Oceania Chapter
of the System Dynamics Society

Systems Thinking & Modelling Symposium

How to quantify pandemic inequality?

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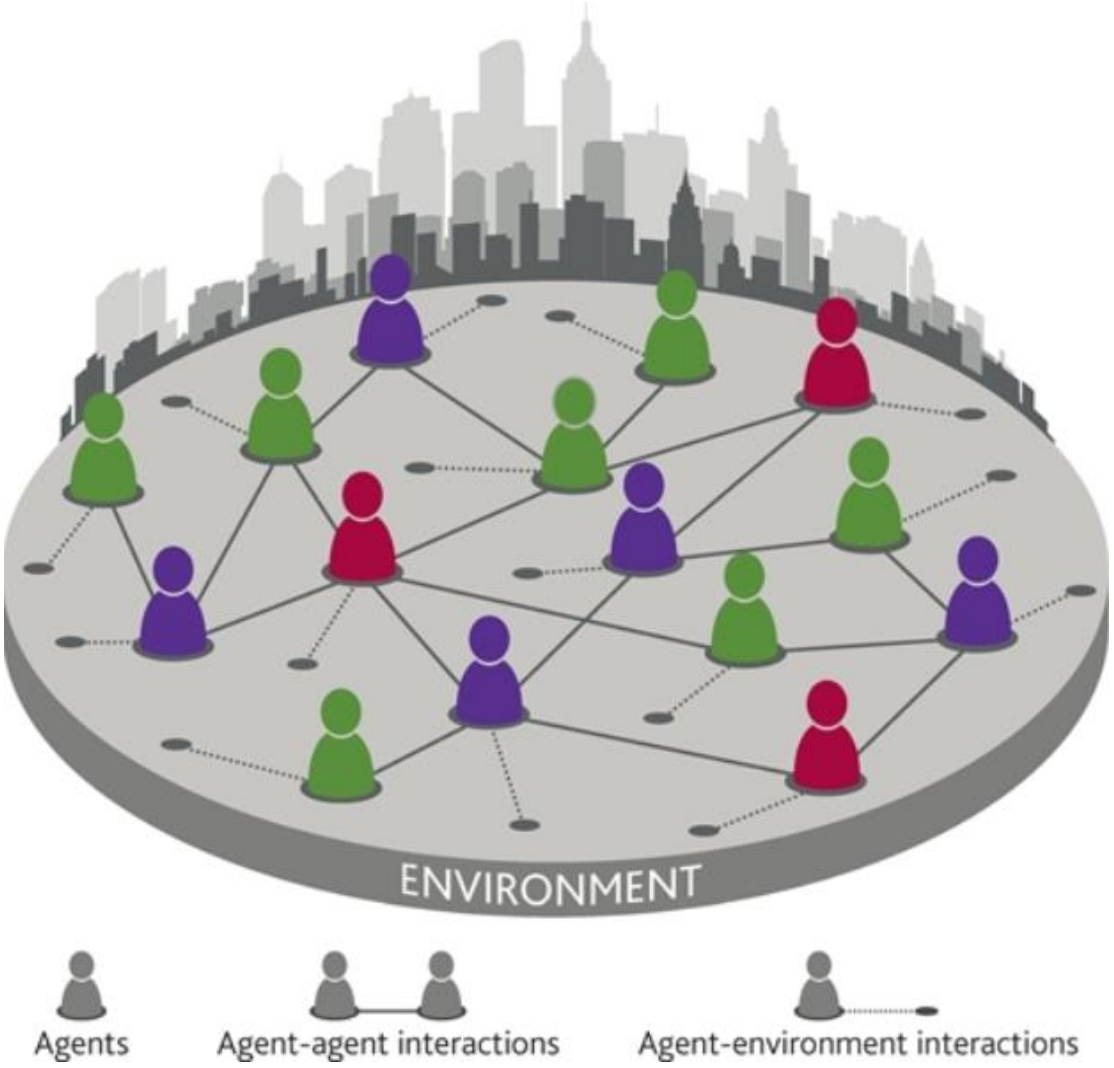
Brief outline

- SDM vs ABM
- Pandemic modelling with ABM
  - census-calibrated demographics
  - context-dependent infection transmission
  - public health interventions (NPI and vaccination)
- Pandemic inequality

Agent-based modelling (ABM)



https://www.bankofengland.co.uk/quarterly-bulletin/2016/q4/agent-based-models-understanding-the-economy-from-the-bottom-up

SDM vs ABM

Criteria	SDM	ABM
Approach	Causal structure of the system produces behaviour	Agent interactions produce emergent system behaviour
Representation	Stocks and flows	Agents and interactions
Feedback	Explicit	Implicit
Type of model	Qualitative / Quantitative	Quantitative
Resolution	Homogenised entities, continuous policy pressures	Individual entities, attributes, decisions and discrete events
Processes	Continuous nonlinear processes	Discrete linear processes
Mathematics	Differential equations	Statistical distributions
System focus	Holistic view, wider focus, aggregate	Analytic view, narrow focus, detailed
Purpose	Gaining conceptual understanding	Precise prediction
Complexity	Increases linearly with model size	Increases exponentially with model size

Adapted from: Introduction of System Dynamics. Eugenia Jenkins. https://slideplayer.com/slide/10521919/

