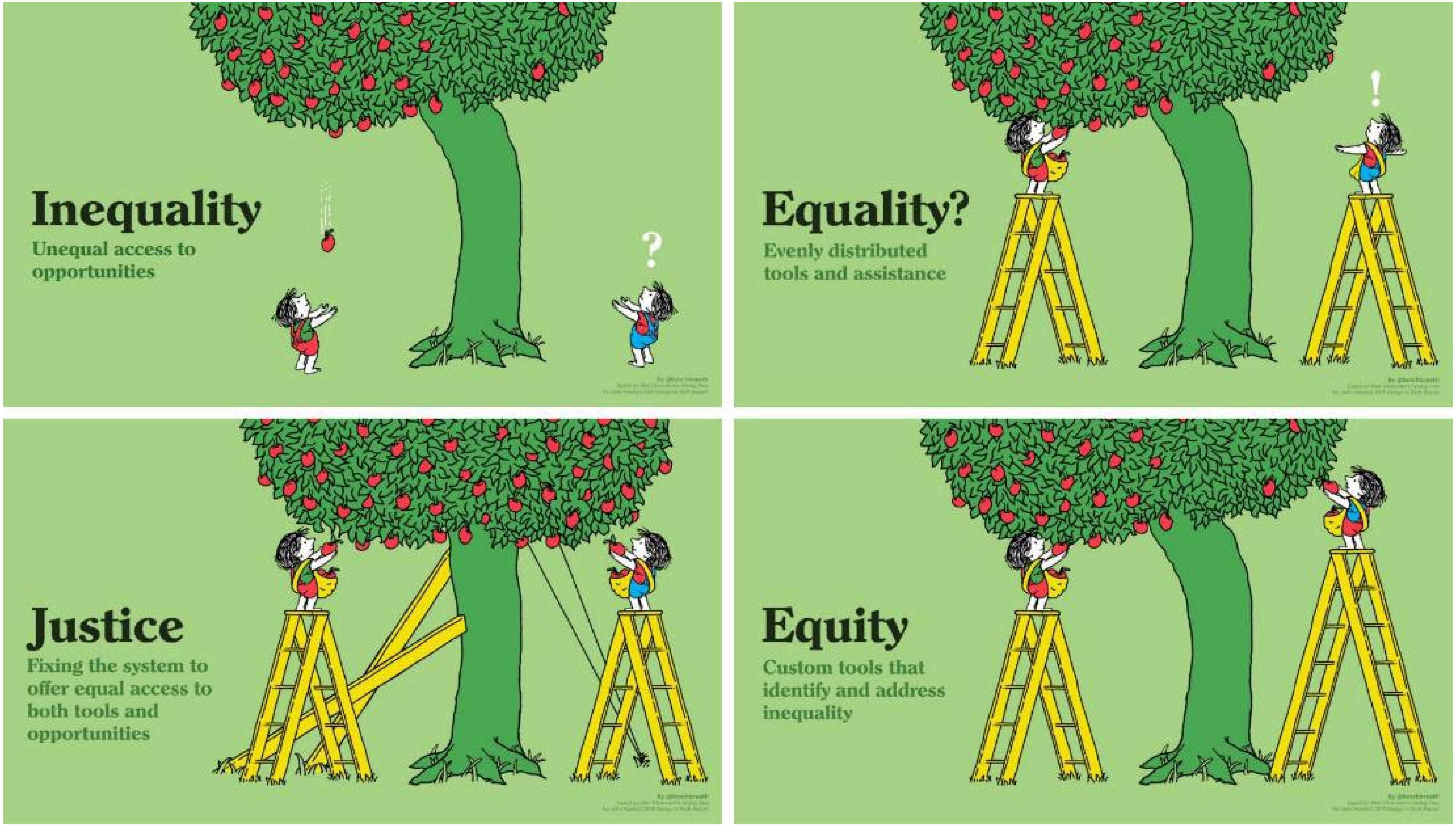
But wait… what is equality? Equity?







But wait… what is equality? Equity? Justice?



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

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

$\bar{H}$ is the mean level of health for the entire population.

H_g is the level of health for subgroup *g*.

ε 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*.

