Incorporating behaviour into infectious disease models: Challenges and Questions

Ed Hill
Tenure Track Fellow in Health Protection Data Science
University of Liverpool

CHIL Civic Health Innovation Labs

THE PANDEMIC INSTITUTE

NIHR | Health Protection Research Unit in Gastrointestinal Infections at University of Liverpool

JUNIPER Partnership

JUNIPER is a collaborative network of researchers from across the UK who work at the interface between mathematical modelling, infectious disease control and public health policy.

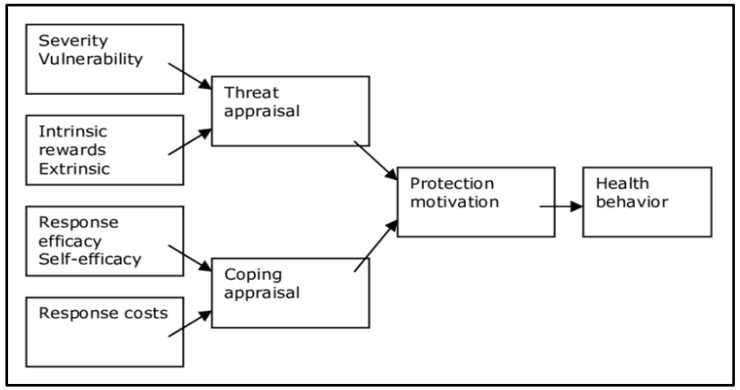
Who we are

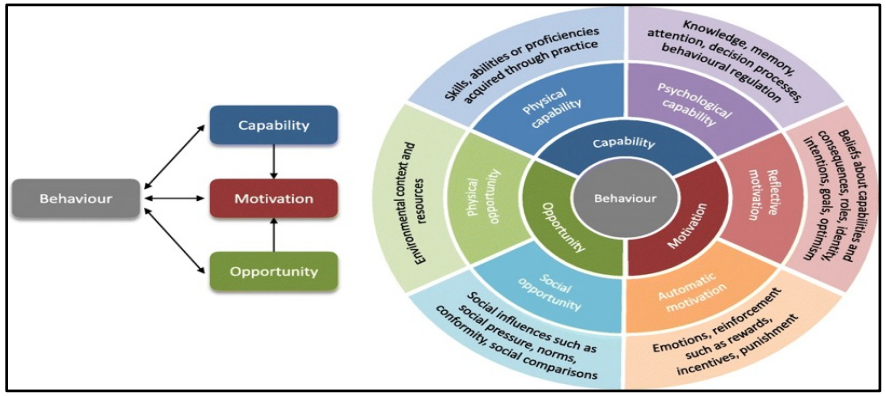
JUNIPER is a partnership that connects epidemic modellers across the country with the aims of building capacity and capability for the UK's epidemiological modelling. A key long-term aim is to ensure that we are better prepared and more resilient to future infectious disease threats, so our research covers a range of infectious diseases that are important regionally, nationally and internationally, as well as supporting underpinning research for strengthening infectious disease modelling.

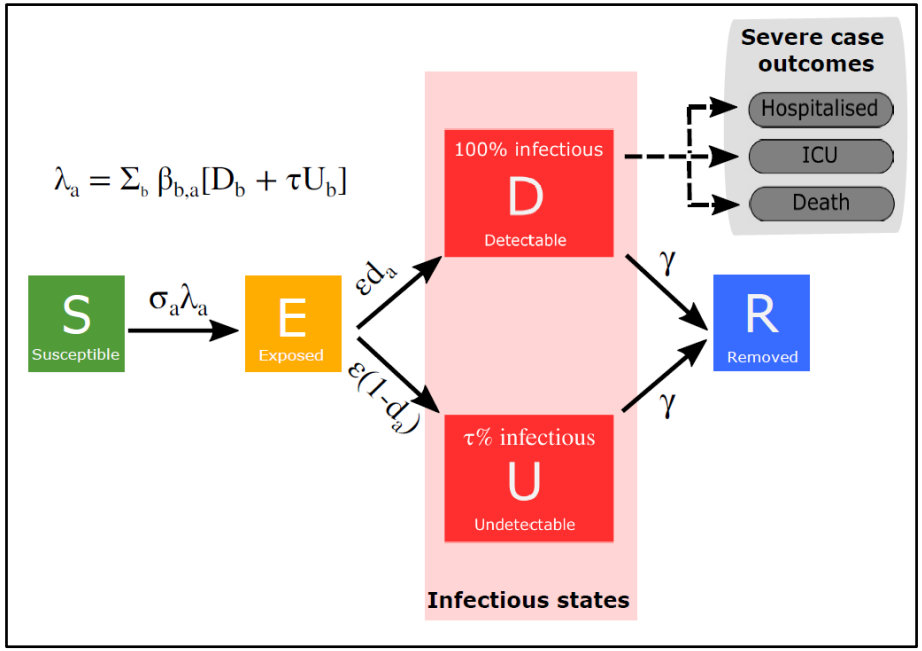
JUNIPER website

https://maths.org/juniper

The ultimate challenge?







