Incorporating heterogeneity in farmer disease control behaviour into a livestock disease transmission model

Ed Hill, Naomi Prosser, Paul Brown, Eamonn Ferguson, Martin Green, Jasmeet Kaler, Martin Green, Matt Keeling, Mike Tildesley

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Approaches to control infectious disease outbreaks in livestock

Direct action of farmers

The BVDFree England Scheme

What is BVD?

Bovine Viral Diarrhoea or BVD is a highly contagious viral disease of cattle. It is one of the biggest disease issues facing the UK cattle industry. BVD has been estimated to cost between £13 and £31 per cow in Great Britain. The national cost could be as high as £61M per year. (Bennett and Ijpelaar, 2005)

What is the BVDFree Scheme?

BVDFree England is a voluntary industry-led scheme, working to eliminate Bovine Viral Diarrhoea (BVD) from all cattle in England. The key to success is to identify and remove all animals persistently infected (PI) with the BVD virus from the English cattle herd.

Government action

Department for Environment Food & Rural Affairs

Contingency Plan for Exotic Notifiable Diseases of Animals in England

Including Foot and Mouth Disease, Avian Influenza, Newcastle Disease and all other exotic notifiable diseases of animals

Updated on 18 July 2022

Farmer-led Epidemic and Endemic Disease-management (FEED)

FEED project webpage: https://feed.warwick.ac.uk

Project motivation

- A knowledge gap on the different factors that drive farmer behaviour in response to an emerging disease.
- Mathematical modelling approaches traditionally treat farmers as passive bystanders & omit variation in disease management behaviours

Study aims

1. Elicit farmers vaccination decisions to an unfolding epidemic and link to their psychosocial and behavioural profiles (within Great Britain)

2. Refine mathematical disease models to capture psychosocial & behaviour change heterogeneities

3. Assess how psychosocial & behaviour change factors impact epidemiological outcomes given a fast-spreading livestock disease

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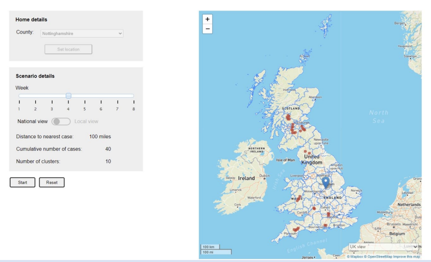
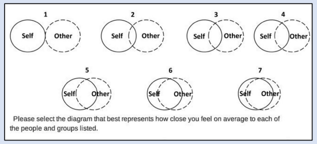
1. **Elicit farmers vaccination decisions to an unfolding epidemic and link to their psychosocial and behavioural profiles (within Great Britain)**

1 Design of a Graphical User Interface (GUI) to act as a core, interactive component of the interview exercise

Visit https://feed.warwick.ac.uk



2 Development and usage of an interview script to elicit farmer disease vaccination behaviours



The script used during the interviews to collect demographic data, explain the hypothetical disease and proceed through the disease outbreak scenario.

County:

Type of cattle: **Beef** **Dairy** **Both**

Thank you for your willingness to take part in this interview.

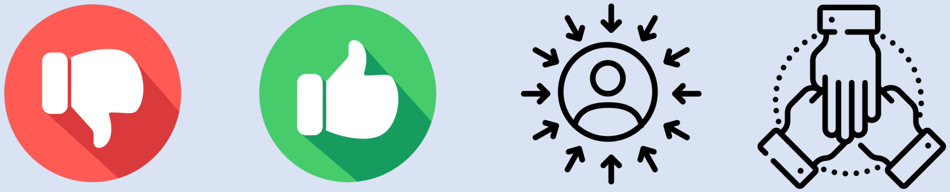
We are interested in capturing the decisions farmers make in an evolving scenario of a disease epidemic. There are no right or wrong answers to the questions, we value your opinion as a farmer responsible for the decisions made about the care of your cattle. We would also like to capture some information about you as a farmer and the type of farm you have.

Imagine you have **won** £700 in a **lottery**. Imagine you had the option to divide some, none or all of this £700, between yourself and the others listed below. You can split the money in any way you see fit, you don't have to give anyone any money or give everyone the same amount. You can decide who gets what, if anything, of the £700. Please indicate how you would like to split the £700 between yourself and these groups (the total divided must equal £700).

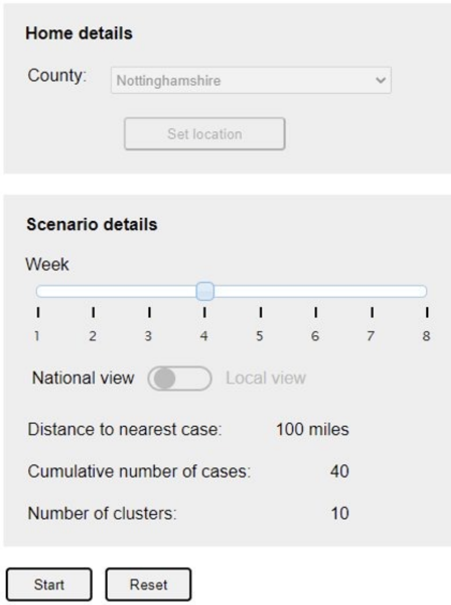
How much of the £700 (some, none or all) would you...

	* Required
Keep for yourself	£
Give to a random unknown farmer	£
Give to a neighbouring farmer	£
Give to a random unknown vet	£
Give to your local vet	£
Give to a stranger	£

3 Grouping of farmer vaccination behaviours in the elicitation exercise



Elicitation methods - GUI



https://feed.warwick.ac.uk/map.html

- Gave a common outbreak experience in terms of distance to the nearest infected herd for all farmers.

Elicitation methods - Questionnaire

Other people and groups

Please indicate how well you agree with each of the following statements.

