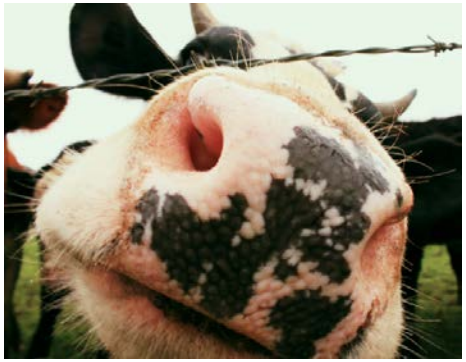



Modelling FMD – translating knowledge from epidemics to endemic settings

Mike Tildesley

Epidemic vs Endemic Control

FMD Epidemics

Outbreaks typically last from a few days to several months.

Restrictions on live animal movements put in place at large scale to prevent spread.

Culling of infected and “high risk” animals is the main form of control policy.

Vaccination may be used though regaining of disease free status usually requires ”vaccination to kill”.

Transmission influenced by: Farm Location and Size, Industry Type, Connectivity

FMD in Endemic Settings

Ongoing circulation of multiple serotypes (depending on setting).

Local restrictions may be enforced around infected farms but in many instances it’s “business as usual”.

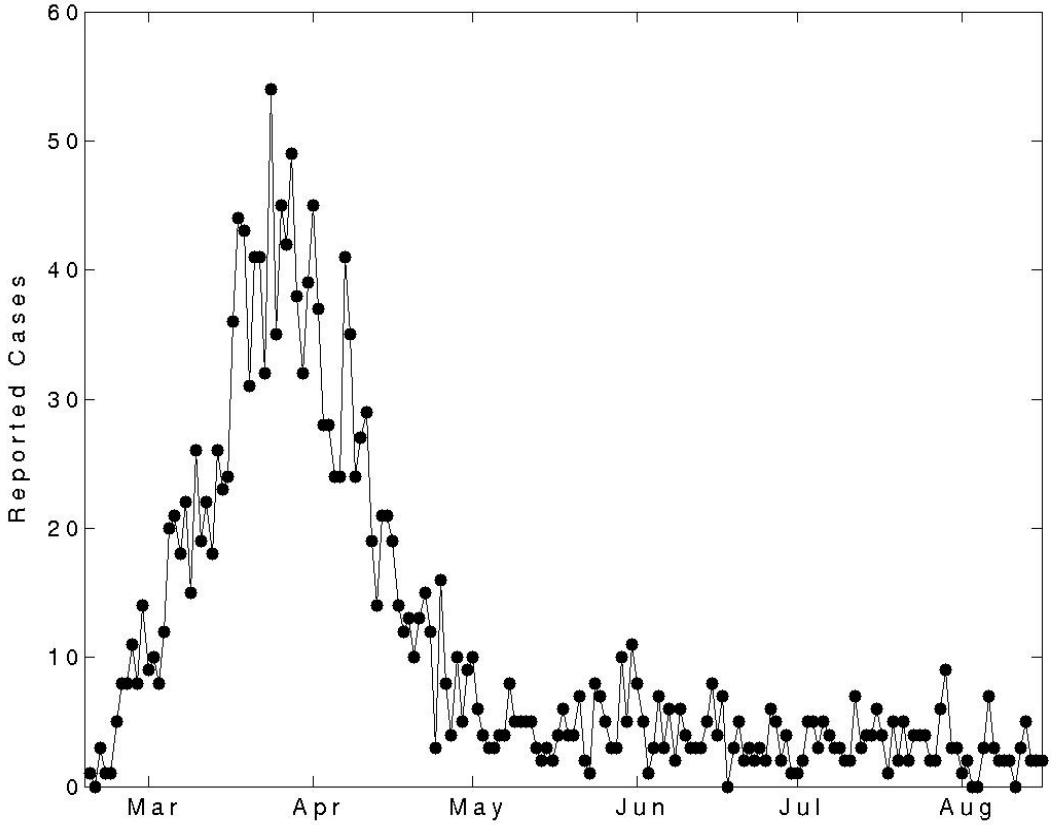
Infected animals will not, in general, be culled, with most animals recovering from infection.

Vaccination may be used reactively, though vaccines can be of varying quality depending on the setting.

Transmission may be influenced by: Local farming practices, vaccine uptake + ??