Unifying theoretical frameworks from behavioural science and infectious disease dynamics.

Talk outline

1. Scenario modelling – Intervention engagement
2. Scenario modelling – Contact rates & mobility
3. Models with behavioural feedback
4. Challenge areas

Talk outline

1. Scenario modelling – Intervention engagement
    a) Vaccine acceptability
    b) NPIs in enclosed settings
    c) Adherence

2. Scenario modelling – Contact rates & mobility

3. Models with behavioural feedback

4. Challenge areas

(1A) Vaccine acceptability

PLOS COMPUTATIONAL BIOLOGY

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

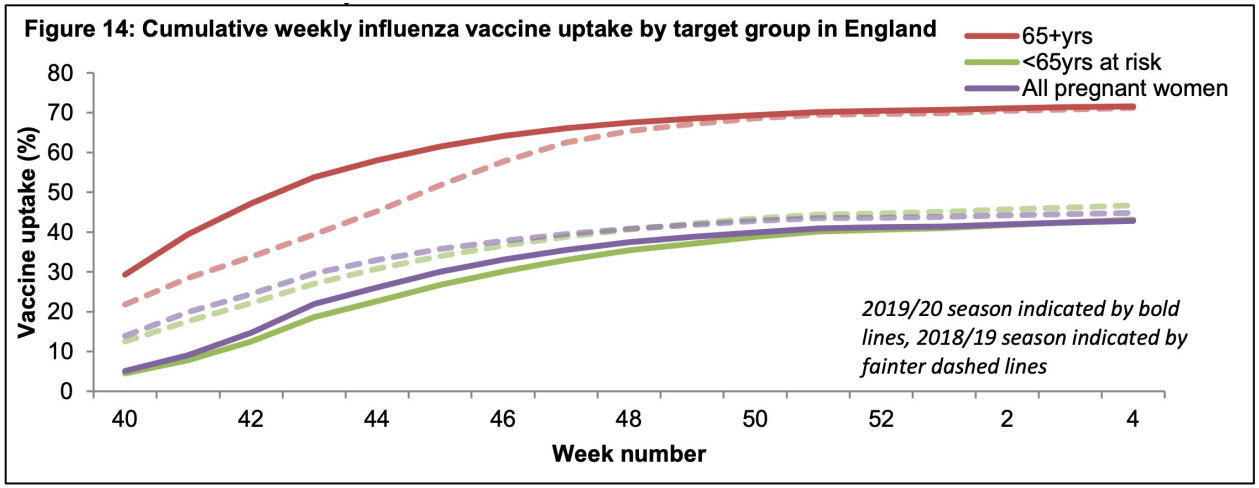
Modelling optimal vaccination strategy for SARS-CoV-2 in the UK

Sam Moore, Edward M. Hill, Louise Dyson, Michael J. Tildesley, Matt J. Keeling

Published: May 6, 2021 • https://doi.org/10.1371/journal.pcbi.1008849

Citation: Moore S, Hill EM, Dyson L, Tildesley MJ, Keeling MJ (2021) Modelling optimal vaccination strategy for SARS-CoV-2 in the UK. PLoS Comput Biol 17(5): e1008849. https://doi.org/10.1371/journal.pcbi.1008849

For simplicity, we assumed 70% vaccine uptake across all age-groups based on what has been obtainable for vaccines targeting other infections, such as within elder age groups and healthcare workers for the UK seasonal influenza vaccination programme [46]. In practice,



Is it reasonable to "repurpose" intervention response data?