	* Required				
	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
When dealing with farmers it is better to be careful before you trust them					
I feel respected by the government					
I trust other farmers nationally to be controlling infectious diseases in their herds					
I trust other farmers I meet for the first time					
When dealing with vets it is better to be careful before you trust them					
When dealing with strangers it is better to be careful before you trust them					
In general, one can trust people					
I feel respected by my vet					

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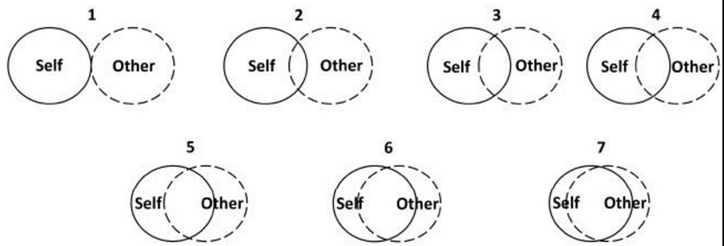


Please select the diagram that best represents how close you feel on average to each of the people and groups listed.

	* Required						
	1	2	3	4	5	6	7
Your vet							
The veterinary community in general (i.e. all vets nationwide)							
Your neighbouring farmers							
The farming community in general (i.e. all farmers nationwide)							
The Government							
Your cows							
Dairy farmers in general (i.e. all dairy farmers nationwide)							
Beef farmers in general (i.e. all beef farmers nationwide)							

Elicitation results – GUI simulation

Table: Number of infected herds, distance of the nearest infected herd from the interviewee's herd and number of farmers that vaccinated each week during the disease epidemic scenario.

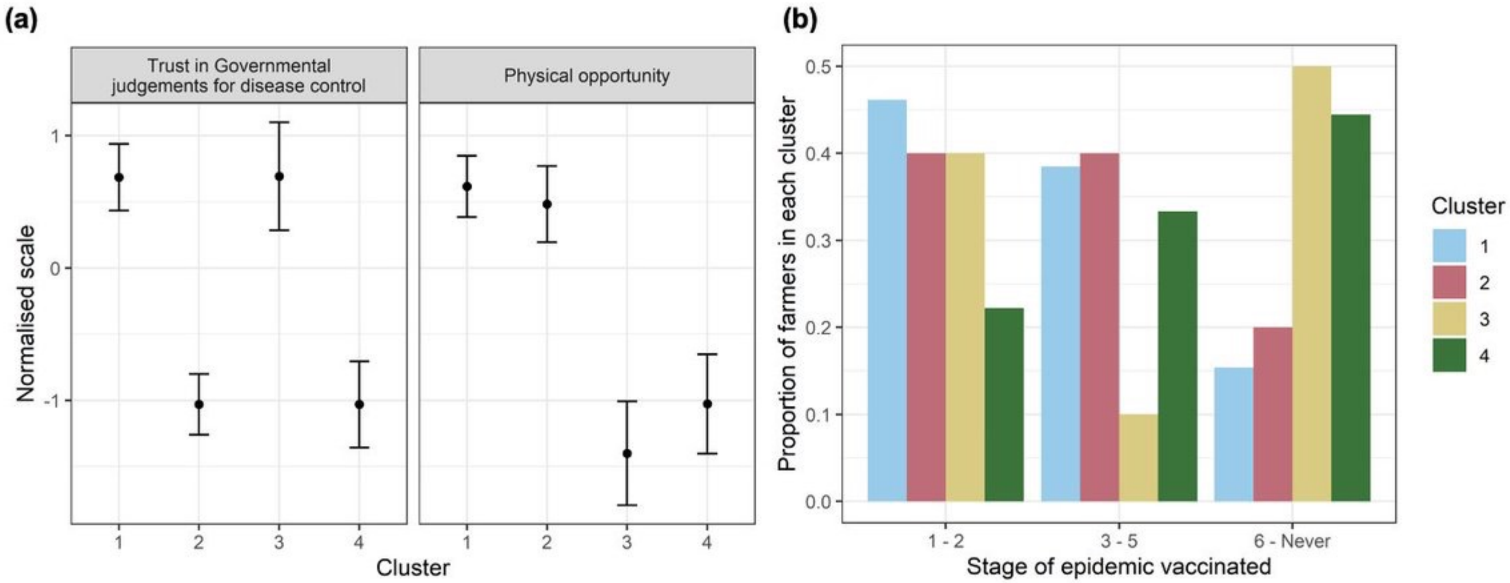
Stage of epidemic	Time since previous stage (weeks)	Number of infected herds (in GB)	Distance to nearest infected herd (km)	Number of farmers vaccinating (/60)
1	2	0	>500*	8
2	2	2	322	16
3	1	10	322	5
4	1	40	161	14
5	1	100	161	1
6	1	150	48	10
7	1	450	16	3
8	1	600	5	1
*Epidemic confined to southern-central France				

- Sixty farmers (39 beef & 21 dairy) participated, with variability apparent in when they would use preventative vaccination.

Elicitation results – Farmer groupings

- Using k-means clustering, four groups gave best fit when clustering by two most stable covariates (trust in Governmental judgements for disease control, high physical opportunity)

Figure: Farmer groups from k-means clustering conducted on the two most stable covariates. (a) Mean and 95% confidence interval scores of the covariates for each group. **(b)** Proportion of farmers in each group that vaccinated in different stages of the outbreak.



Elicitation results – Farmer groupings

- Grouping using five most stable covariates, three groups gave best fit.
- Additional covariates: Trust in vet advice, trust in other famers to control disease, herd size.