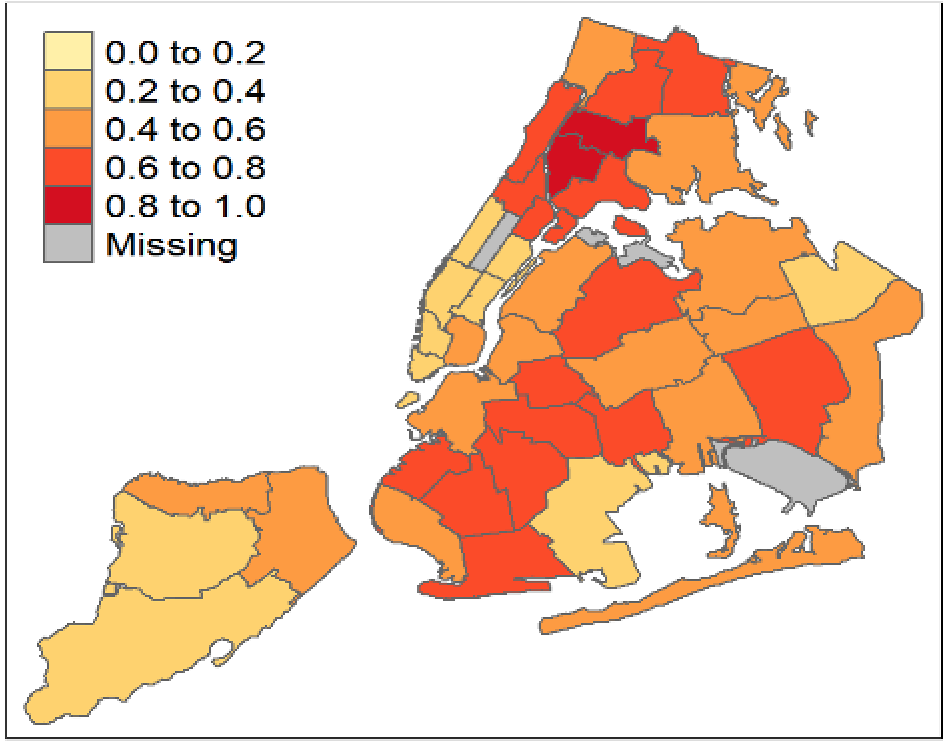
- If there is no inequality aversion ($\varepsilon = 0$), then $EDE_H = \bar{H}$
- If there is inequality aversion ($\varepsilon > 0$), then $EDE_H > \bar{H}$
  - Extent to which one would "sacrifice" some amount of net utilitarian benefit to reduce inequality
- Empirically assessed inequality aversion
  - $\varepsilon \approx 10$ in survey of British general public
  - $\varepsilon \approx$ 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 ε?

Robson, M. et al. (2017). Health Economics, 26(10), 1328-1334.

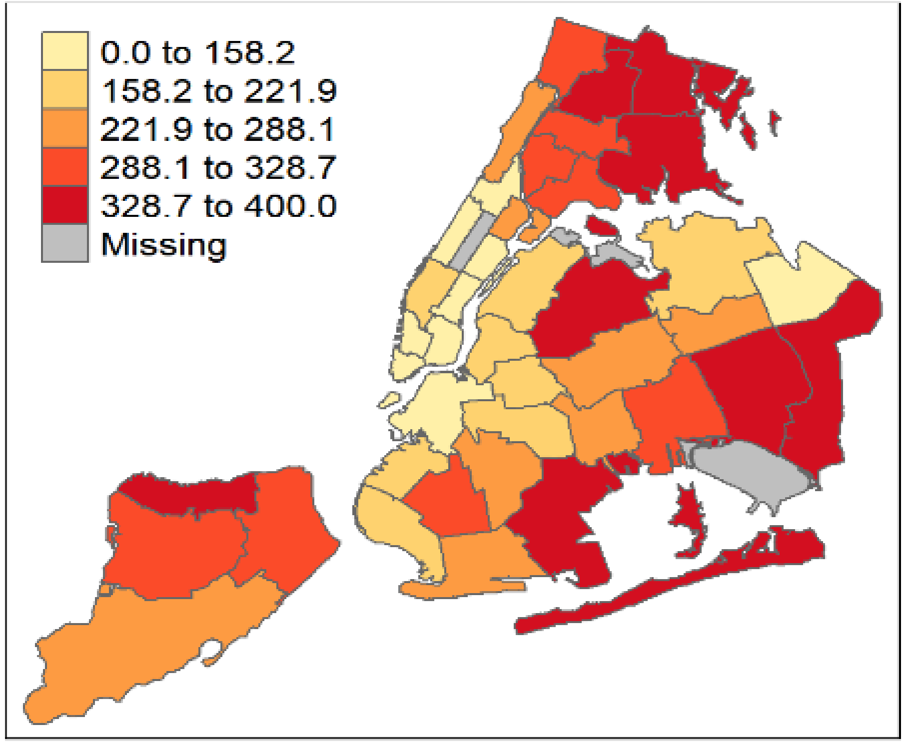
Motivating example: COVID-19 vaccine distribution in NYC

- Vaccines became available in early 2021 with limited stocks
- Neighborhoods with high social vulnerability had highest mortality but accrued the most immunity.

