Integrating economics and behaviour into disease transmission modelling

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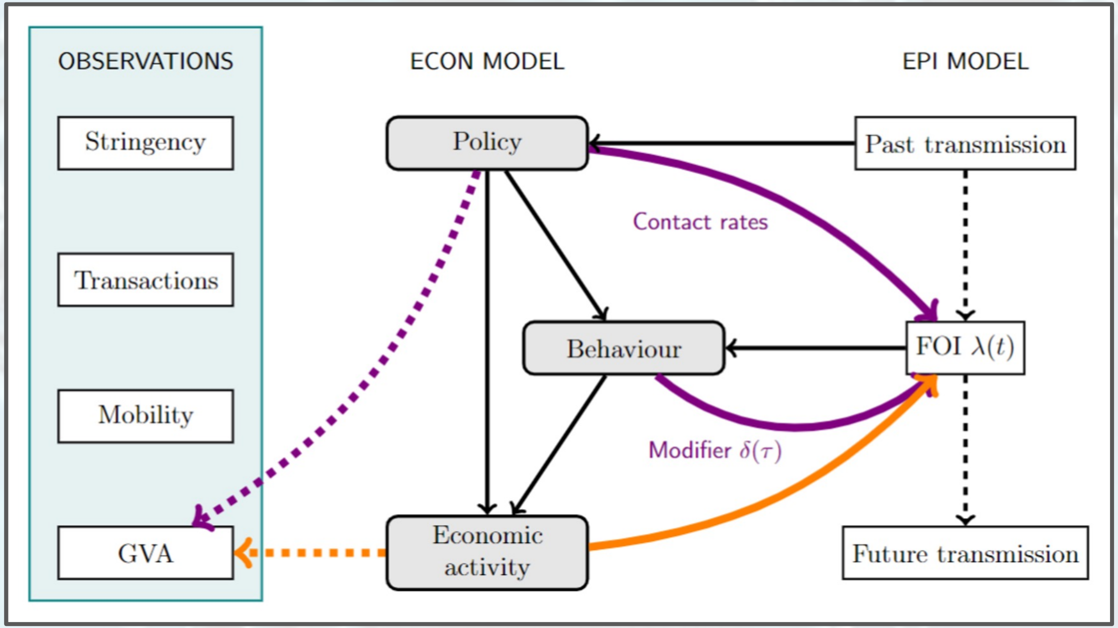
Integrated modelling

DAEDALUS:

Optimisation problem:

- Maximise GVA
- H_{max} respected
- $R_{end}<1$
- Education sector active

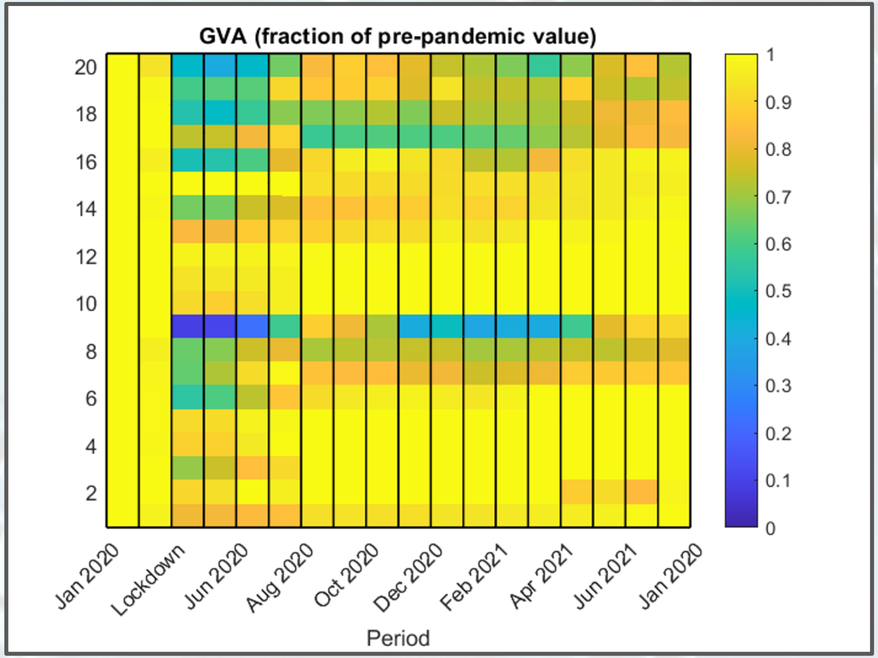


DAEDALUS: heterogeneity

- 4 age groups, working age split by sector
- GVA (Gross Value Added) indicates opening mapped to workplace/community contacts
- Sectors of note: hospitality, education, transport