The UK 2001 Foot and Mouth Disease Epidemic

UK 2001 epidemic timescale



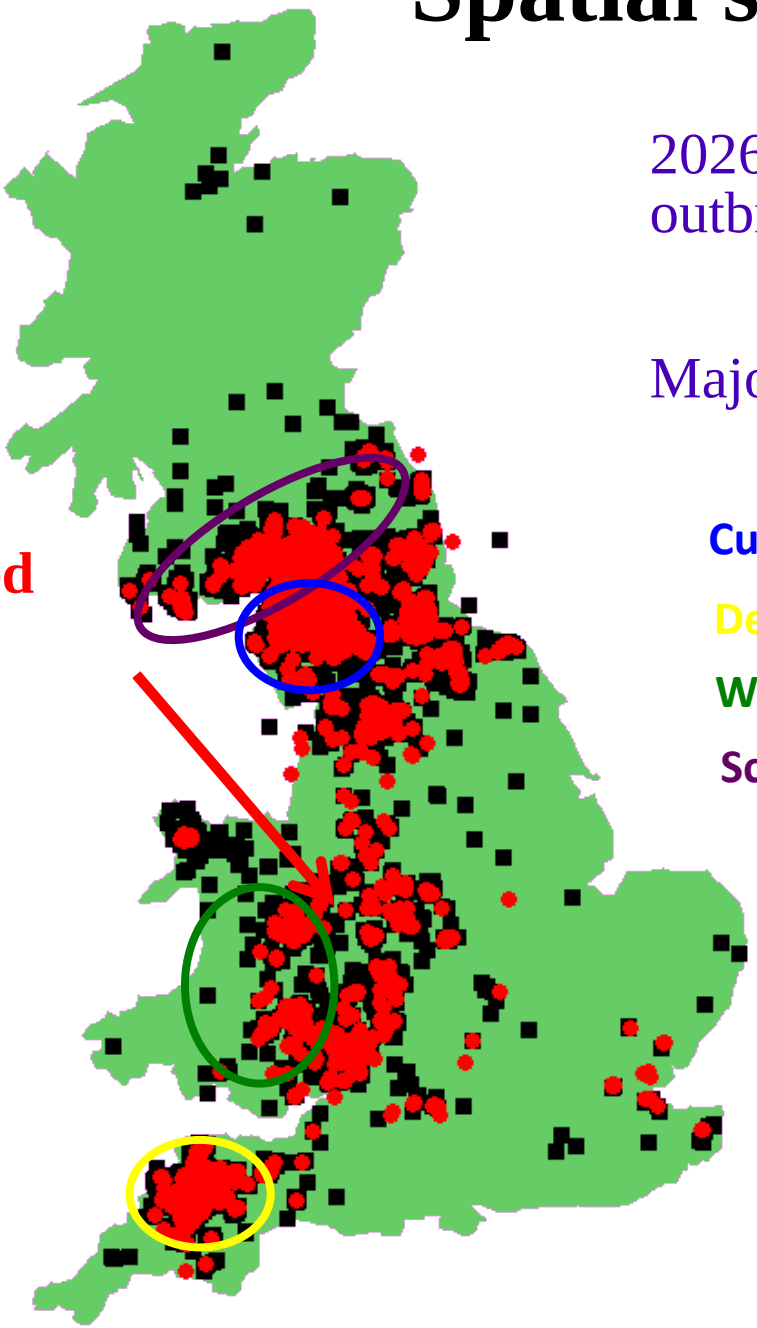
FMD entered the UK in early February.

Epidemic peak occurred in late March/early April.

Very long epidemic tail.

Over 10,000 farms were affected by the epidemic (either infected or culled as part of the control) and a total of 850,000 cattle and 4,000,000 sheep were culled.

Spatial spread of Disease



2026 premises were infected during the outbreak (Infected Premises)

Major epidemic hot spots in:

Cumbria – 892 IPs + 2952 control culls

Devon – 172 IPs + 775 control culls

Wales – 113 IPs + 684 control culls

Scottish Borders – 187 IPs + 1266 control culls

The Impact of Movement Restrictions

- For outbreaks of FMD in the UK, nationwide controls are introduced, regardless of location of outbreak.

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- In 2007, there were 9 premises infected with FMD in Surrey.

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- For outbreaks of FMD in the UK, nationwide controls are introduced, regardless of location of outbreak.
- In 2001, a delay in introduction of control caused spread around the country.
- In 2007, there were 9 premises infected with FMD in Surrey.
- In this outbreak, the largest cost of the outbreak was due to this movement ban.

Economic Costs of the Outbreak

The costs of the UK 2001 outbreak can be split into five main categories:

Direct Costs to the Farmer (compensation and disposal) - £3 billion

Welfare Cull costs - £0.2 billion

Costs to the Wider Agricultural Sector - £0.3 billion

Export Costs - £0.3 billion

Costs to the Tourist Industry - £5 billion

The nationwide movement ban and related restrictions was directly responsible for increased costs in several of these categories (though may, of course, have significantly reduced the outbreak size).

Are nationwide movement restrictions always justified for FMD epidemics?

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We will use the Warwick FMD model to simulate the economic impact of regional movement control

How do we calculate costs?

Direct Costs: Proportional to total livestock culled (~£1200/cattle, ~£320 sheep)

Welfare Costs: Proportional to total number of farms per day subject to movement restrictions (~£5 per Farm Day Restricted)

Agricultural Costs: Proportional to total number of movements prevented (~£140 per movement prevented)

Export Costs: Proportional to length of the export ban (~£400,000 per day)

Tourism Costs: Proportion to scale of outbreak (~£170 per Farm Day Restricted)

All of these figures have been estimated from the 2002 Anderson Lessons to be Learned Enquiry (sensitivity to these shown later).