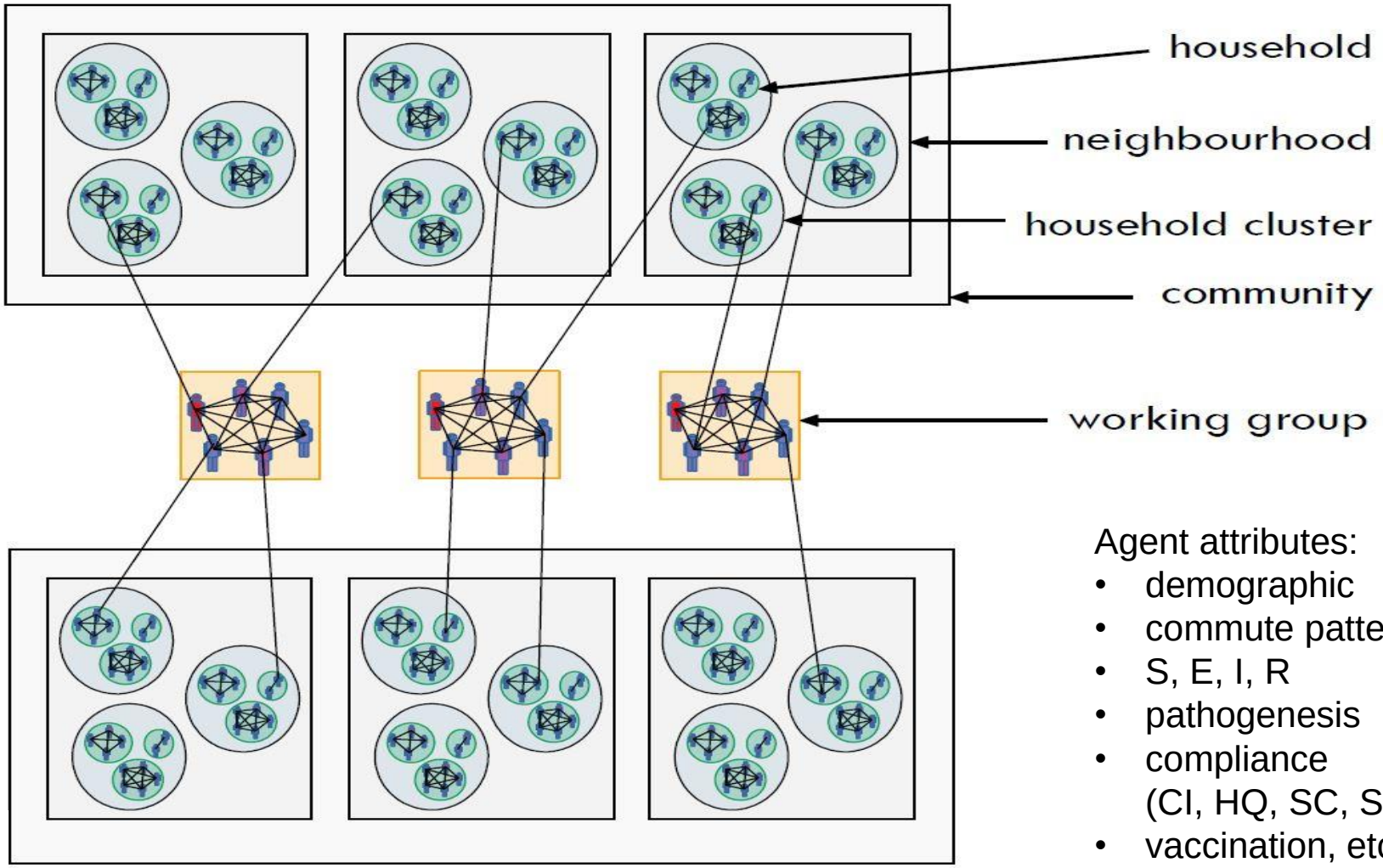
COVID-19 pandemic modelling using ABM

- Large-scale high-resolution agent-based models
  - *demographics*: from census based data to agents
  - *mobility*: travel patterns including long-distance
  - *infection*: epidemiology

- AMTraC-19: **A**gent-based **M**odel of **Tra**nsmission and **C**ontrol of the COVID-**19** pandemic in Australia (~ 24M agents)

- Model calibration and validation during COVID-19 pandemic
  - 1st stage, ancestral (March – June 2020)
  - 2nd stage, ancestral (July – September 2020)
  - 3rd stage, Delta (June – November 2021)
  - 4th stage, Omicron (December 2021 – November 2022)

“Same storm, different boats”



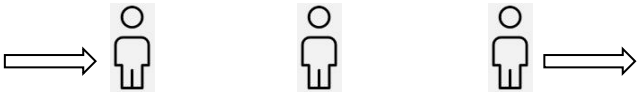
Agent attributes:

- demographic
- commute pattern
- S, E, I, R
- pathogenesis
- compliance (CI, HQ, SC, SD)
- vaccination, etc.

C. Zachreson, K. M. Fair, N. Harding, M. Prokopenko, Interfering with influenza: nonlinear coupling of reactive and static mitigation strategies, *Journal of Royal Society Interface*, 17(165): 20190728, 2020.

Features of AMTraC-19

- ~24M stochastically generated agents (Census, ABS & ACARA data)
- household size and composition vary across different local areas
- commuting patterns between residence and work / study
- flexible infection seeding scenarios
- transmission within mixing contexts
- different symptomatic ratios for children and adults
- vaccination rollout with two vaccines



- vaccine efficacy split across components (infection, symptoms, transmission)
- varying social distancing (“stay-at-home” restrictions)

S. L. Chang, N. Harding, C. Zachreson, O. M. Cliff, M. Prokopenko, Modelling transmission and control of the COVID-19 pandemic in Australia, *Nature Communications*, 11, 5710, 2020.

C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *The Lancet Regional Health – Western Pacific*, 14: 100224, 2021.

Population partitions: residential areas and destination zones

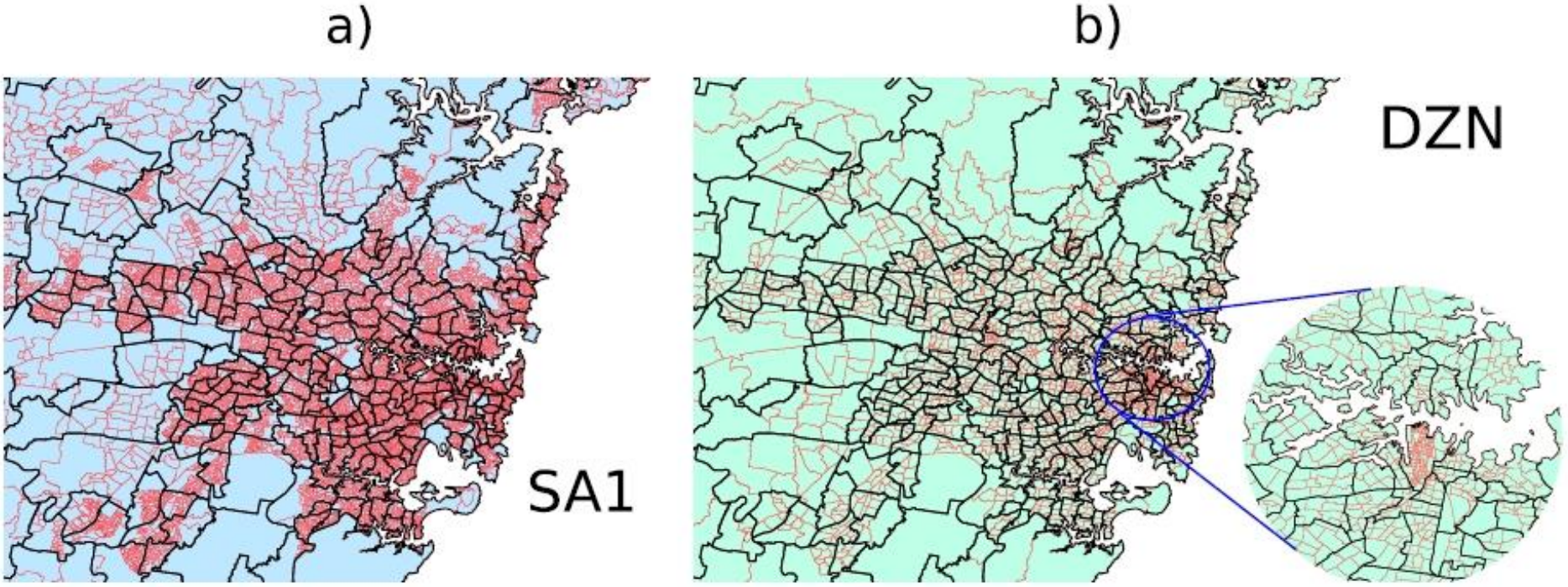
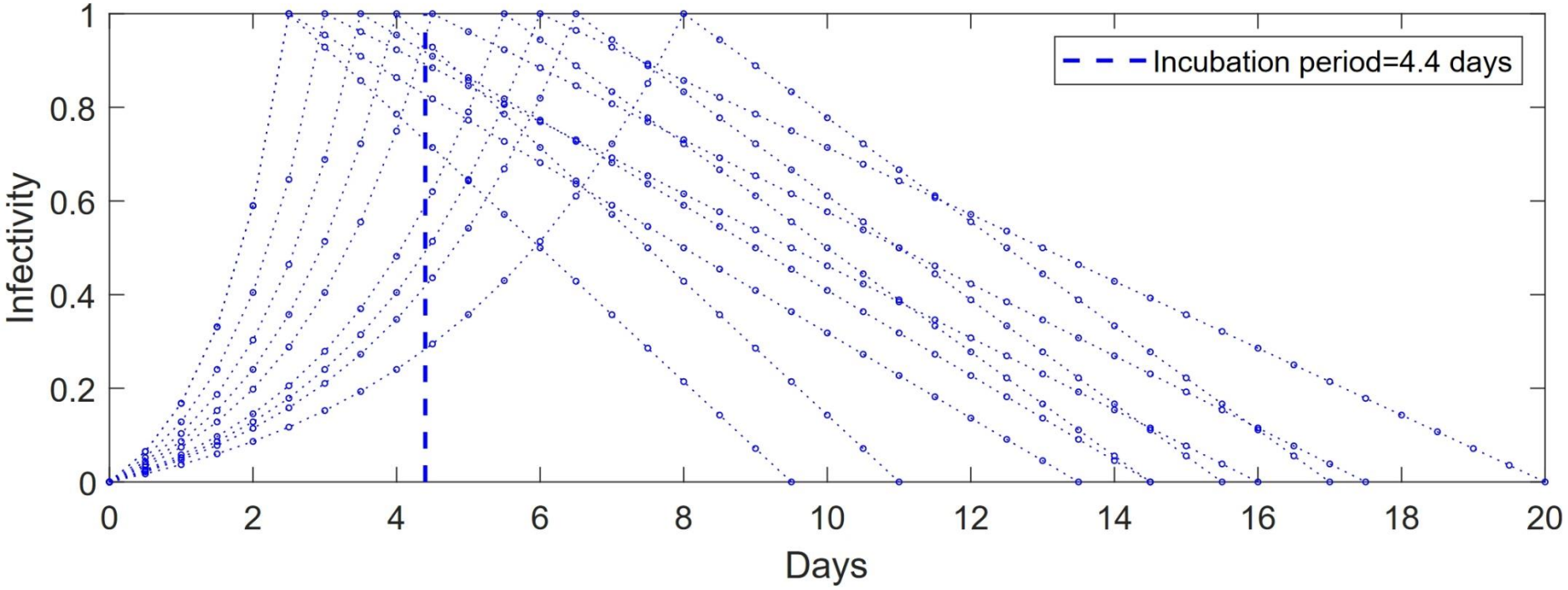