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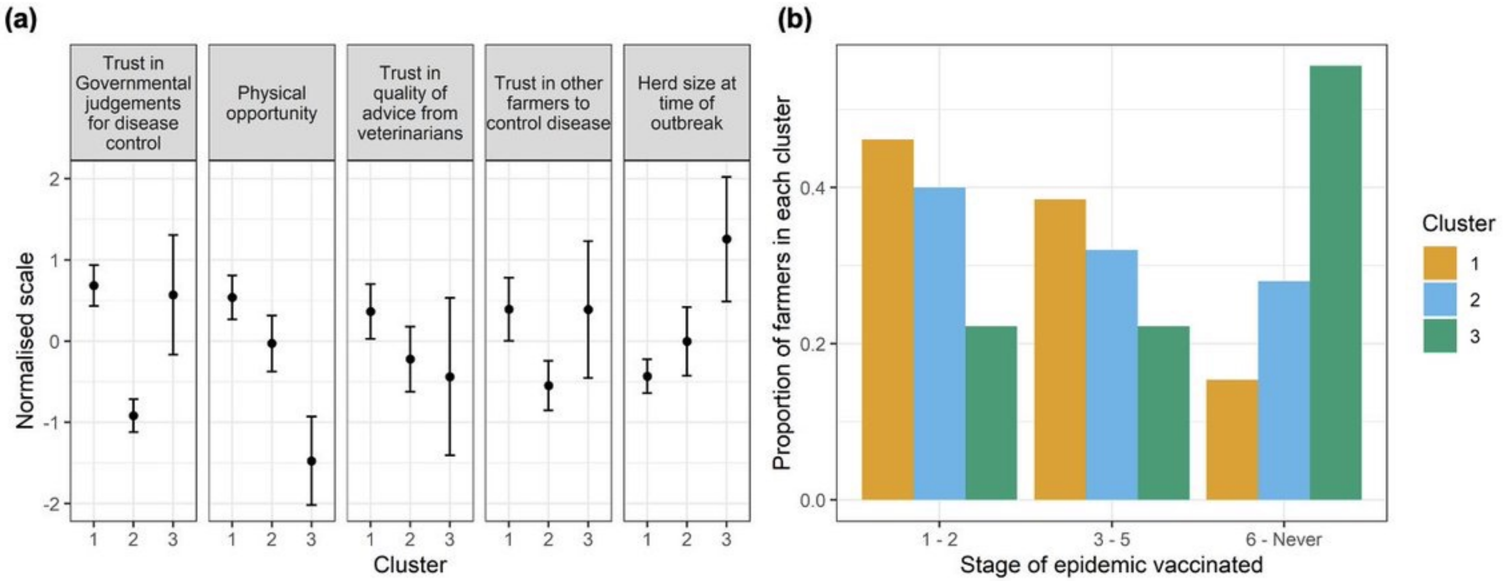


Study aims

1. Elicit farmers vaccination decisions to an unfolding epidemic and link to their psychosocial and behavioural profiles (within Great Britain)

2. **Refine mathematical disease models to capture psychosocial & behaviour change heterogeneities**

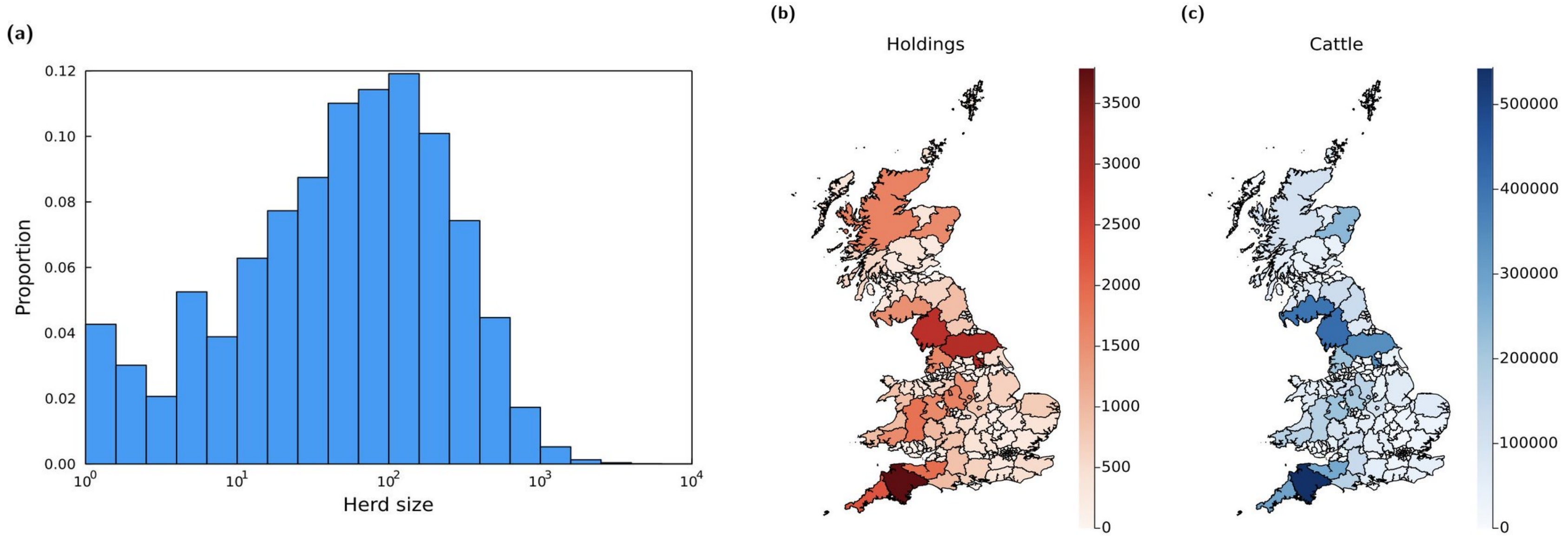
Data-driven model framework with epidemiological and behavioural layers.

3. Assess how psychosocial & behaviour change factors impact epidemiological outcomes given a fast-spreading livestock disease

Modelling methods - Cattle data

- Average 2020 cattle herd sizes from the Cattle Tracing System.

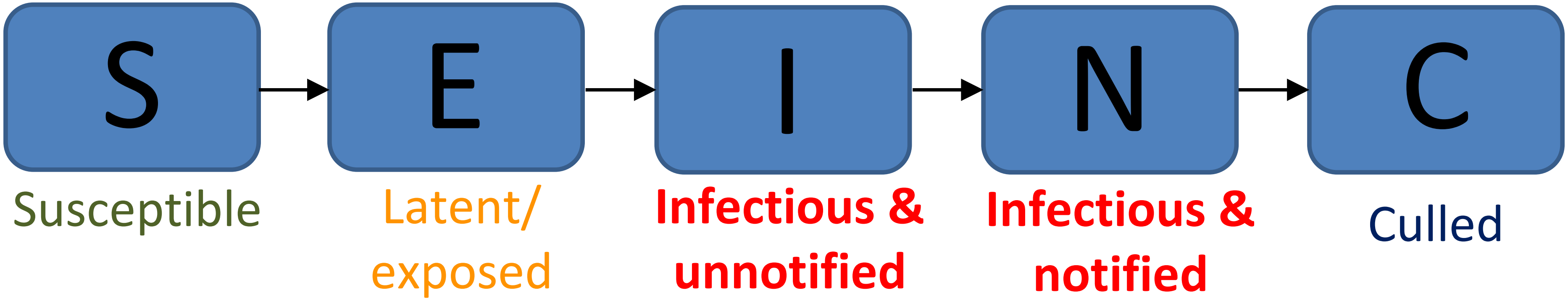
Figure: **(a)** Distribution of cattle herd sizes. **(b)** Number of holdings with cattle per region. **(c)** Number of cattle per region.