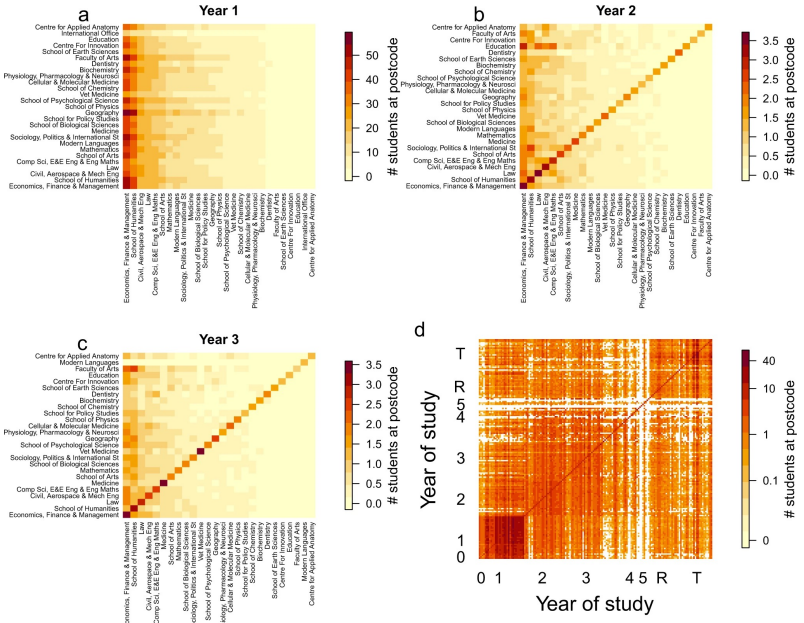
(1B) NPIs in enclosed settings

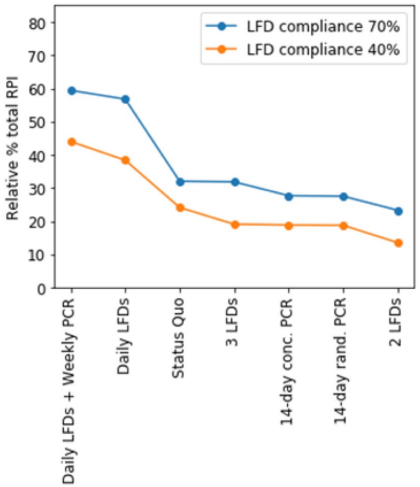
Article | Open Access | Published: 17 August 2021

High COVID-19 transmission potential associated with re-opening universities can be mitigated with layered interventions

Ellen Brooks-Pollock ✉, Hannah Christensen, Adam Trickey, Gibran Hemani, Emily Nixon, Amy C. Thomas, Katy Turner, Adam Finn, Matt Hickman, Caroline Relton & Leon Danon

Nature Communications **12**, Article number: 5017 (2021) | Cite this article



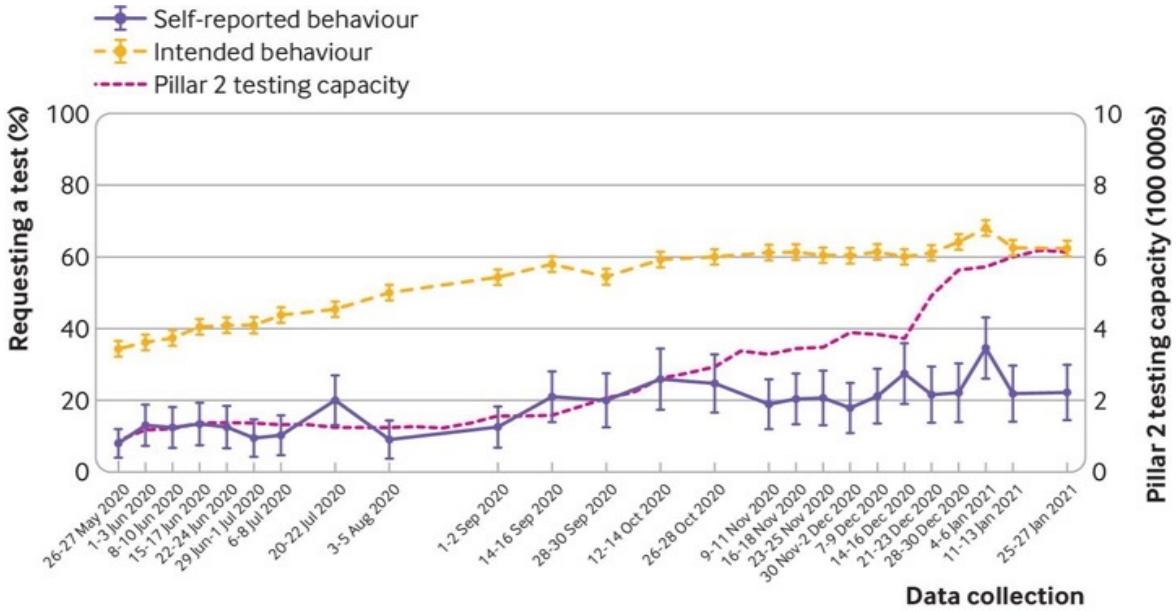


C. Whitfield & I. Hall. Social Care Working Group chairs summary of role of shielding. (Annex A) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043615/S1453_SCWG_chairs_summary_of_role_of_shielding.pdf

Impact of heterogeneity & what level of detail to include?

(1C) Adherence

Figure: Percentage of people who reported requesting a test after developing COVID-19 symptoms and who reported intending to request a test if they were to develop COVID-19 symptoms.



Reproduced from Smith LE et al. (2021) Adherence to the test, trace, and isolate system in the UK: results from 37 nationally representative surveys. *BMJ*. 372; n608.

How to reconcile intended behaviour vs actual behaviour?