Fig. 1 Maps of the Greater Sydney region illustrating the distribution of population partitions. (**a**) A map of the Greater Sydney region showing SA2 (black) and SA1 (red) population partitions. (**b**) A map of the same area showing SA2 (black) and DZN (red) partitions. The inset in (**b**) zooms in on the Sydney central business district to illustrate the much denser packing of DZN partitions in that area.

K. M. Fair, C. Zachreson, M. Prokopenko, Creating a surrogate commuter network from Australian Bureau of Statistics census data, *Scientific Data*, 6, 150, 2019.

Natural history of the disease (the Delta variant)



	R_0	T_{gen} (days)	T_{inc} (days)	T_{rec} (days)
Mean	6.2	6.93	4.4	10
95% CI	6.16 – 6.23	6.87 – 6.99	3.9 – 5.0	range: 7 – 14 (uniform)

S. L. Chang, O. M. Cliff, C. Zachreson, M. Prokopenko, Simulating Transmission Scenarios of the Delta Variant of SARS-CoV-2 in Australia, *Frontiers in Public Health,* 10, 10.3389/fpubh.2022.823043, 2022.

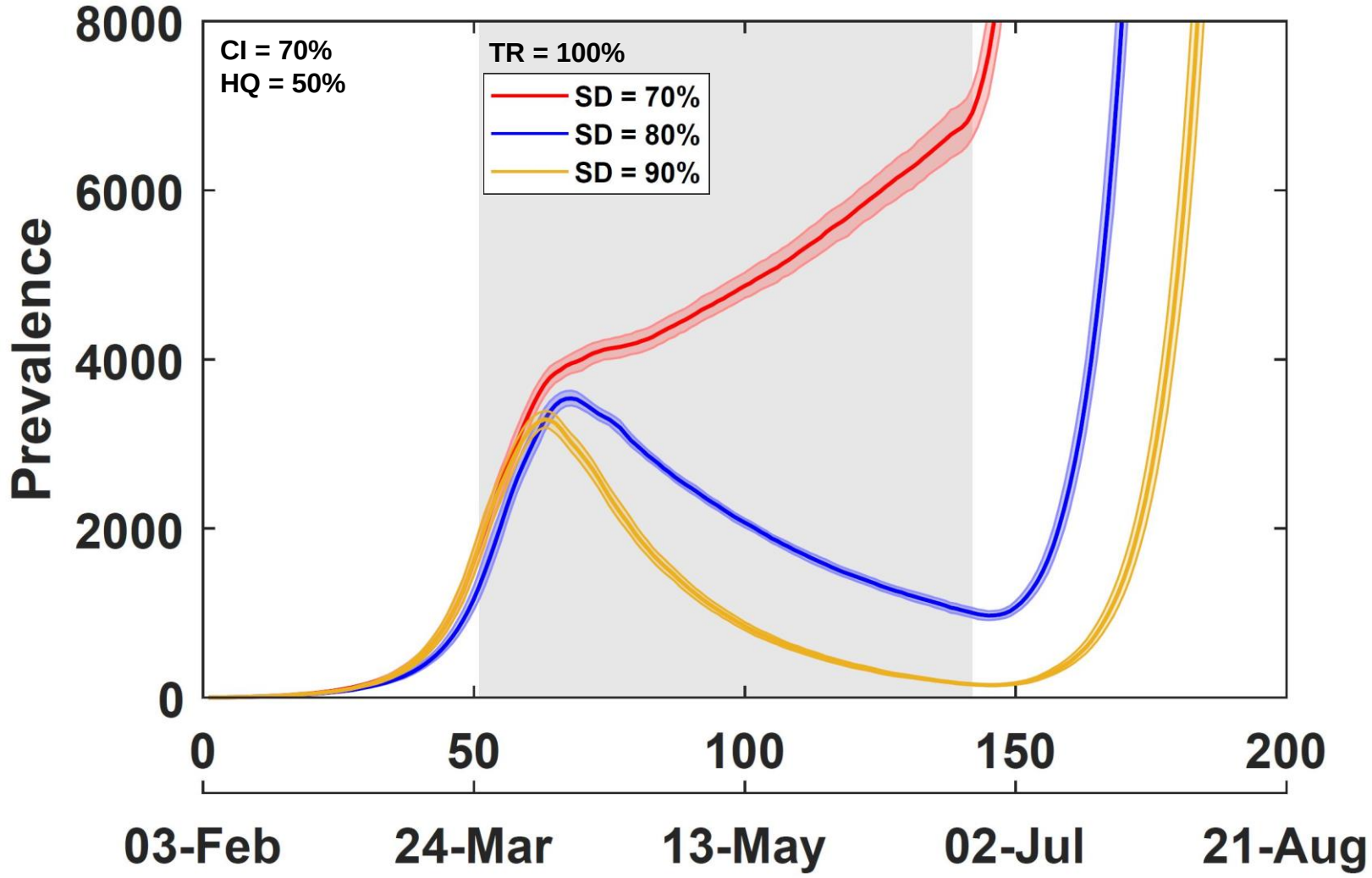
Non-pharmaceutical interventions (NPIs)

NPI	Compliance (macro)	Interaction strength (micro)		
		Household	Community	Workplace
Case isolation	0.7 – 0.8	1.0	0.1 – 0.25	0.1 – 0.25
Home quarantine	0.5 – 0.7	2.0	0.1 – 0.25	0.1 – 0.25
School (students)	1.0	1.0	0.1 – 0.5	0.0
School (parents)	0.5	1.0	0.1 – 0.5	0.0
Social distancing	0.0 – 1.0	1.0	0.1 – 0.25	0.1

S. L. Chang, O. M. Cliff, C. Zachreson, M. Prokopenko, Simulating Transmission Scenarios of the Delta Variant of SARS-CoV-2 in Australia, *Frontiers in Public Health,* 10, 10.3389/fpubh.2022.823043, 2022.