Modelling methods – Disease states

- **Epidemiological unit:** Premises.

- **Spatial model**, based loosely on the dynamics of FMD.
  - **Force of infection dependencies:** Number of livestock, livestock type specific transmissibility and susceptibility, distance between premises.
  - **Infection to infectiousness (latent period):** 5 days
  - **Infection to notification:** 9 days
  - **Infection to culled:** 13 days



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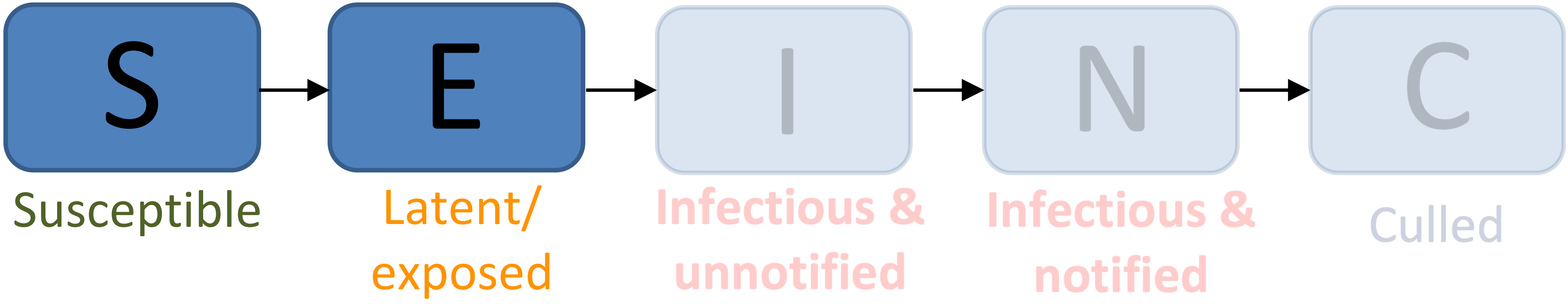

Modelling methods – Force of infection

Force of infection on premises i from premises j: $\lambda_{ij} = t_c N_{c,j}^{q} N_{c,i}^{p} K(d_{ij})$

- Infected premises contribution: Dependent on herd size
- Susceptible premises contribution: Dependent on herd size
- Transmission kernel: Force of infection between premises dependent on the distance between them.

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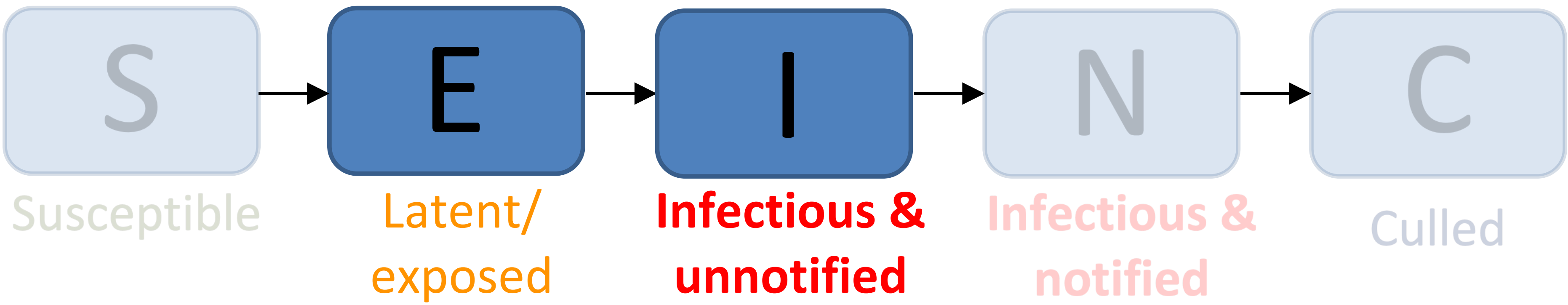

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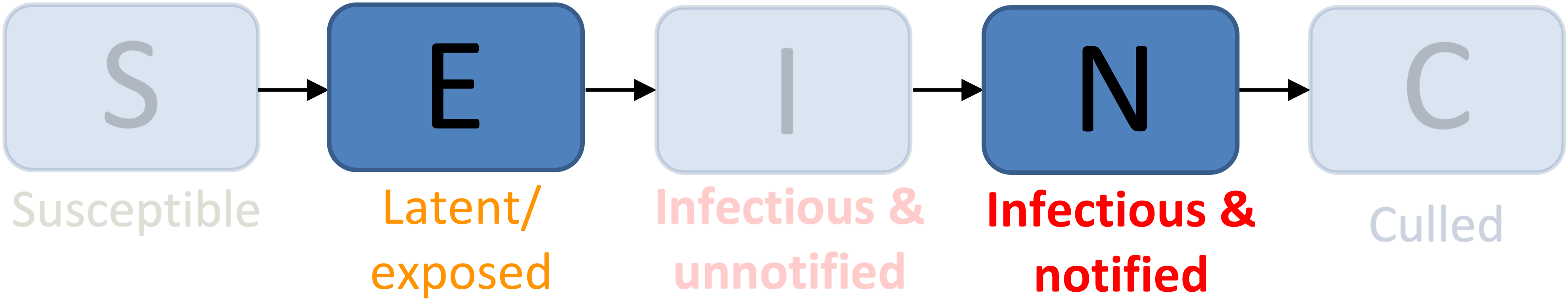