Talk outline

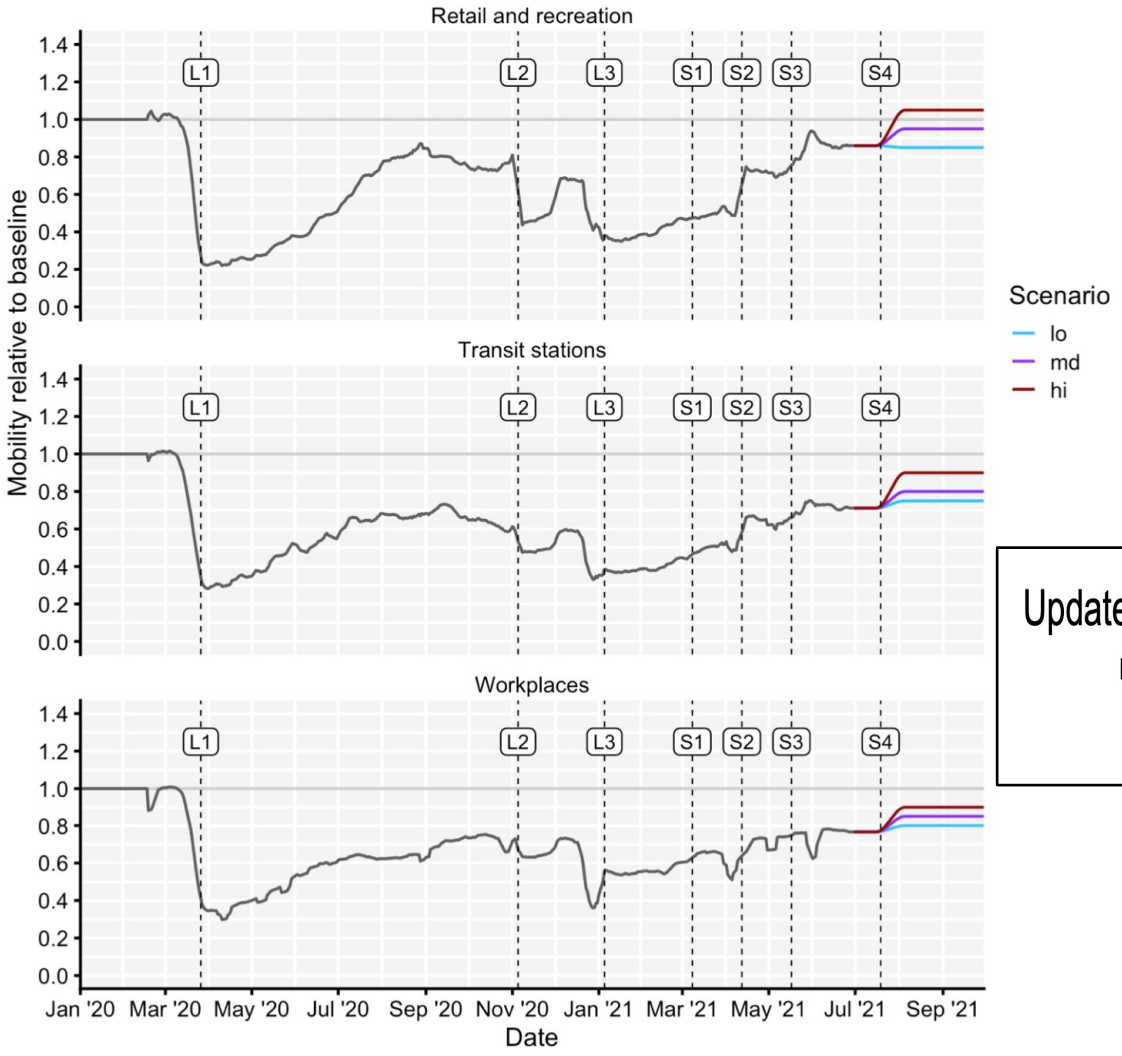
1. Scenario modelling – Intervention engagement

2. **Scenario modelling – Contact rates & mobility**
   a) **Roadmap**
   b) **Voluntary risk mitigation**

3. Models with behavioural feedback

4. Challenege areas

(2A) Roadmap modelling



Updated roadmap assessment: prior to delayed step 4

Rosanna C. Barnard, Nicholas G. Davies, Mark Jit & W. John Edmunds
London School of Hygiene & Tropical Medicine
7th July 2021