Physical distancing vs social distancing

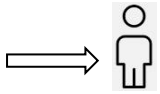
Tipping point in social distancing



S. L. Chang, N. Harding, C. Zachreson, O. M. Cliff, M. Prokopenko, Modelling transmission and control of the COVID-19 pandemic in Australia, *Nature Communications,* 11, 5710, 2020.

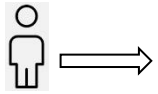
Modelling vaccination rollout

- Susceptibility-reducing efficacy (VEs): reduces the probability of becoming infected if exposed



- Disease-preventing efficacy (VEd): reduces the probability of expressing symptoms if infected

- Transmission-limiting efficacy (VEt): reduces the force of infection produced by infected individuals who are vaccinated



$$VE = VEd + VEs - VEs \times VEd \qquad VEt = \sim 0.5$$

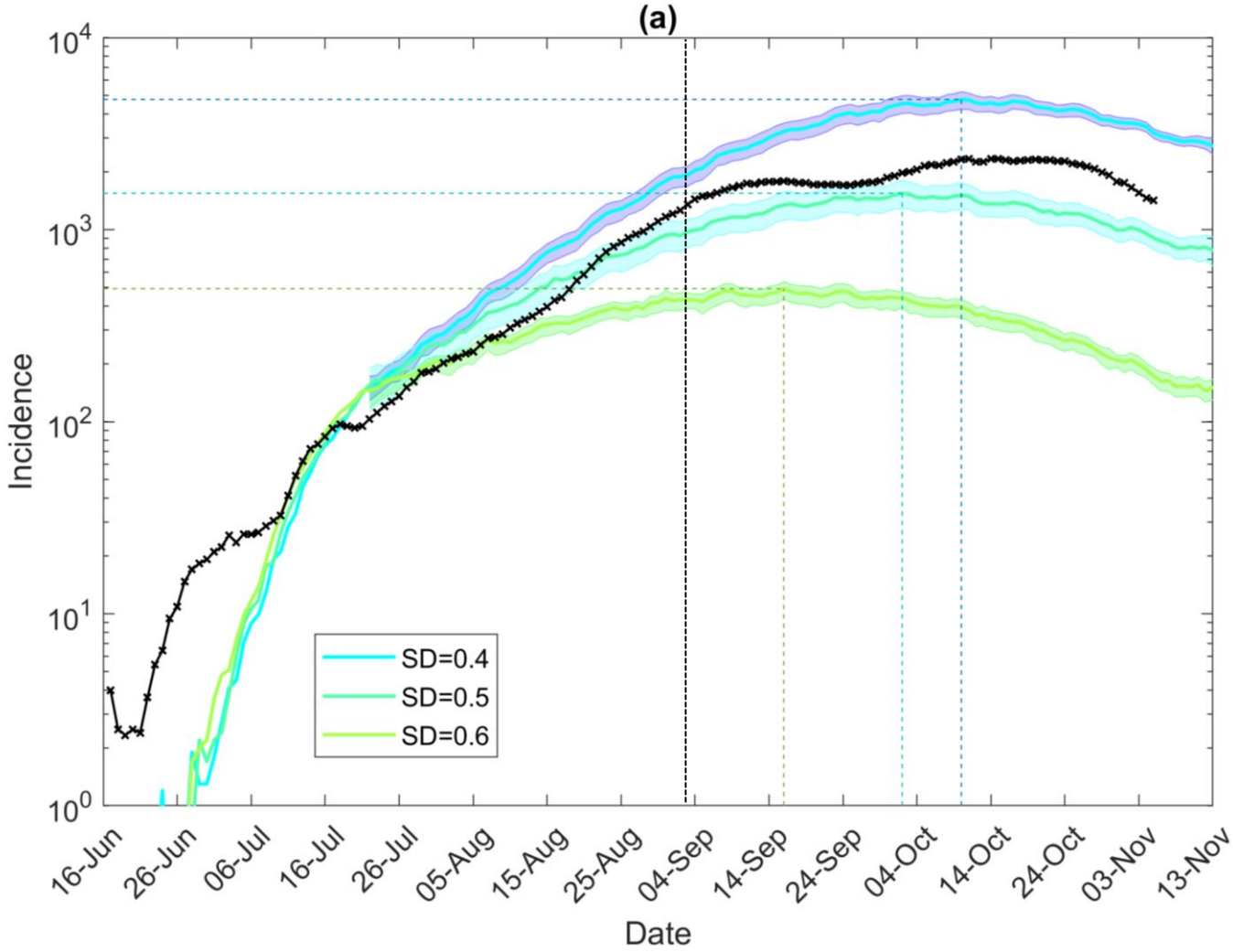
for example:

$$0.91 = 0.7 + 0.7 - 0.7 \times 0.7$$
$$0.92 = 0.8 + 0.6 - 0.8 \times 0.6$$

$$0.75 = 0.5 + 0.5 - 0.5 \times 0.5$$
$$0.65 = 0.5 + 0.3 - 0.5 \times 0.3$$

C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *The Lancet Regional Health – Western Pacific*, 14: 100224, 2021.