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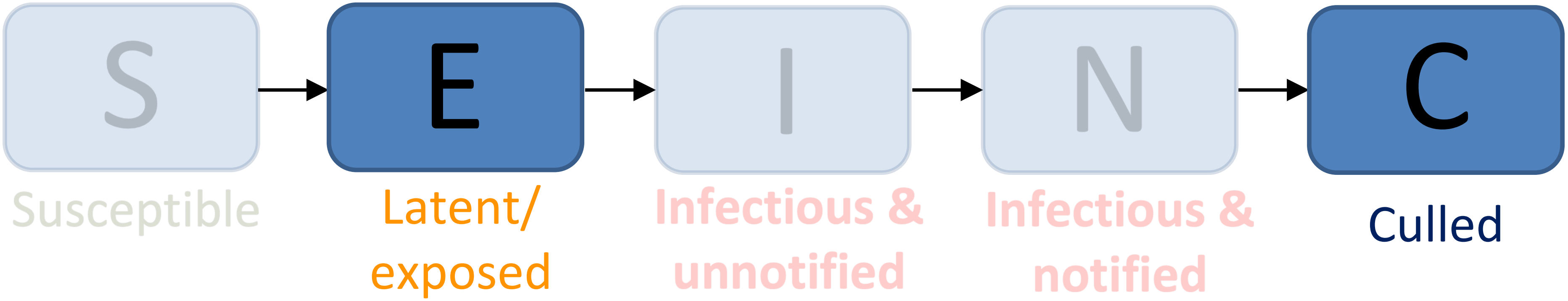


Modelling methods – Behavioural configurations

Uncooperative Only control is cattle being removed at holdings with confirmed infection. i.e. No holdings apply vaccination.

Homogeneous: Non-data informed

Farmer vaccinates when infection is within:

- Strong parasitism – 50km
- Weak parasitism – 320km
- Mutual cooperation – Before pathogen emergence

Heterogeneous: Non-data informed

Even split across different groups.

- Coop-Parasitism-Free riders (FR)
- Coop-Parasitism

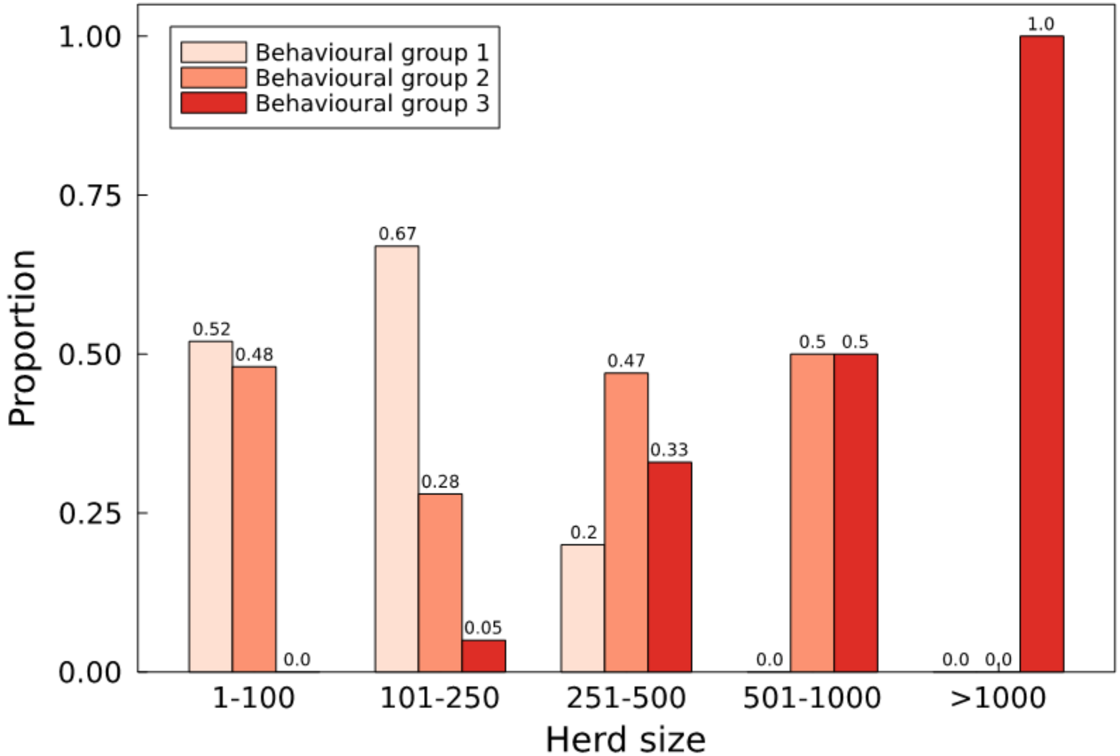
Heterogeneous: Data informed

Parameterised using interview results

- Trust expectancy (two covariate model)
- Herd size dependent (five covariate model)

Modelling methods – Behavioural configurations

Figure: For the “Herd size dependent” behavioural configuration, the probability of a holding being assigned to each of the behavioural groups with respect to the herd size.