$$\frac{dS_i}{dt} = \beta S_i \sum_j C_{ij} \frac{I_j}{N_j}$$

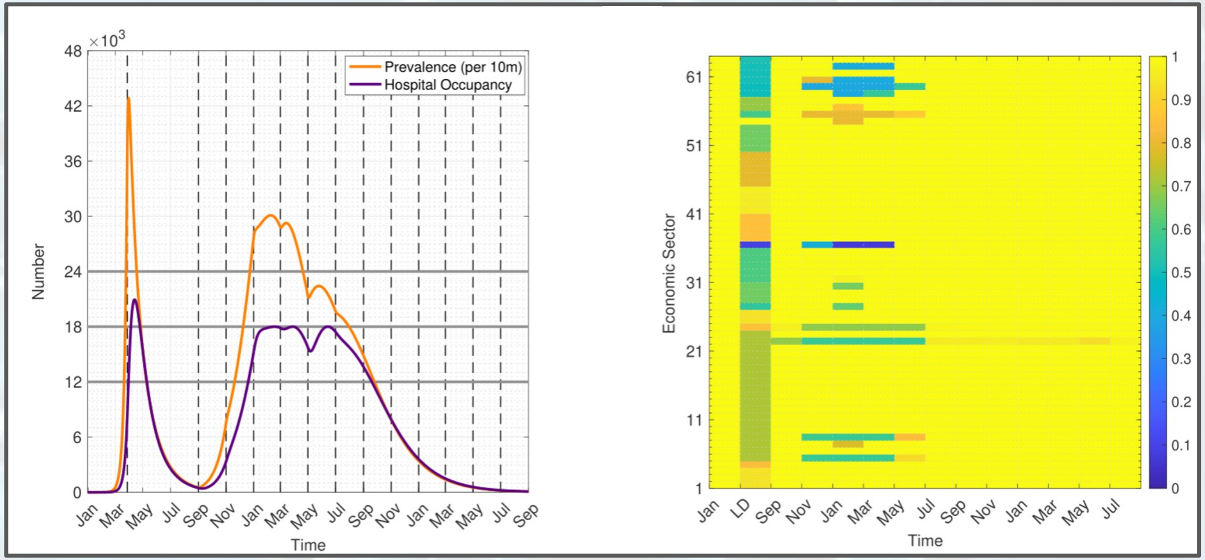
$$C = \begin{pmatrix} c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \\ c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \end{pmatrix}$$