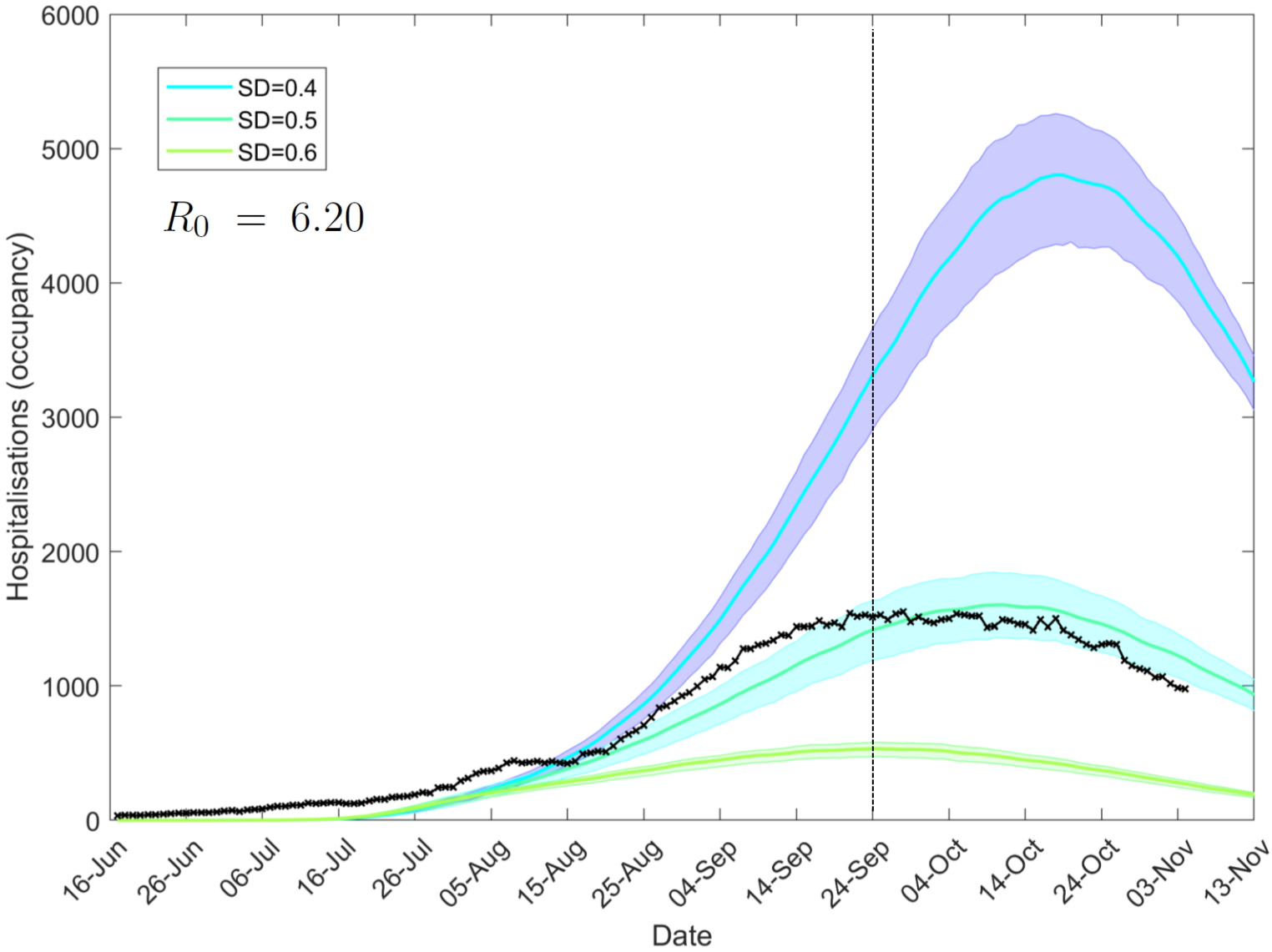
The Delta variant: SD compliance scenarios (25 August → 5 November 2021)



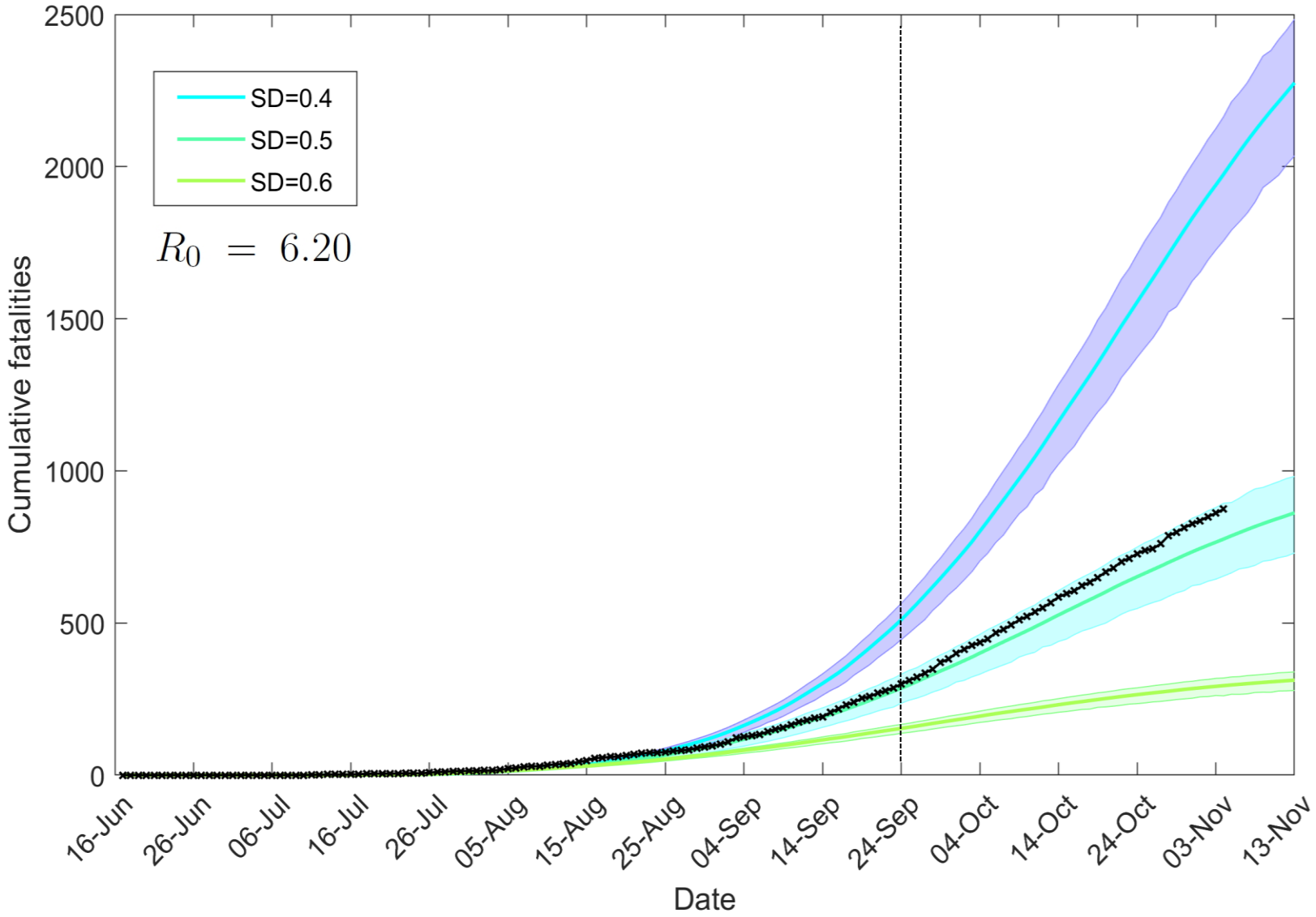
$R_0 = 6.20$

S. L. Chang, O. M. Cliff, C. Zachreson, M. Prokopenko, Simulating Transmission Scenarios of the Delta Variant of SARS-CoV-2 in Australia, *Frontiers in Public Health,* 10, 10.3389/fpubh.2022.823043, 2022.