Social Vulnerability Index



COVID-19 death rate per 100K residents



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

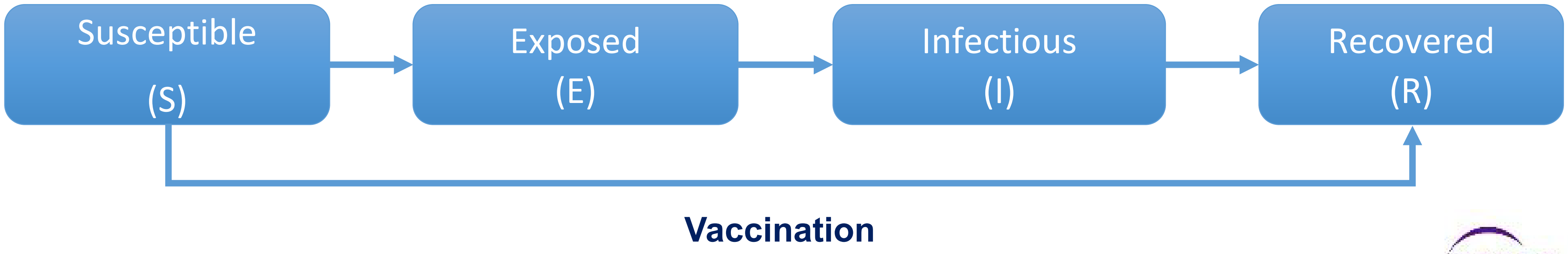
- Early 2021 policy challenge: cannot vaccinate instantaneously across all neighborhoods

- 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 (βSI) 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



Kim et al. (2022). Sci Rep 12, 10312.