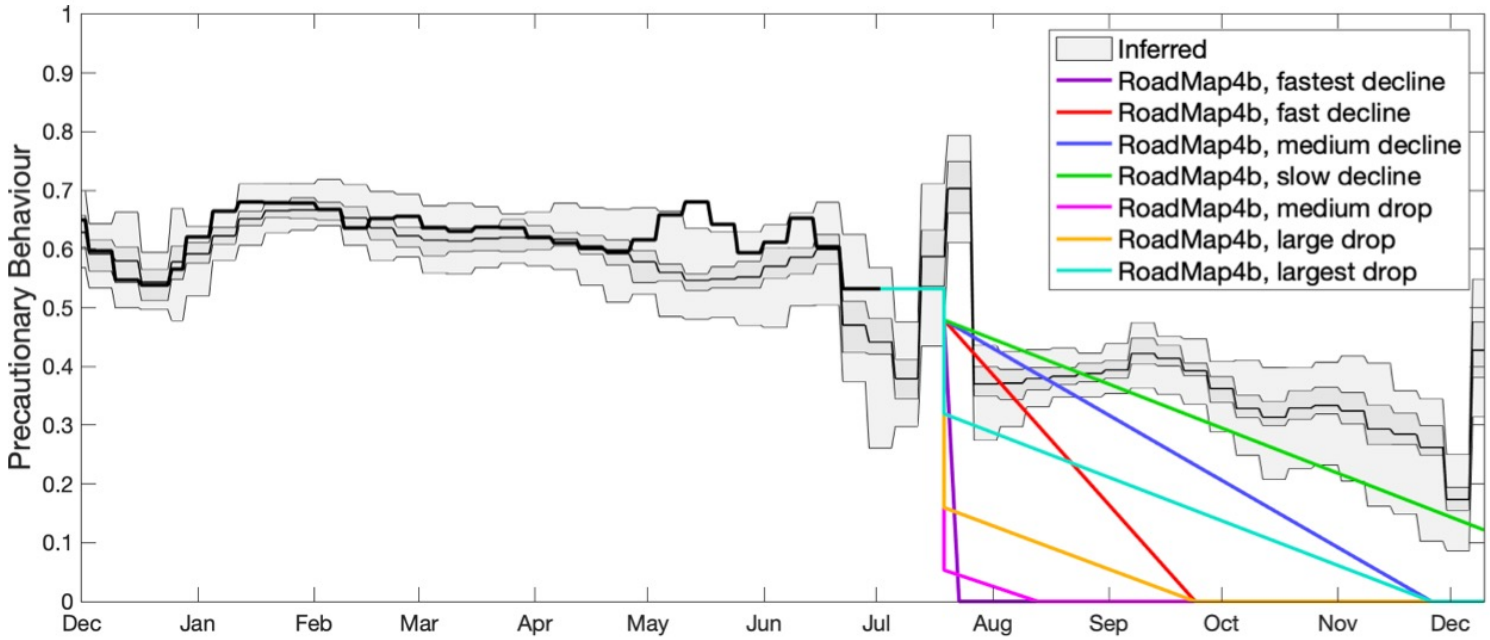
URL:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1001174/S1304_LSHTM_Updated_roadmap_assessment_prior_to_delayed_step_4.2__7_July_2021__1_.pdf

(2A) Roadmap modelling

Comparison of the 2021 COVID-19 'Roadmap' Projections against Public Health Data

Matt J. Keeling, Louise Dyson, Michael J. Tildesley, Edward M. Hill, Samuel Moore

doi: https://doi.org/10.1101/2022.03.17.22272535



How to account for uncertainty in behavioural response in the face of changing restrictions and changing risk?