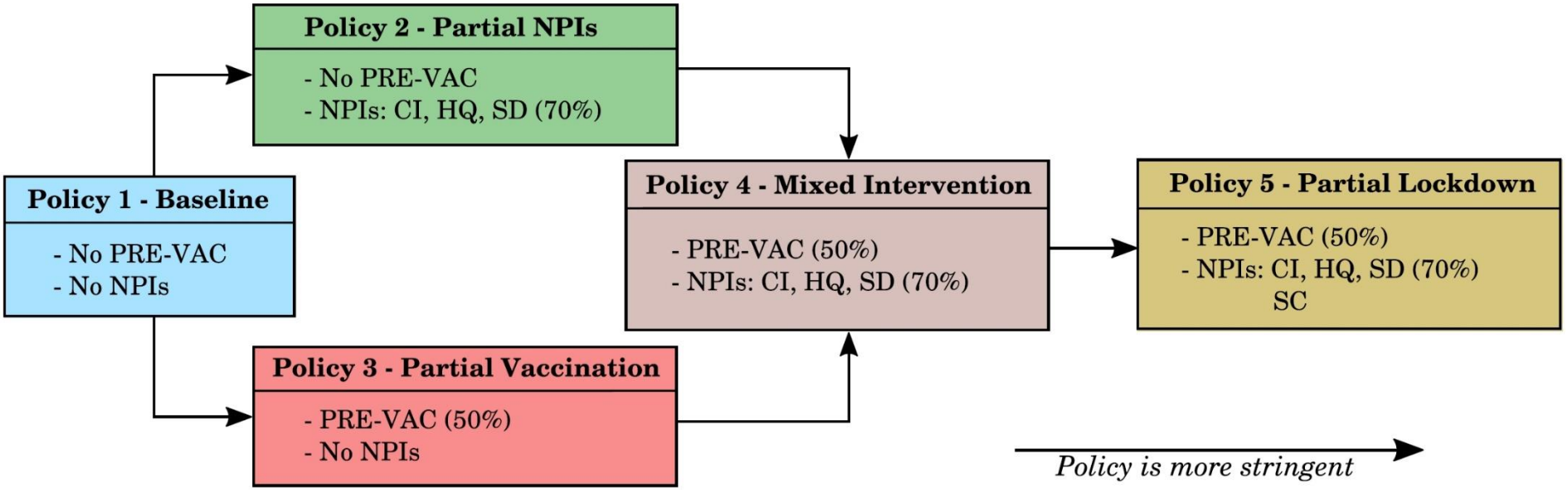
Hospitalisations (occupancy): a threefold reduction for 10% increase in SD



Mortality (cumulative deaths): a two-fold reduction for 10% increase in SD

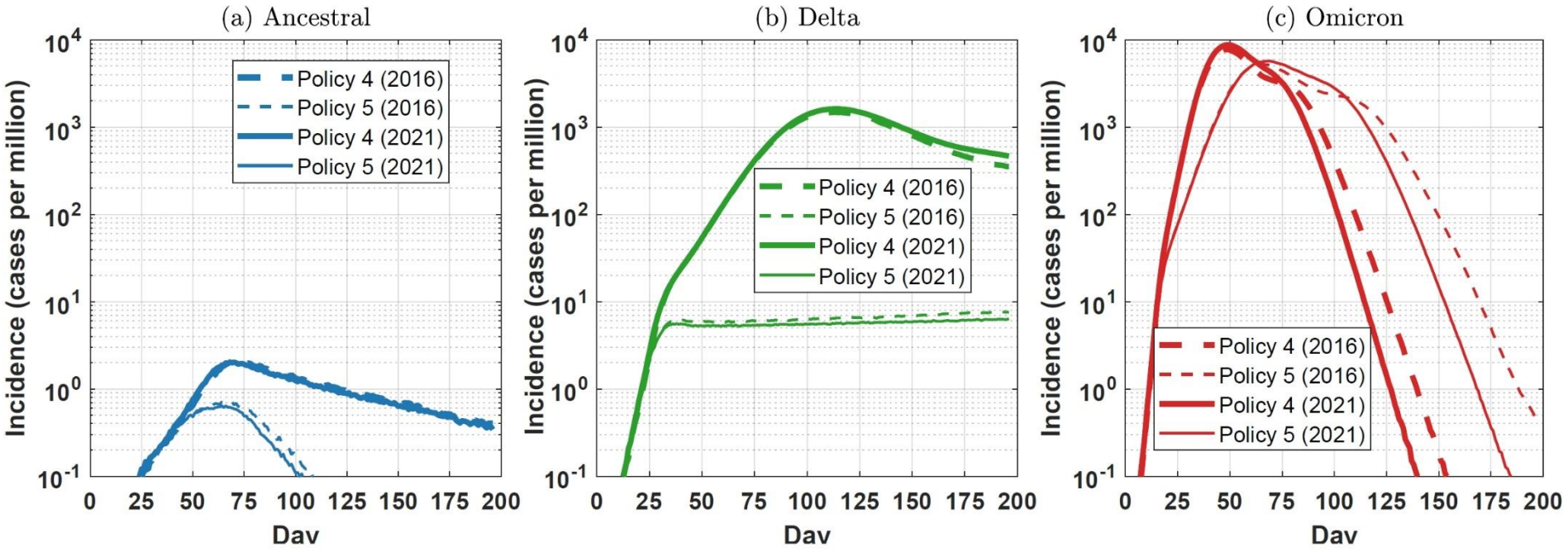


Representative NPIs



Q. D. Nguyen, S. L. Chang, C. M. Jamerlan, M. Prokopenko, Measuring unequal distribution of pandemic severity across census years, variants of concern and interventions, *Population Health Metrics*, 21, 17, 2023.