NYC COVID modeling assumptions & scenarios

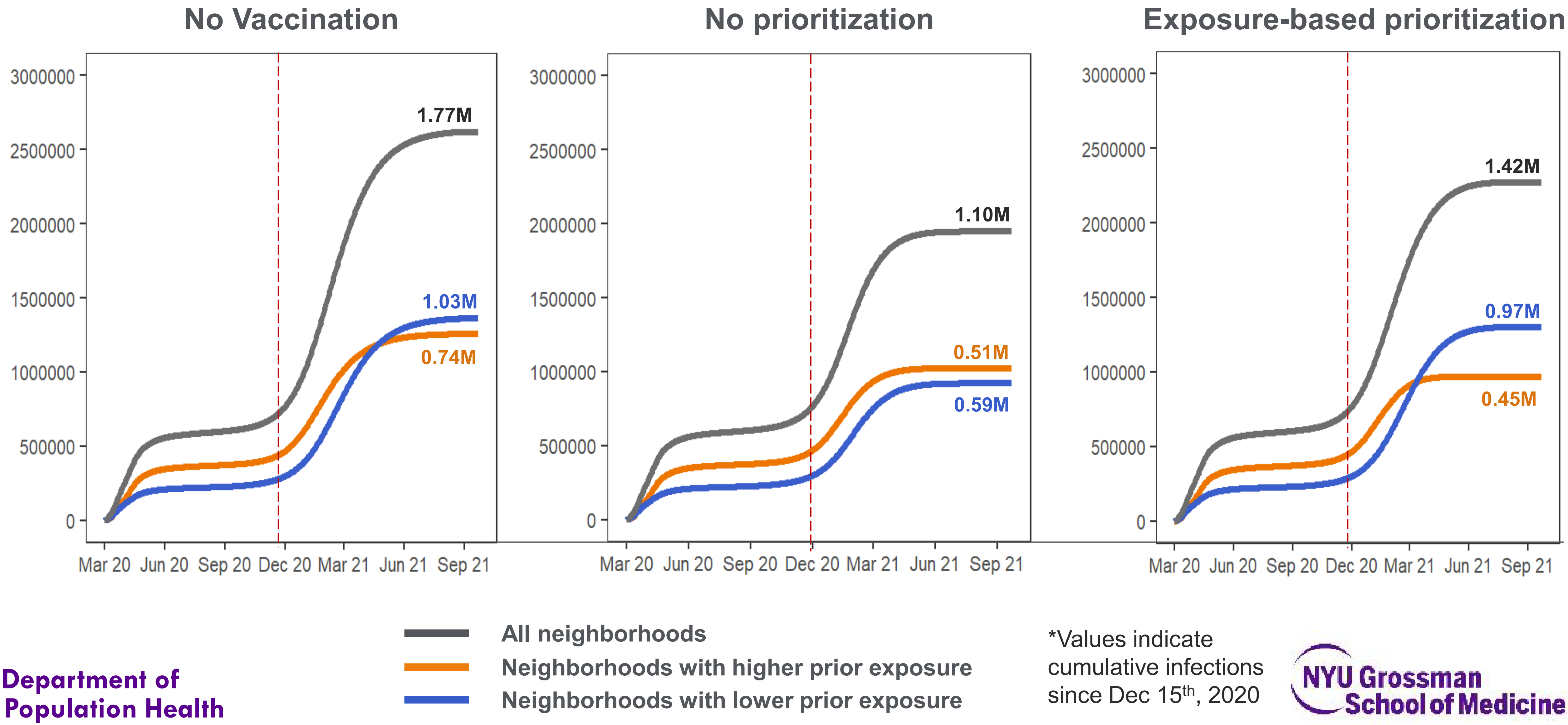
Assumptions

- **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



*Values indicate cumulative infections since Dec 15th, 2020

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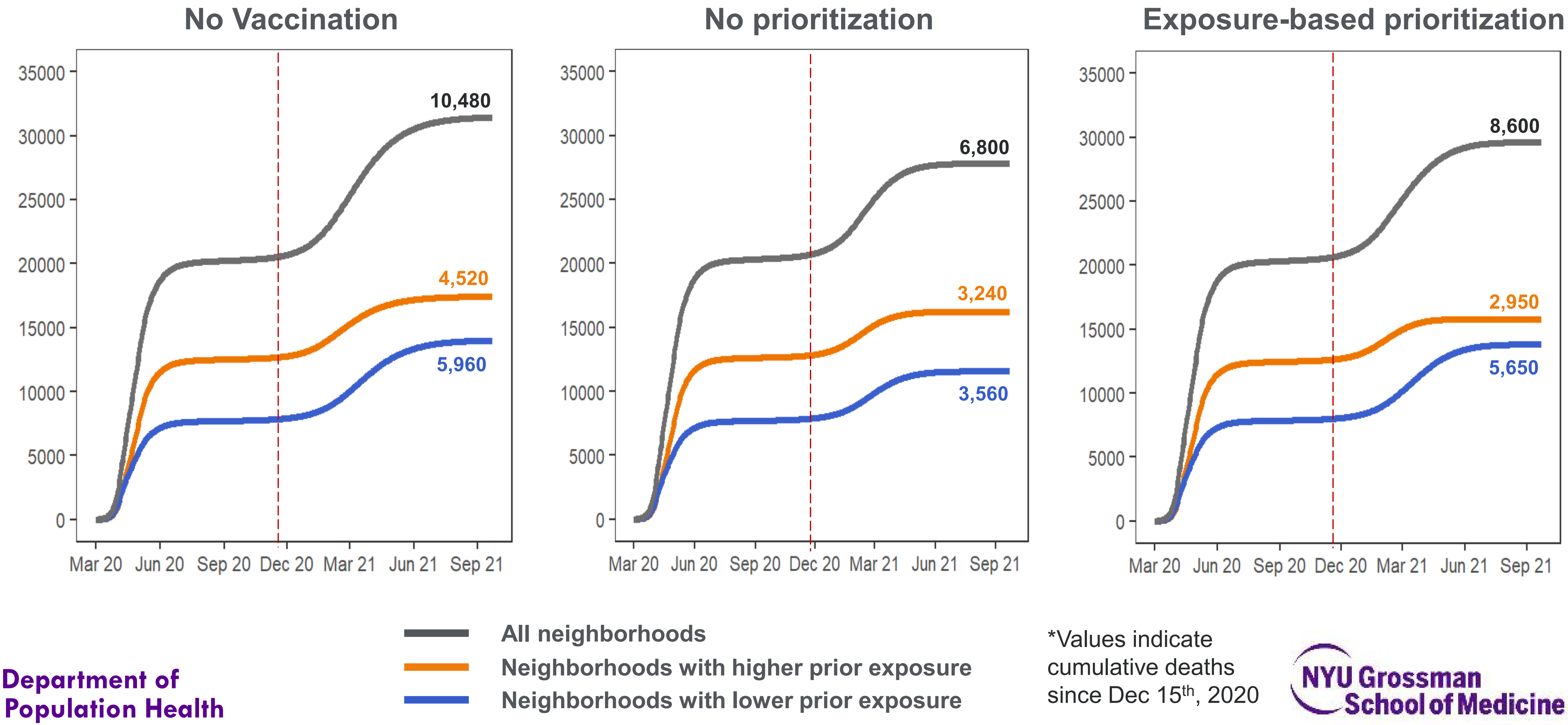
Model results: NYC cumulative deaths by vaccine distribution strategy