(2B) Voluntary risk mitigation

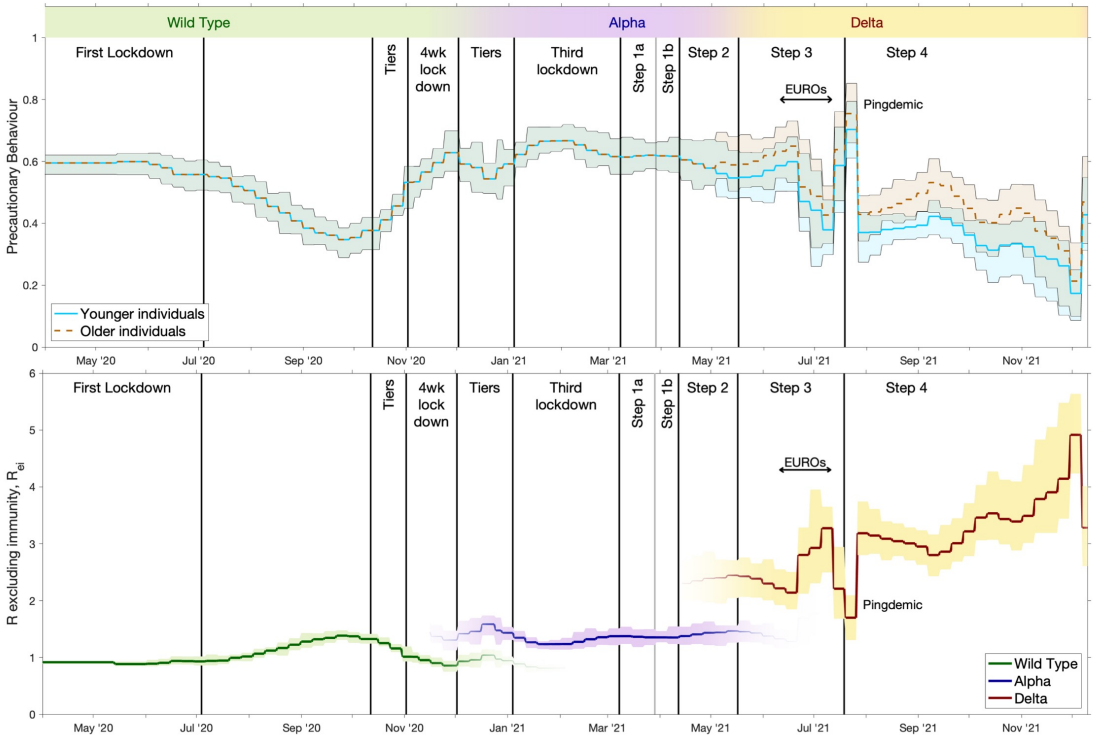


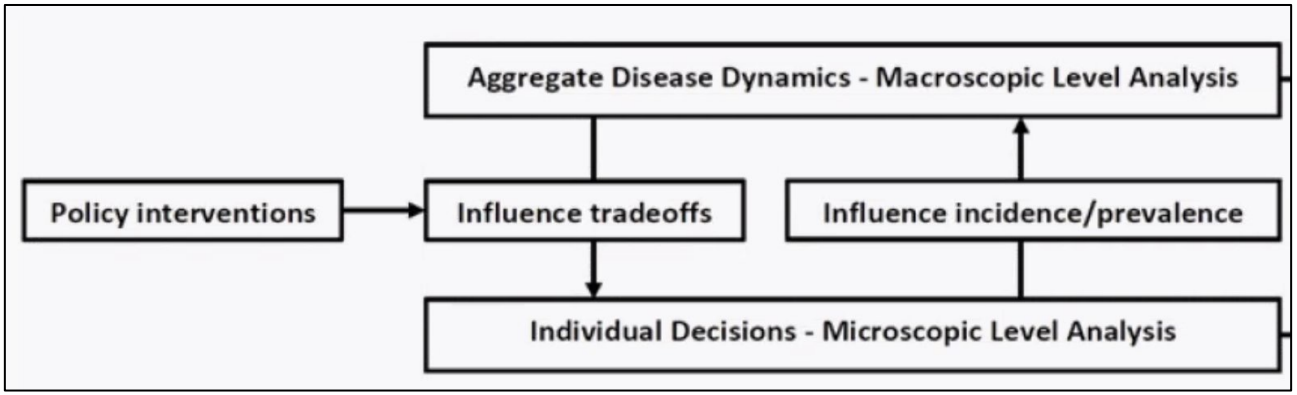
Fig. 1: Changes in the inferred precautionary behaviour from April 2020 to December 2021 (top panel), together with the resultant changes to R excluding immunity for the three main variants (lower panel). Vertical lines indicate the time of key changes to the control measures, while the top bar specifies the dominant variant over time. From May 2021 onwards, we have inferred two levels of precautionary behaviour applying to younger (under 40) and older (over 65) individuals, with those between 40 and 65 scaling between the two.

Do we have the means to parameterise behaviour change attributable to policy vs voluntary action?

Talk outline

1. Scenario modelling – Intervention engagement
2. Scenario modelling – Contact rates & mobility
3. **Models with behavioural feedback**
4. Challenge areas

(3) Models with behavioural feedback



Schematic by Flavio Toxvaerd

Can these processes be realistically characterised by a unified behavioural science and infectious disease modelling framework?