Effect of school closures



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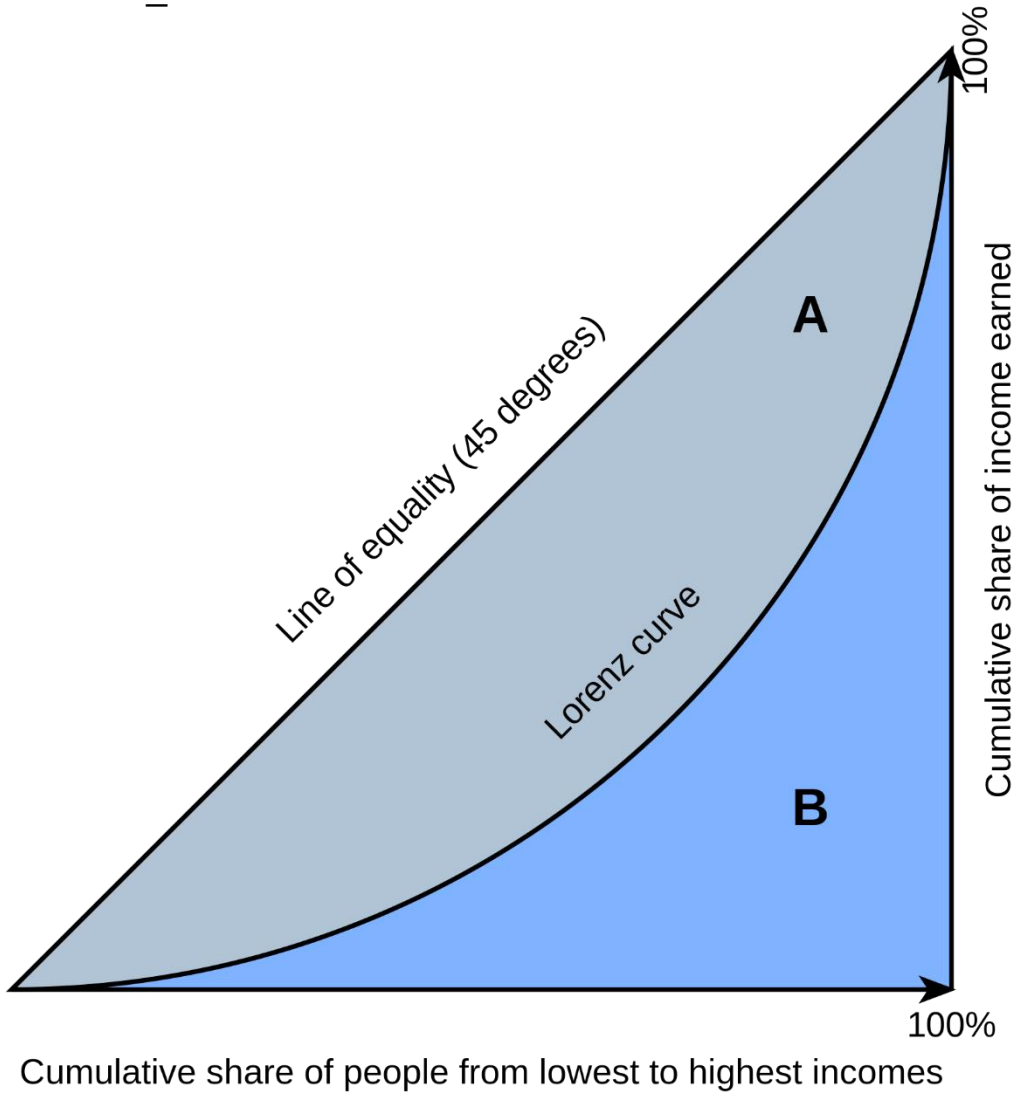
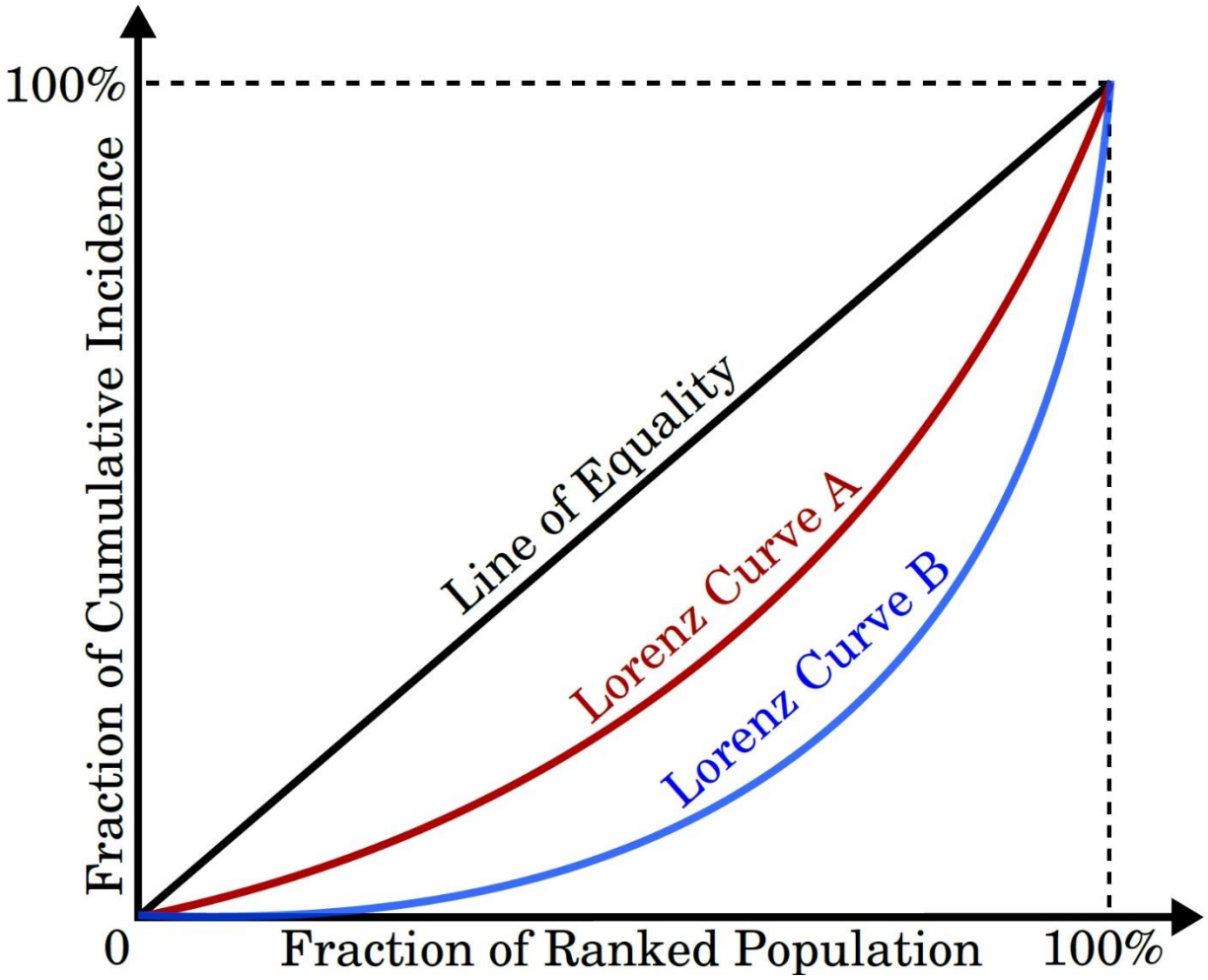
Analogy: inequality of wealth distribution