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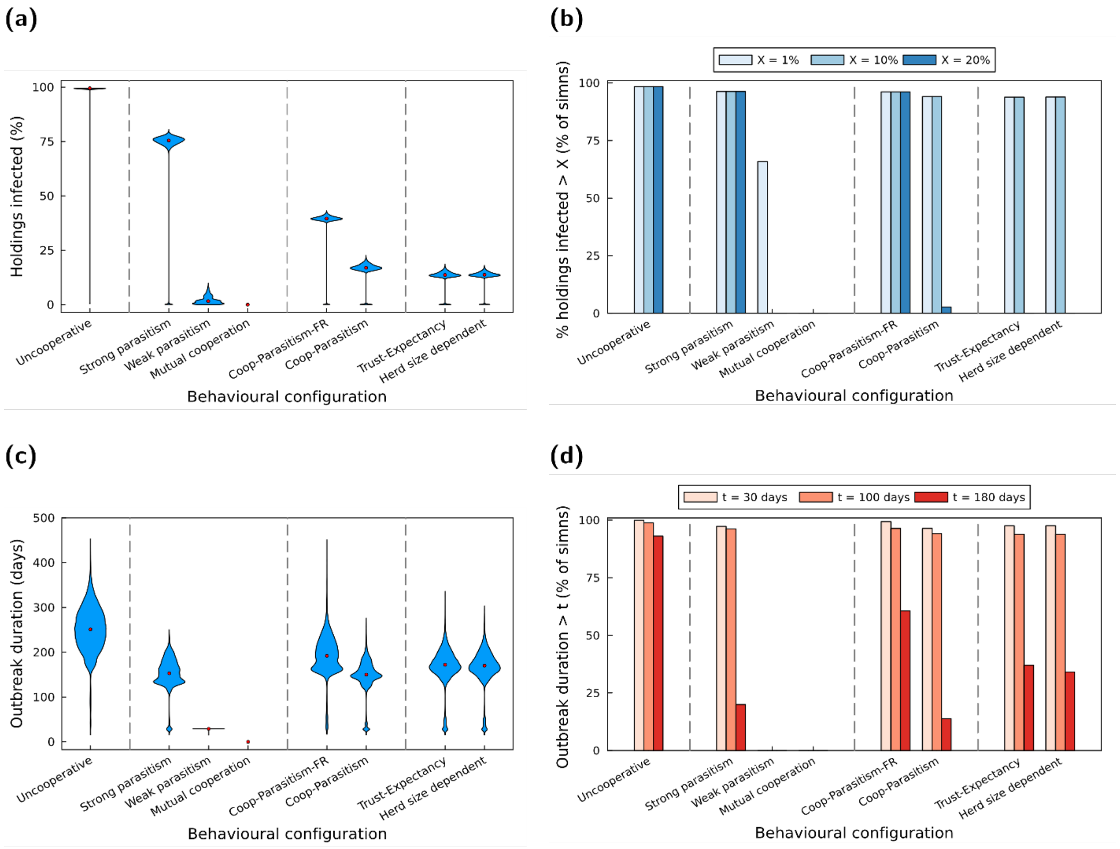
3. **Assess how psychosocial & behaviour change factors impact epidemiological outcomes given a fast-spreading livestock disease**

Spatial stochastic simulations of a fast-spreading epidemic process in Great Britain amongst cattle holdings:

- Per behavioural configuration, ran 500 replicates for each of the 89 seed region locations.
- Per simulation replicate, seeded infection in a randomly selected cluster of three premises.

Modelling results – Epidemiological metrics

Figure: For each behavioural configuration: **(a)** Distribution of percentage of holdings infected; **(b)** Percentage of simulations exceeding the stated final size; **(c&d)** Analogous summary statistics for outbreak duration.



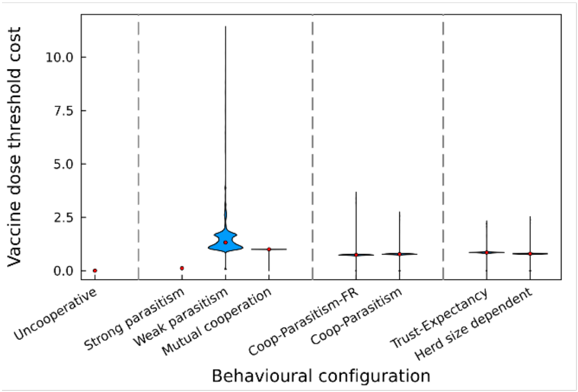
- Homogeneity in farmer behaviour vs data-informed psychosocial profile clusters estimates: **Disconnect in outcomes**

Modelling results – Health economic metrics

- **Vaccine dose threshold cost:** The maximum amount you can spend on a single vaccine dose where the total monetary cost (across vaccines and losses due to infection) does not exceed the monetary cost of infection incurred in the no intervention scenario (uncooperative configuration).

Figure: For each behavioural configuration: **(e)** Distribution of vaccine dose threshold costs; **(f)** Percentage of simulations exceeding the stated vaccine dose threshold cost.

(e)



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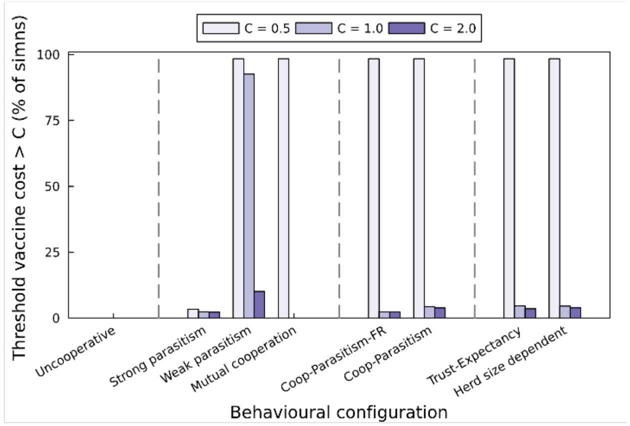
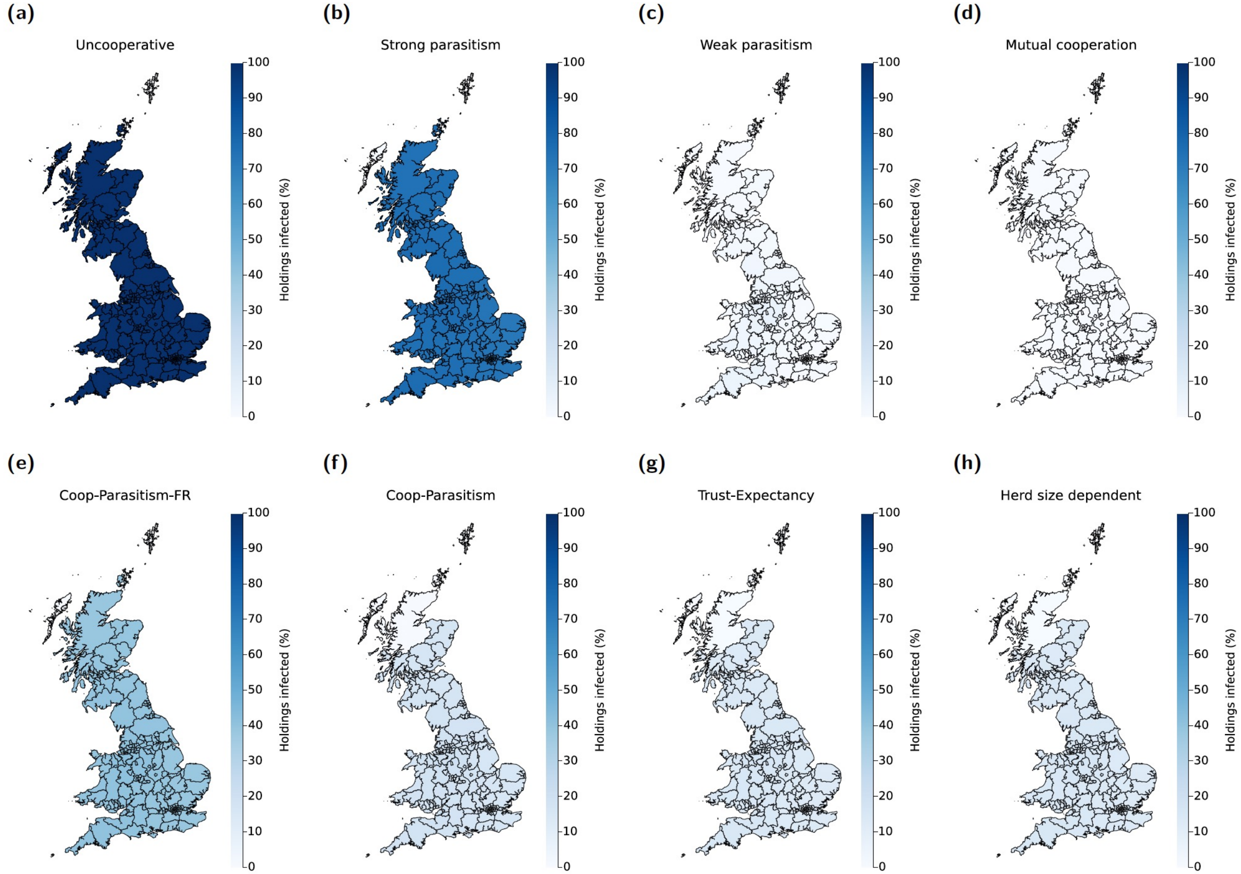