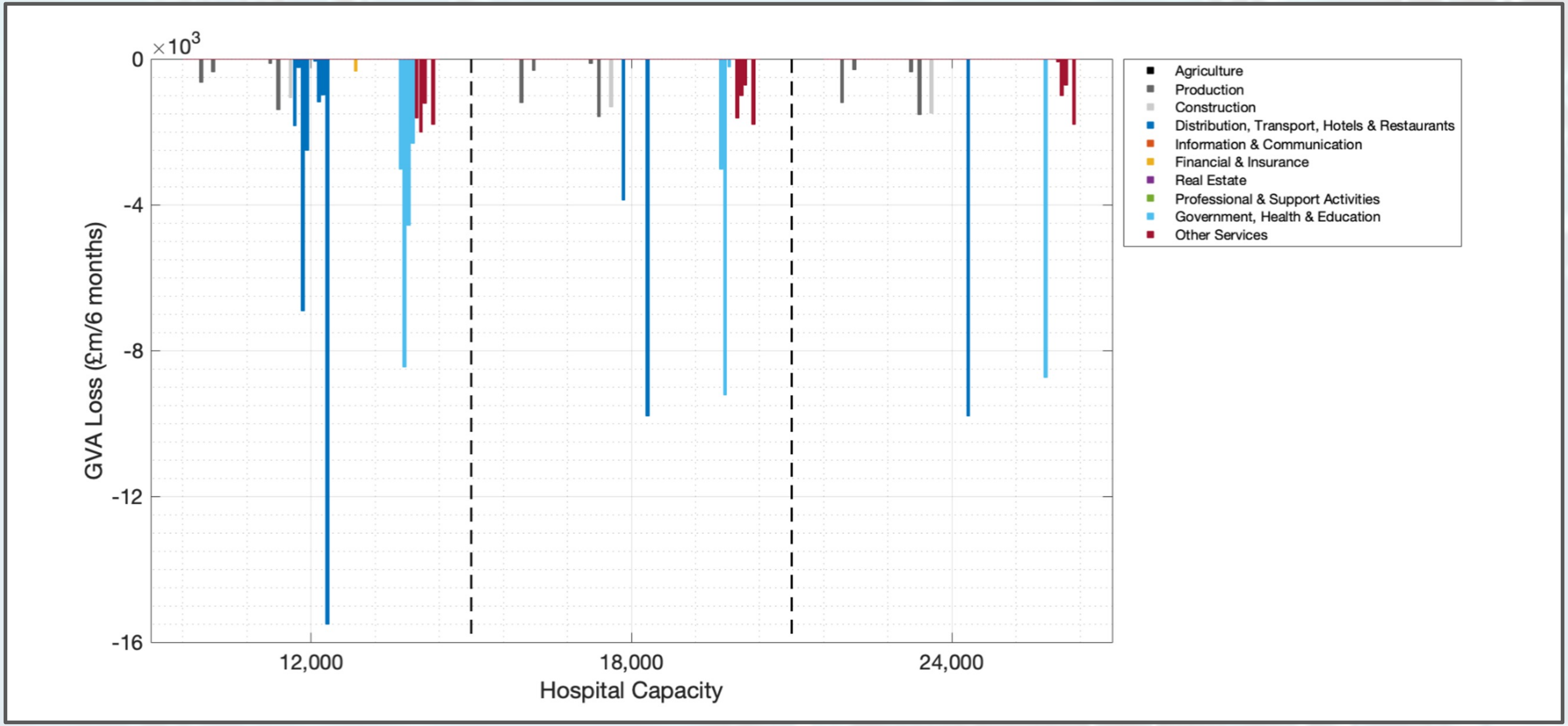
DAEDALUS: example solution

Example solution:

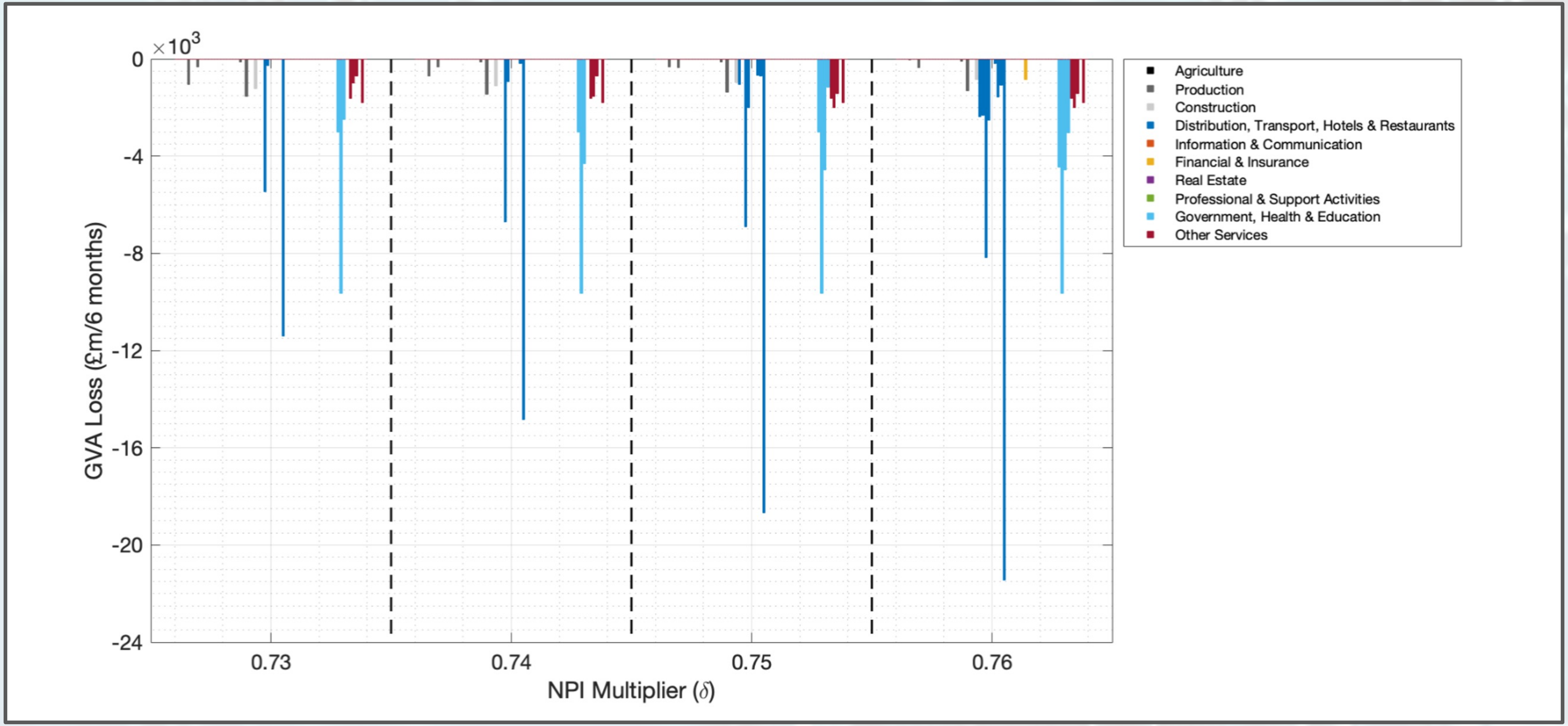
- *H_{max}=18,000*
- *δ=0.72 fixed*
- *Education @ 80%*