https://en.wikipedia.org/wiki/Lorenz_curve

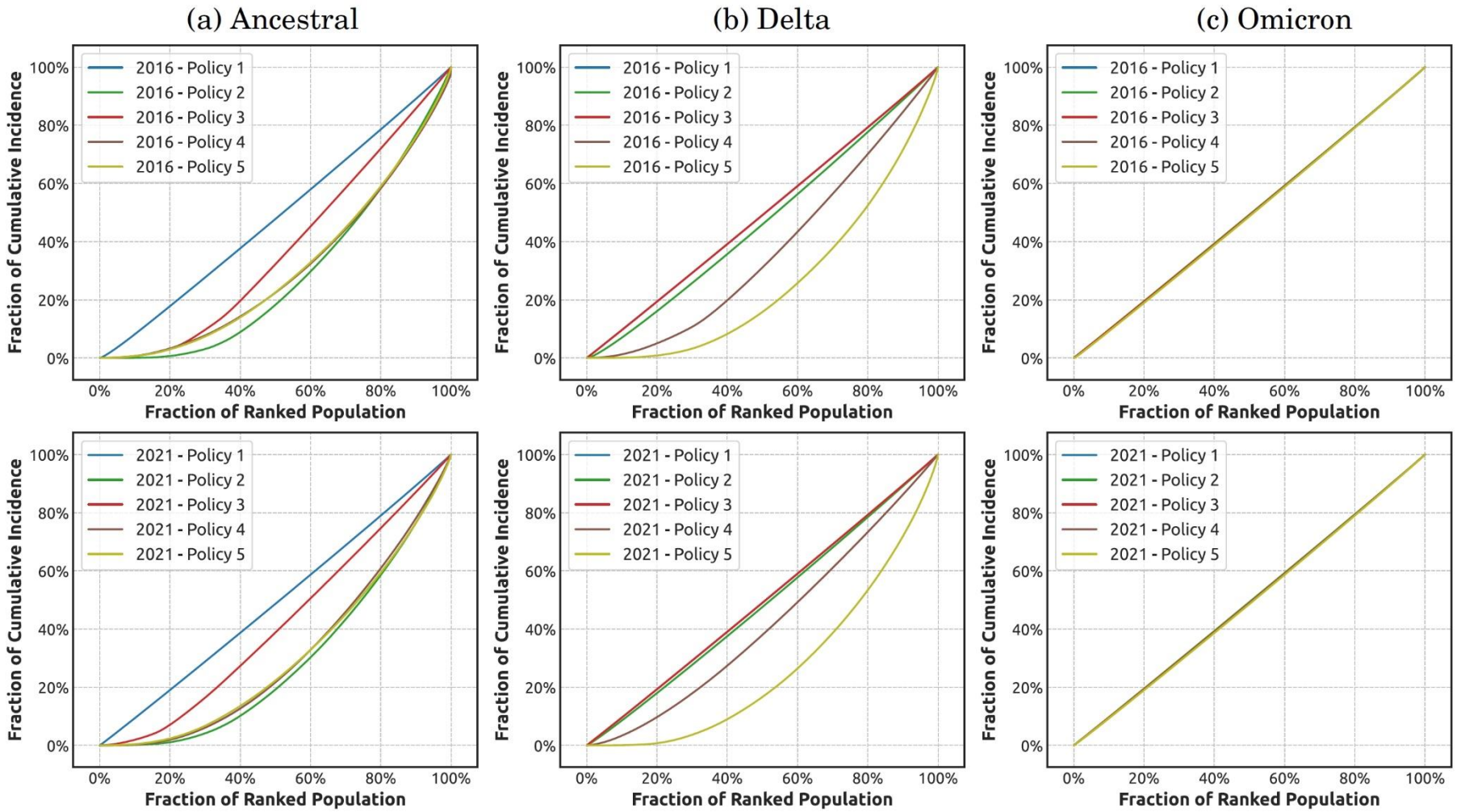


Pandemic inequality: pandemic Lorenz curves



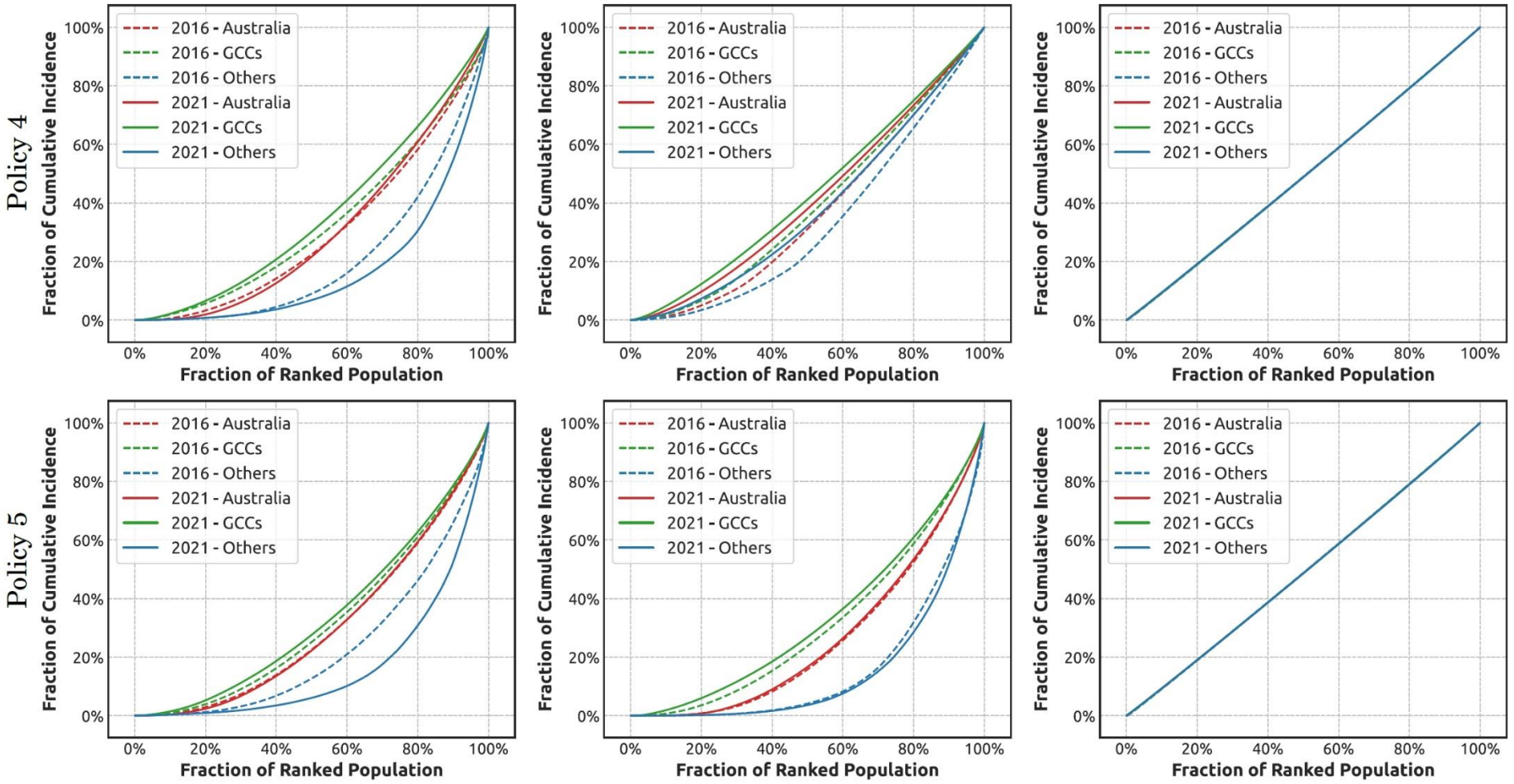
Q. D. Nguyen, S. L. Chang, C. M. Jamerlan, M. Prokopenko, Measuring unequal distribution of pandemic severity across census years, variants of concern and interventions, *Population Health Metrics*, 21, 17, 2023

Pandemic inequality across years, NPIs and VOC



Q. D. Nguyen, S. L. Chang, C. M. Jamerlan, M. Prokopenko, Measuring unequal distribution of pandemic severity across census years, variants of concern and interventions, *Population Health Metrics*, 21, 17, 2023

Pandemic inequality: urban vs regional



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Summary

- systematic comparative analysis of several COVID-19 pandemic scenarios:
  - two most recent Australian census years (2016 and 2021)
  - three variants of concern (ancestral, Delta and Omicron)
  - five representative intervention policies
- pandemic Lorenz curves measure pandemic severity across local areas
- unequal distribution across regional areas increased from 2016 to 2021
- school closures more effective against Delta variant

THE UNIVERSITY OF SYDNEY

AMTraC-19 open source

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There is a **newer version** of this record available.

December 14, 2021

Software Open Access

AMTraC-19 Source Code: Agent-based Model of Transmission and Control of the COVID-19 pandemic in Australia

Chang, Sheryl L.; Harding, Nathan; Zachreson, Cameron; Cliff, Oliver M.; Prokopenko, Mikhail

The software implements an agent-based model for a fine-grained computational simulation of the COVID-19 pandemic in Australia. This model is calibrated to reproduce several features of COVID-19 transmission, including its age-dependent epidemiological characteristics. The individual-based epidemiological model accounts for mobility (worker and student commuting) patterns and human interactions derived from the Australian census and other national data sources. The high-precision simulation comprises approximately 24 million stochastically generated software agents and traces various scenarios of the COVID-19 pandemic in Australia. The software has been used to evaluate various intervention strategies, including (1) non-pharmaceutical interventions, such as restrictions on international air travel, case isolation, home quarantine, school closures, and stay-at-home restrictions with varying levels of compliance (i.e., "social distancing"), and (2) pharmaceutical interventions, such as pre-pandemic vaccination phase and progressive vaccination rollout.

The paper describing the model and the scenarios investigated with AMTRaC-19 (v7_7d):

S. L. Chang, C. Zachreson, O. M. Cliff, M. Prokopenko, Simulating transmission scenarios of the Delta variant of SARS-CoV-2 in Australia, *Frontiers in Public Health*, 10, 10.3389/fpubh.2022.823043, 2022.

Please cite it, as well as other publications referenced below, when using the software.

The dataset generated during this study is also available on Zenodo:

425 views

22 downloads

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Publication date:
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DOI:
DOI 10.5281/zenodo.5778218

Keyword(s):
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References

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