(3) Feedback example: Disease awareness

PLOS MEDICINE

OPEN ACCESS PEER-REVIEWED

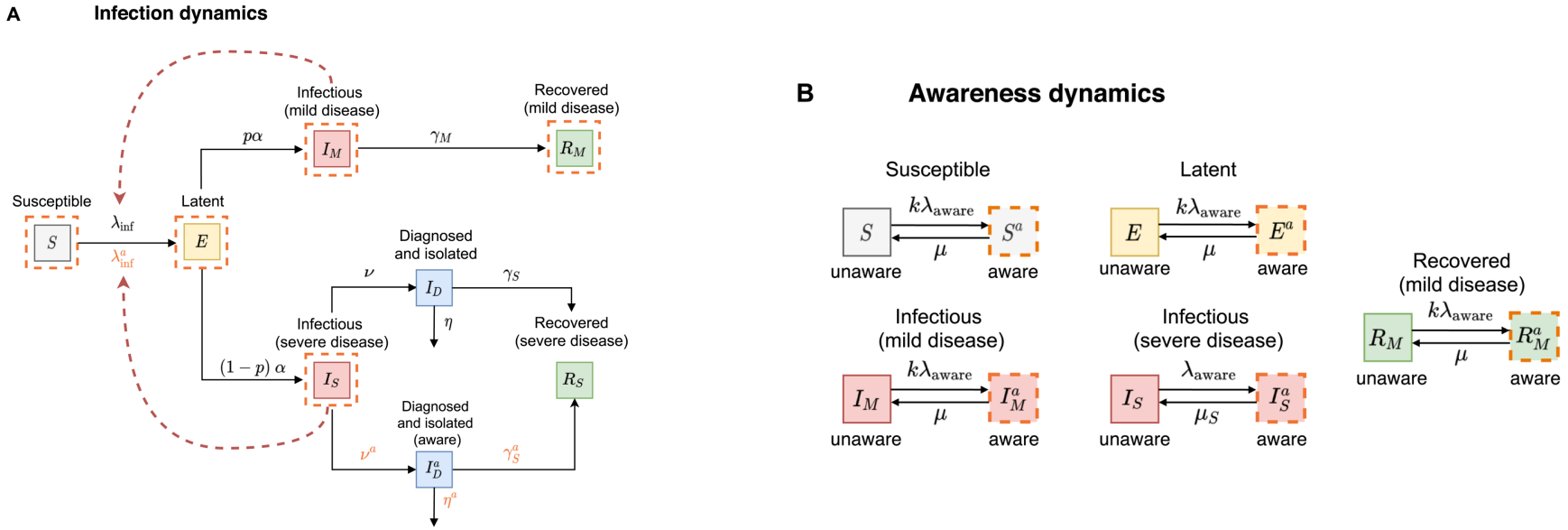
RESEARCH ARTICLE

Impact of self-imposed prevention measures and short-term government-imposed social distancing on mitigating and delaying a COVID-19 epidemic: A modelling study

Alexandra Teslya, Thi Mui Pham, Noortje G. Godijk, Mirjam E. Kretzschmar, Martin C. J. Bootsma, Ganna Rozhnova

Published: July 21, 2020 • https://doi.org/10.1371/journal.pmed.1003166

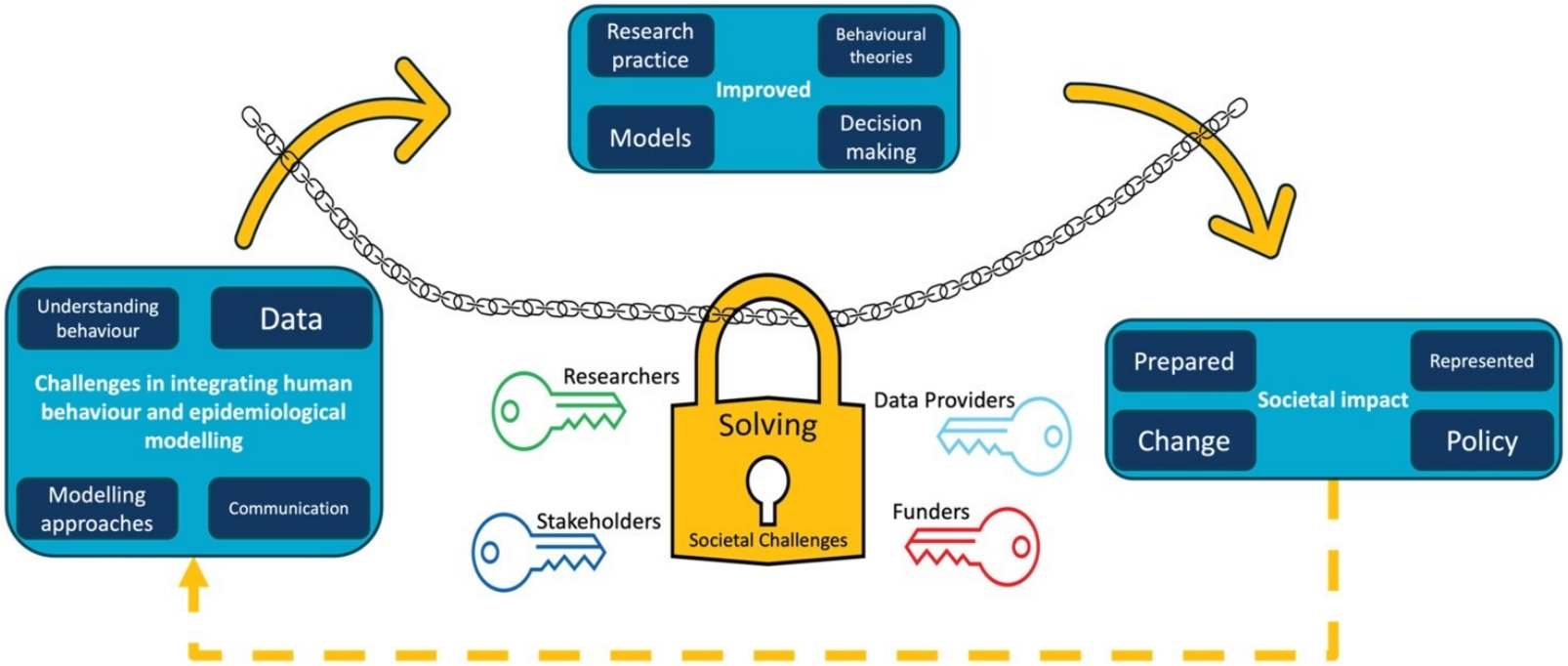
Citation: Teslya A, Pham TM, Godijk NG, Kretzschmar ME, Bootsma MCJ, Rozhnova G (2020) Impact of self-imposed prevention measures and short-term government-imposed social distancing on mitigating and delaying a COVID-19 epidemic: A modelling study. PLoS Med 17(7): e1003166. https://doi.org/10.1371/journal.pmed.1003166



Talk outline

1. Scenario modelling – Intervention engagement
2. Scenario modelling – Contact rates & mobility
3. Models with behavioural feedback
4. **Challenge areas**
    a) **Data**
    b) **Modelling approaches**
    c) **Communication & informing policy**