*Values indicate cumulative deaths since Dec 15th, 2020

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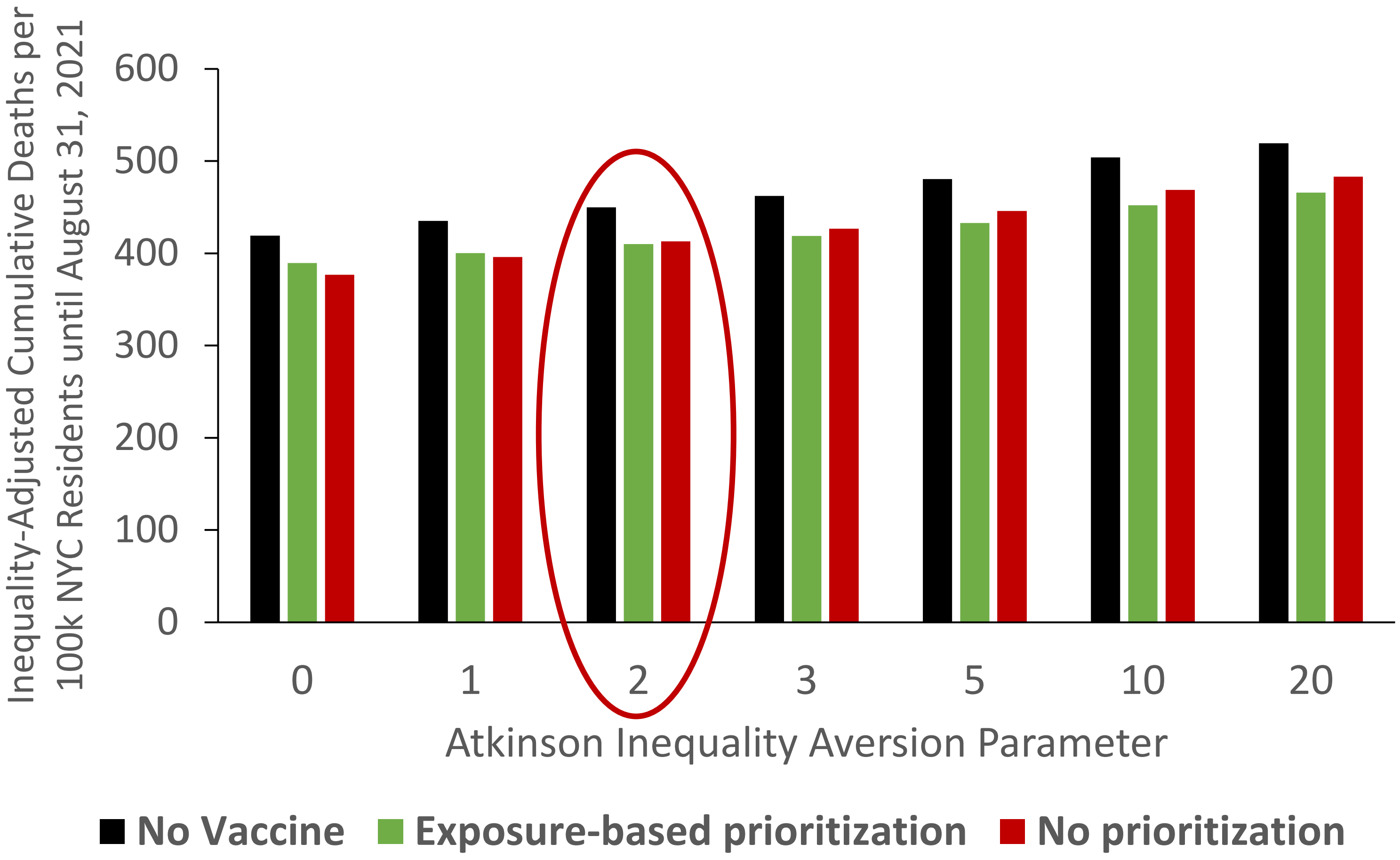
Model results: NYC cumulative deaths adjusted for inequality aversion



- At ε = 0, "no prioritization" is preferable with the lowest cumulative deaths.
- At ε ~2, "exposure-based prioritization" becomes preferable.
- At ε ~ 10, "exposure-based prioritization" is strongly preferable.

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 (ε ~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 ε in different groups, domestic vs. global applications…

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Collaborators around the world!