Modelling results – Role of seed infection region

Figure: Median percentage of holdings infected, dependent on region of outbreak emergence and behavioural configuration. Statistics computed from 500 replicates per scenario.



Limitations & further work

Elicitation

- Behavioural cluster analysis not feasible at regional level
- Are other intervention practices available to farmers

Modelling

- Focused on a limited set of interventions
- Considered a single set of epidemiological parameters

Open questions– what are the next steps?

- Support to establish longitudinal elicitation studies
- Tailored elicitation exercises to instruct behavioural group attributes amongst farmers towards control of enzootic diseases

Implications

A demonstration of a conjoined epidemiological and socio-behavioural workflow in action!

Encourage consideration of actions of individual farmers in policy frameworks for tackling future livestock disease outbreaks

Acknowledgements

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EM Hill, NS Prosser, PE Brown, E Ferguson, MJ Green, J Kaler, MJ Keeling, MJ Tildesley. (2023)
Preventive Veterinary Medicine.
doi:10.1016/j.prevetmed.2023.106019

FEED project webpage:

https://feed.warwick.ac.uk

Personal webpage:

https://edmhill.github.io

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Email: Edward.Hill@warwick.ac.uk

Zak Ogi-Gittins, William Hart, Jiao Song, Rebecca Nash, Jonathan Polonsky, Anne Cori, Edward M Hill, Robin N Thompson. (2023)
A simulation-based approach for estimating the time-dependent reproduction number from temporally aggregated disease incidence time series data.
medRxiv doi:10.1101/2023.09.13.23295471

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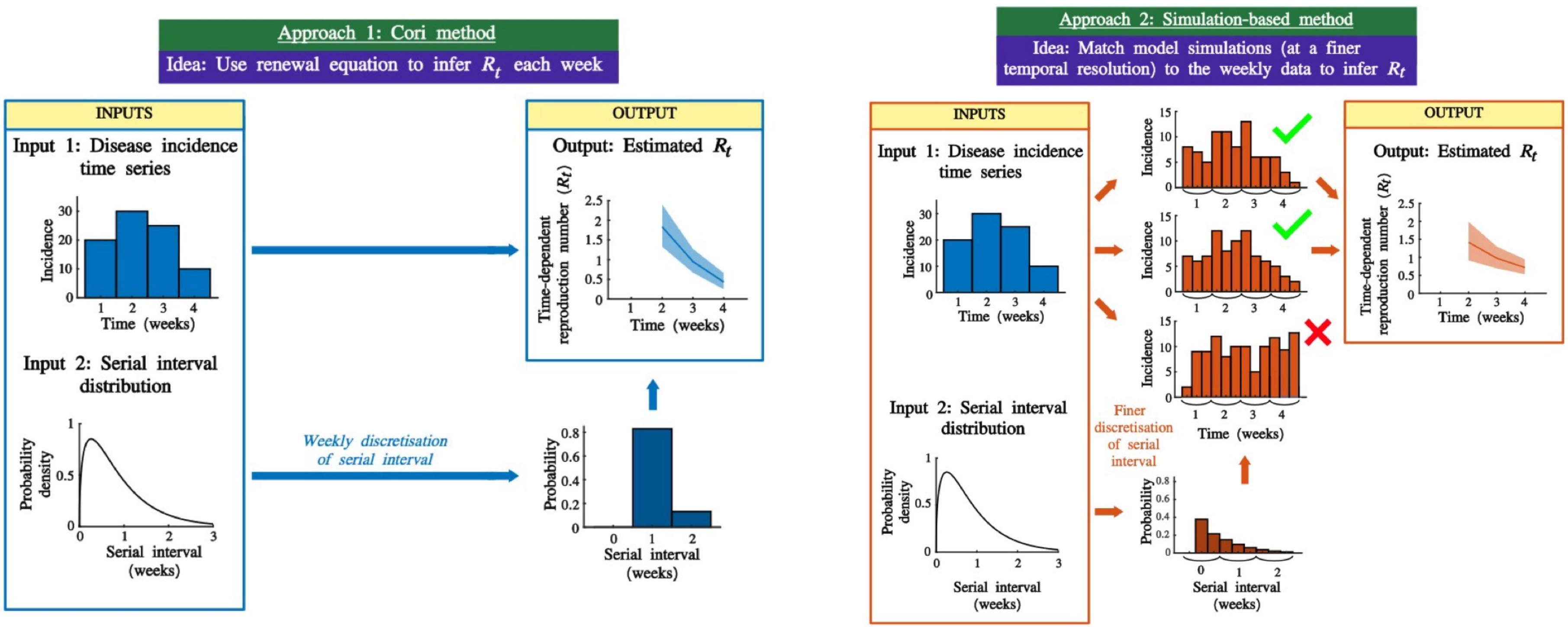