Challenges areas



MATHEMATICS IN MEDICAL AND LIFE SCIENCES
2024, VOL. 1, NO. 1, 2429479
https://doi.org/10.1080/29937574.2024.2429479

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Integrating human behaviour and epidemiological modelling: unlocking the remaining challenges

Edward M. Hill [a,b], Matthew Ryan [c], David Haw [d], Mark P. Lynch [e], Ruth McCabe [f], Alice E. Milne [g], Matthew S. Turner [h], Kavita Vedhara [i], Fanqi Zeng [j], Martine J. Barons [k], Emily J. Nixon [d], Stephen Parnell [l] and Kirsty J. Bolton [m]

https://doi.org/10.1080/29937574.2024.2429479

(4A) Challenge area: Data

- Data collection - “Striking a balance”
- Pipelines to synthesise a range of data sources
- Format and accessibility
- What already exists that could be used/repurposed/tweaked that would be informative?

MATHEMATICS IN MEDICAL AND LIFE SCIENCES
2024, VOL. 1, NO. 1, 2429479
https://doi.org/10.1080/29937574.2024.2429479

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Integrating human behaviour and epidemiological modelling: unlocking the remaining challenges

Edward M. Hill [a,b], Matthew Ryan [c], David Haw [d], Mark P. Lynch [e], Ruth McCabe [f], Alice E. Milne [g], Matthew S. Turner [h], Kavita Vedhara [i], Fanqi Zeng [j], Martine J. Barons [k], Emily J. Nixon [d], Stephen Parnell [l] and Kirsty J. Bolton [m]

https://doi.org/10.1080/29937574.2024.2429479

(4B) Challenge area: Modelling approaches

- Should behaviour always be included in models?
- A checklist for constructing an interdisciplinary model?
- Building the team that has the expertise across research disciplines
- Having flexible frameworks to cater for future challenges, when we do not even know what those challenges may be…

MATHEMATICS IN MEDICAL AND LIFE SCIENCES
2024, VOL. 1, NO. 1, 2429479
https://doi.org/10.1080/29937574.2024.2429479

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Integrating human behaviour and epidemiological modelling: unlocking the remaining challenges

Edward M. Hill [a,b], Matthew Ryan [c], David Haw [d], Mark P. Lynch [e], Ruth McCabe [f], Alice E. Milne [g], Matthew S. Turner [h], Kavita Vedhara [i], Fanqi Zeng [j], Martine J. Barons [k], Emily J. Nixon [d], Stephen Parnell [l] and Kirsty J. Bolton [m]

https://doi.org/10.1080/29937574.2024.2429479

(4C) Challenge area: Communication & informing policy

- Objective matters, Perspective matters
- What is the end game in the face of uncertainty?
- Role of the public in the research process – Public Involvement
- Communicating findings to different audiences

MATHEMATICS IN MEDICAL AND LIFE SCIENCES
2024, VOL. 1, NO. 1, 2429479
https://doi.org/10.1080/29937574.2024.2429479

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Integrating human behaviour and epidemiological modelling: unlocking the remaining challenges

Edward M. Hill [a,b], Matthew Ryan [c], David Haw [d], Mark P. Lynch [e], Ruth McCabe [f], Alice E. Milne [g], Matthew S. Turner [h], Kavita Vedhara [i], Fanqi Zeng [j], Martine J. Barons [k], Emily J. Nixon [d], Stephen Parnell [l] and Kirsty J. Bolton [m]

https://doi.org/10.1080/29937574.2024.2429479

INI satellite programme: Maths of human behaviour

Why?

- Inability to forecast behaviour limits predictive power of epidemic models.
- Behaviour important driver of dynamics in other fields (e.g. energy systems).
- Need for a new interdisciplinary field akin to mathematical biology?

Details?

- 4-week programme, July/August 2026
- Venue: School of Mathematical Sciences, University of Nottingham
- Participants spanning behavioural sciences, complex systems, statistics, data science, epidemic and energy systems modelling.

Who?

Kirsty Bolton (Nottingham)

Ed Hill (Liverpool)

Ellen Zapata-Webborn (UCL)

Deepak Padmanabhan (Queens')

Matt Ryan (CSIRO)

Jon Ward (Leeds)

Challenges and Questions

Is it reasonable to "repurpose" intervention response data?

Impact of heterogeneity & what level of detail to include?

How to reconcile intended behaviour vs actual behaviour?

How to account for uncertainty in behavioural response in the face of changing restrictions and changing risk?

Do we have the means to parameterise behaviour change attributable to policy vs voluntary action?

Unifying theoretical frameworks from behavioural science and infectious disease dynamics – The ultimate challenge?

In our podcast, hear from CHIL personnel share their research, discuss their project roles and career pathways.

Listen on Spotify:

https://open.spotify.com/show/1kbSyvlQUeLCjsSAORwlxr

Watch on YouTube:

https://www.youtube.com/@HealthDataDecoded