DAEDALUS: economic loss



DAEDALUS: transmission modifiers



Limitations

- Point estimates of sector-stratified contact rates
- GVA determines sector closure
- High sensitivity to some contact rates and to modifiers
- Modifiers are extrinsic

- **How can we make behavioural factors intrinsic to the model?**

What is behaviour?

Activities:
Mask wearing
Hand washing
Social distancing
Meeting outdoors
Rule of six
Cancelling plans
Avoiding healthcare facilities
Avoiding children/childcare facilities
Shopping online
Working from home
Virtual meetings
Testing (symptomatic/asymptomatic)

Psychological drivers:
Risk version
Time preferences
Overconfidence
Trust in government
Altruist/pro-social behaviour

Relevance to force-of-infection:

Number of contacts
Probability of infection given contact

Relevance to economics:

Workplace structure
Expenditure (hospitality/retail)

Behavioural feedback

Simple model:

For all age/sector groups i,j split contact rate into 2 behavioural subgroups

$$\frac{dS_i}{dt} = \beta S_i \sum_j C_{ij} \frac{I_j}{N_j}$$

$$C = \begin{pmatrix} c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \\ c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \end{pmatrix}$$

$c_{23} \rightarrow$

	j=3,1	j=3,2
i=2,1	$\alpha^2 c_{23} p$	$\alpha c_{23}(1-p)$
i=2,2	$\alpha c_{23} p$	$c_{23}(1-p)$

Behavioural feedback

Simple model: for all age/sector groups, split contact rate into 2 behavioural subgroups

$$\frac{dS_i}{dt} = \beta S_i \sum_j C_{ij} \frac{I_j}{N_j}$$

$$C = \left(\begin{array}{cc|cc|cc|c|cc}
\alpha^2 p c_{11} & \alpha(1-p)c_{11} & \alpha^2 p c_{12} & \alpha(1-p)c_{12} & \alpha^2 p c_{13} & \alpha(1-p)c_{13} & \cdots & \alpha^2 p c_{1n} & \alpha(1-p)c_{1n} \\
\alpha p c_{11} & (1-p)c_{11} & \alpha p c_{12} & (1-p)c_{12} & \alpha p c_{13} & (1-p)c_{13} & \cdots & \alpha p c_{1n} & (1-p)c_{1n} \\
\hline
\alpha^2 p c_{21} & \alpha(1-p)c_{21} & \alpha^2 p c_{22} & \alpha(1-p)c_{22} & \alpha^2 p c_{23} & \alpha(1-p)c_{23} & \cdots & \alpha^2 p c_{2n} & \alpha(1-p)c_{2n} \\
\alpha p c_{21} & (1-p)c_{21} & \alpha p c_{22} & (1-p)c_{22} & \alpha p c_{23} & (1-p)c_{23} & \cdots & \alpha p c_{2n} & (1-p)c_{2n} \\
\hline
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
\hline
\alpha^2 p c_{n1} & \alpha(1-p)c_{n1} & \alpha^2 p c_{n2} & \alpha(1-p)c_{n2} & \alpha^2 p c_{n3} & \alpha(1-p)c_{n3} & \cdots & \alpha^2 p c_{nn} & \alpha(1-p)c_{nn} \\
\alpha p c_{n1} & (1-p)c_{n1} & \alpha p c_{n2} & (1-p)c_{n2} & \alpha p c_{n3} & (1-p)c_{n3} & \cdots & \alpha p c_{nn} & (1-p)c_{nn}
\end{array}\right)$$