Phoebe Asplin, Matt J Keeling, Rebecca Mancy, Edward M Hill. (2023) Epidemiological and health economic implications of symptom propagation in respiratory pathogens: A mathematical modelling investigation. *medRxiv* doi:10.1101/2023.07.12.23292544

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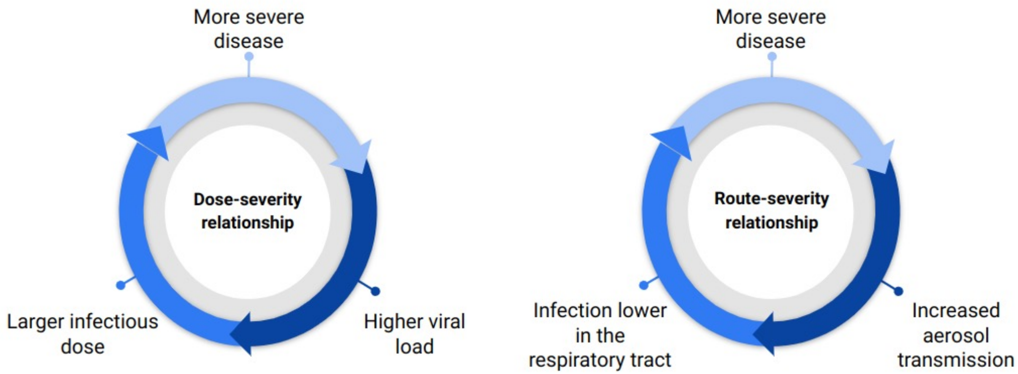

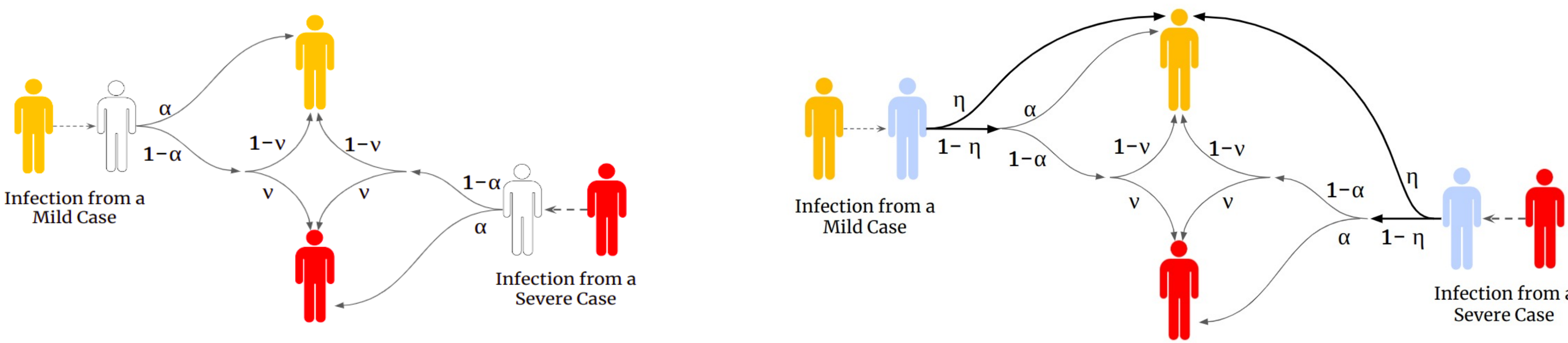

Rachel Seibel (co-supervised with Mike Tildesley)
Synthesising behavioural and epidemiological models and their methodologies to simulate predictive spread of infectious diseases

Research questions

- **Q1.** In the context of behavioural-epidemiological modelling of **human** infectious disease dynamics, how does individual-level information about the state of the outbreak affect epidemic impact?
- **Q2.** In disease systems impacting **livestock**, how do farmer behaviours regarding interventions impact epidemic severity?
- **Q3.** When considering **plant**-epidemiological models, how should opinion dynamics models be incorporated?

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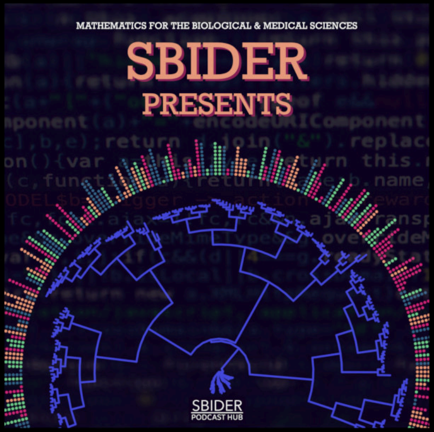

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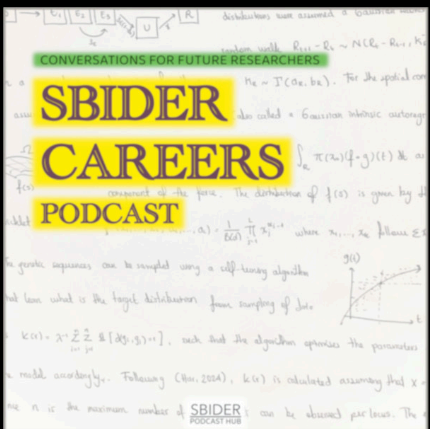

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What are the paths to a research career in epidemiology and infectious disease modelling? What are the day-to-day tasks?

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