Note: $p=p_{age}$, time dependence $\alpha(t), p(t)$

Behavioural parameters: α (effectiveness of behavioural change), p_{age} (proportions of age group changing behaviour)

Parameter interpretation

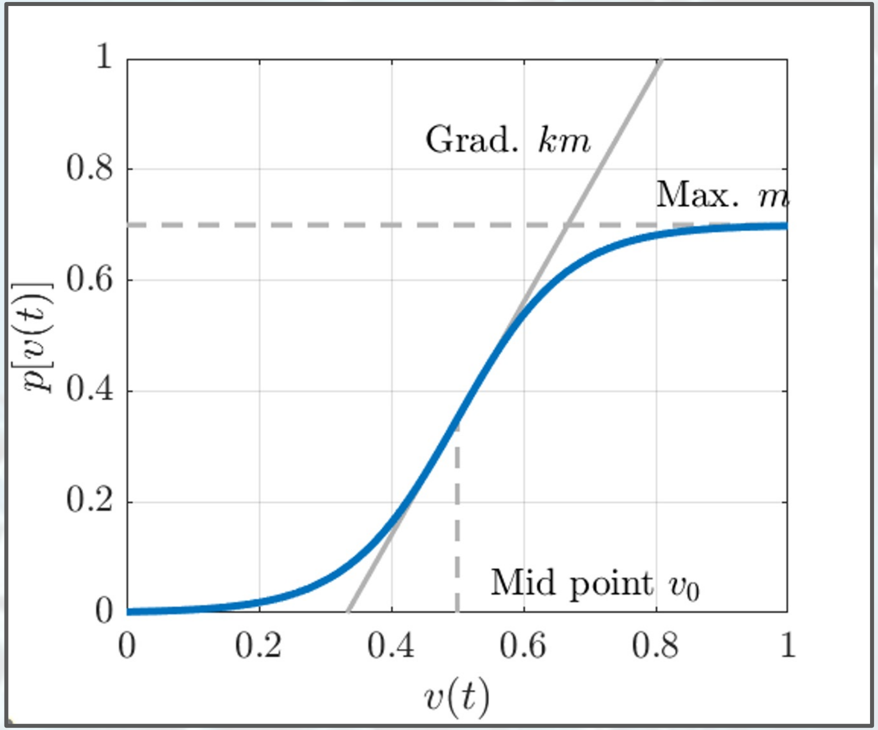
Example: logistic feedback

α fixed, *p* depends on some real-time quantity *v(t)*

In reality:

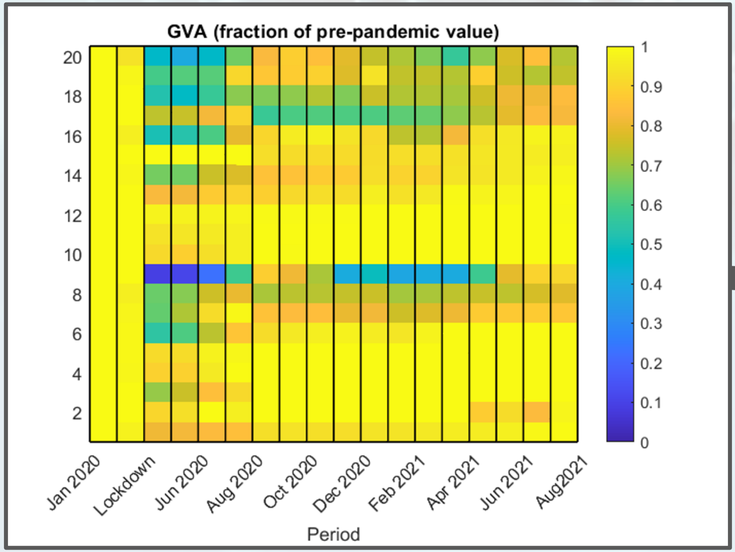
- Work in discrete time intervals
- Require several variables:

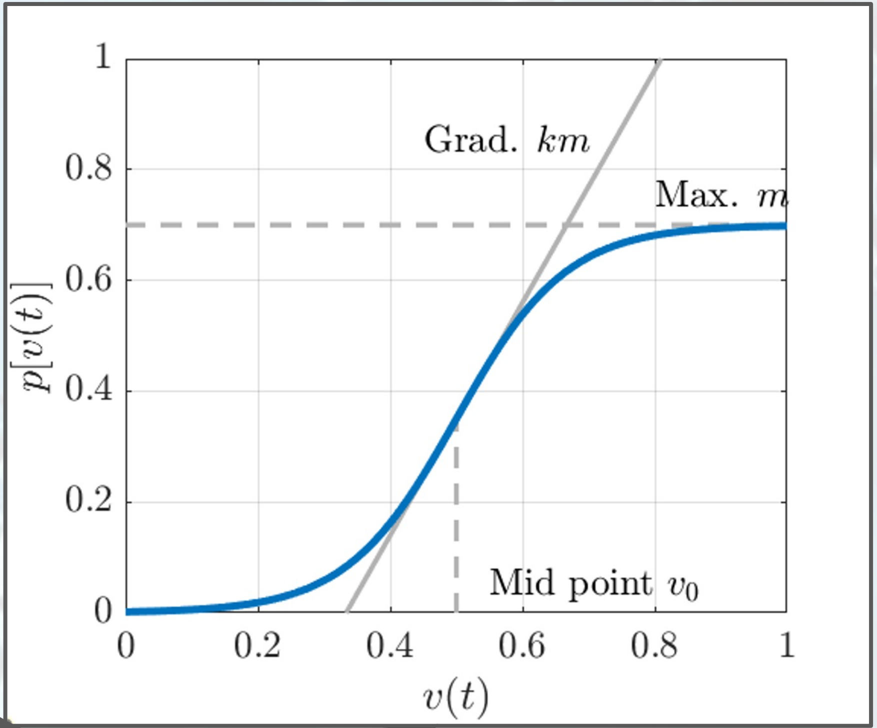
$$p(t) = \frac{m}{1 + e^{v_0 - \mathbf{k} \cdot \mathbf{v}(t)}}$$



Parameter interpretation

Logistic feedback using GVA

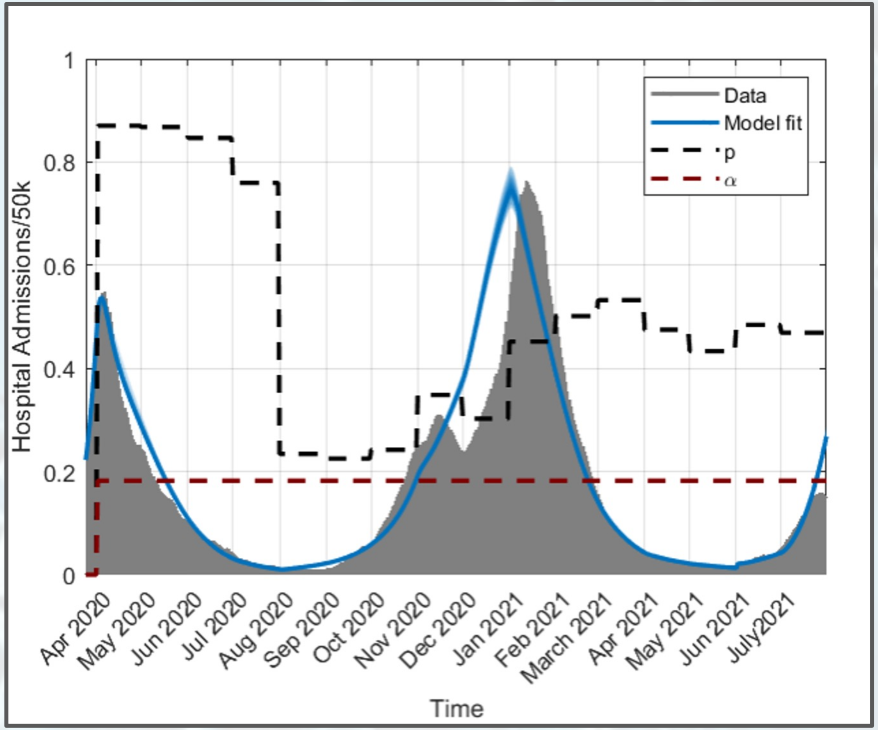




Model Calibration B: GVA

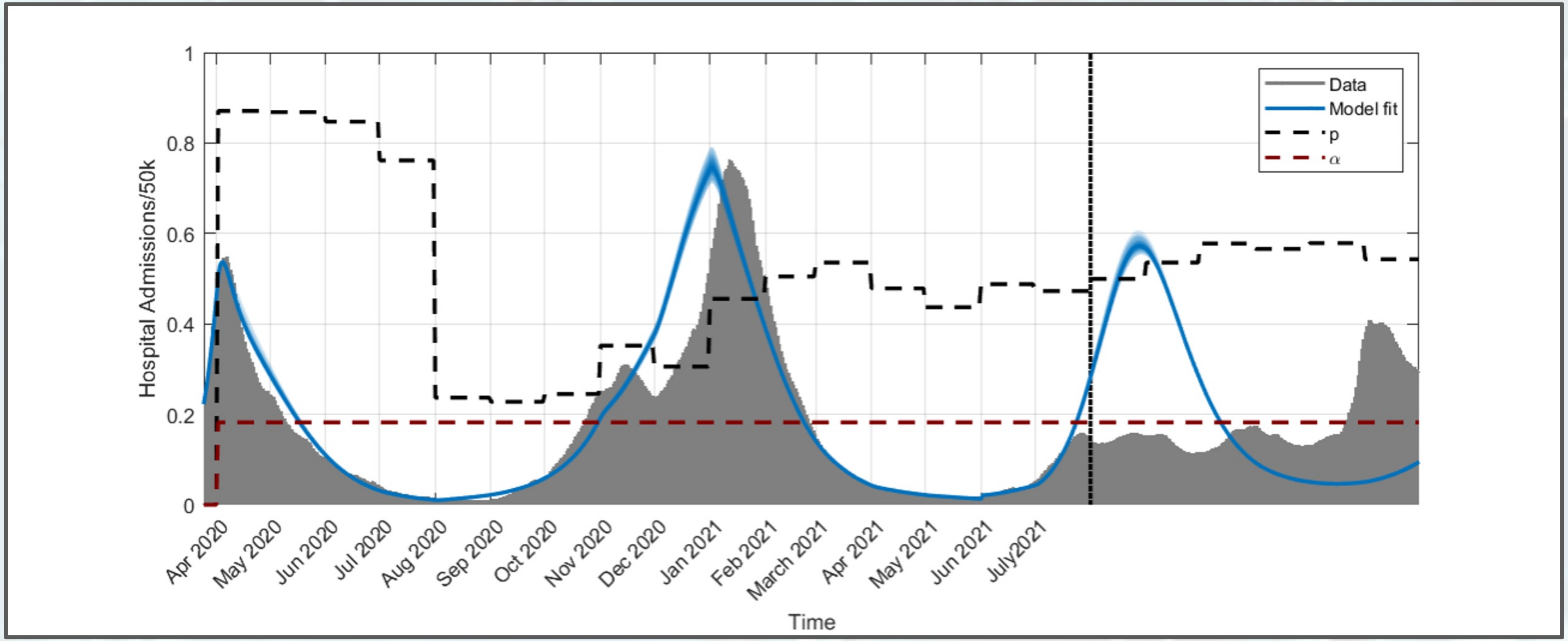
Model fit

- 3 principal components of GVA: $k_1, k_2, k_3, m, v_0, \alpha$
- Fixed *p* in each monthly period
- Calibration informative retrospectively
- **Use in projections requires prescription of GVA values** i.e. simultaneous modelling of economic activity



Model projections

Project forwards (GVA)



Moving forward

Proof of concept:
simple models of behavioural change can encapsulate outbreak dynamics when calibrated so simple data sets

Behavioural parameter are companion to natural history parameters of a new outbreak

Finding model parameters can be done directly (survey) or indirectly (fitting)

Projection requires dependency of parameters on measurable/modelable quantities

Identify behavioural archetypes

Thank you

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