The Warwick Model

- **The model was originally used during the 2001 FMD outbreak, to predict the risk of local spread, after a nationwide movement ban.**

Risk of infection = "Infectiousness" of Farm A

×

"Susceptibility" of Farm B

×

Distance Factor **(The closer the farm, the higher the risk)**

The Local Spread Model

Probability of infection per day for every susceptible farm is given by:

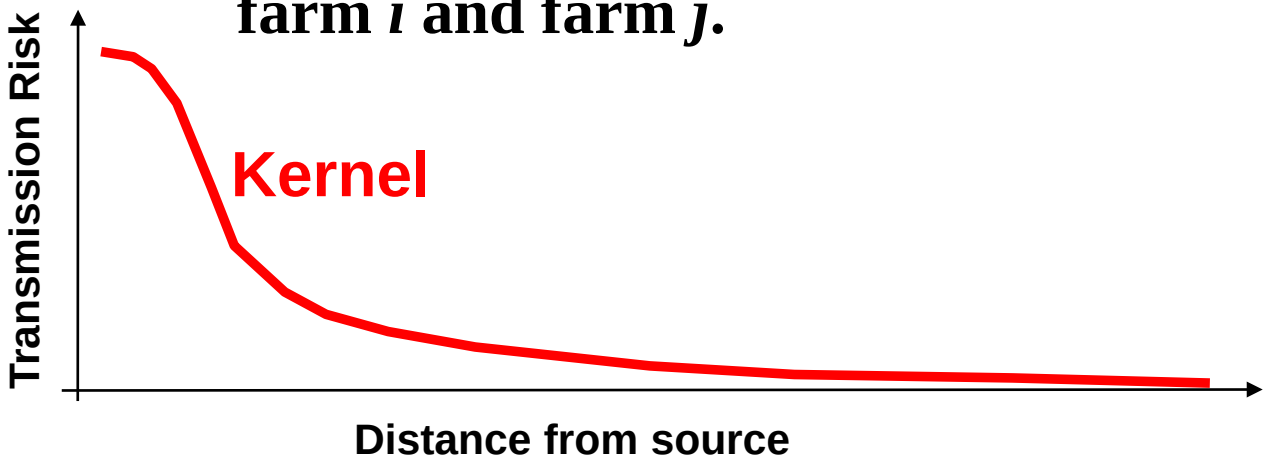
$$\text{Prob}_i = 1 - \exp\left[[S_c N_{c,i}^{pc} + S_s N_{s,i}^{ps}] \sum_{\text{Infected } j} [T_c N_{c,j}^{qc} + T_s N_{s,j}^{qs}] K(d_{ij}) \right]$$

$S_{c/s}$ - susceptibility of cattle/sheep.

$N^{i}_{c/s}$ - number of cattle/sheep on farm *i*.

$T_{c,s}$ - Transmission rate of cattle/sheep.

$K(d_{ij})$ **- The transmission kernel. A parameter which weights the probability of infection based on the distance between farm *i* and farm *j*.**

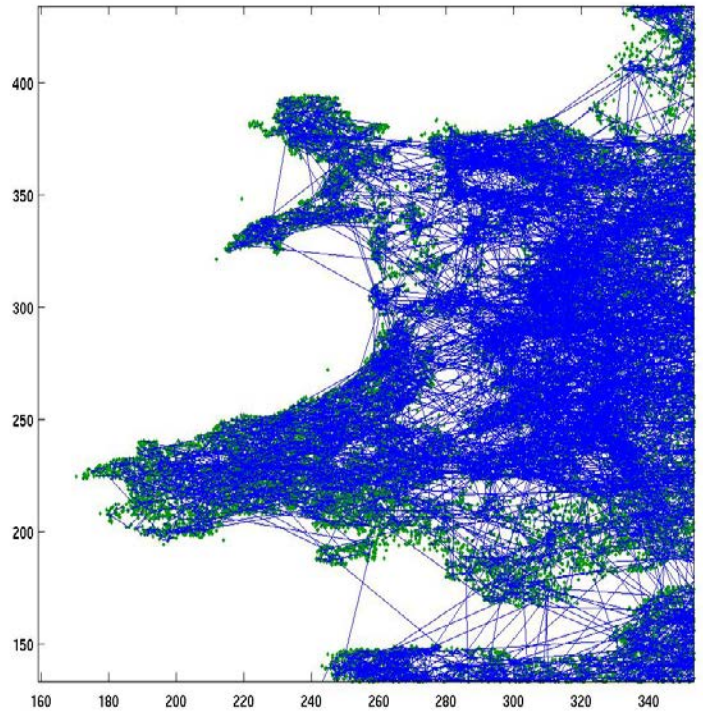


Modelling Movements

In addition, we want to consider the risk of transmission via livestock movements.

When a farm is reported, we will consider the following options:

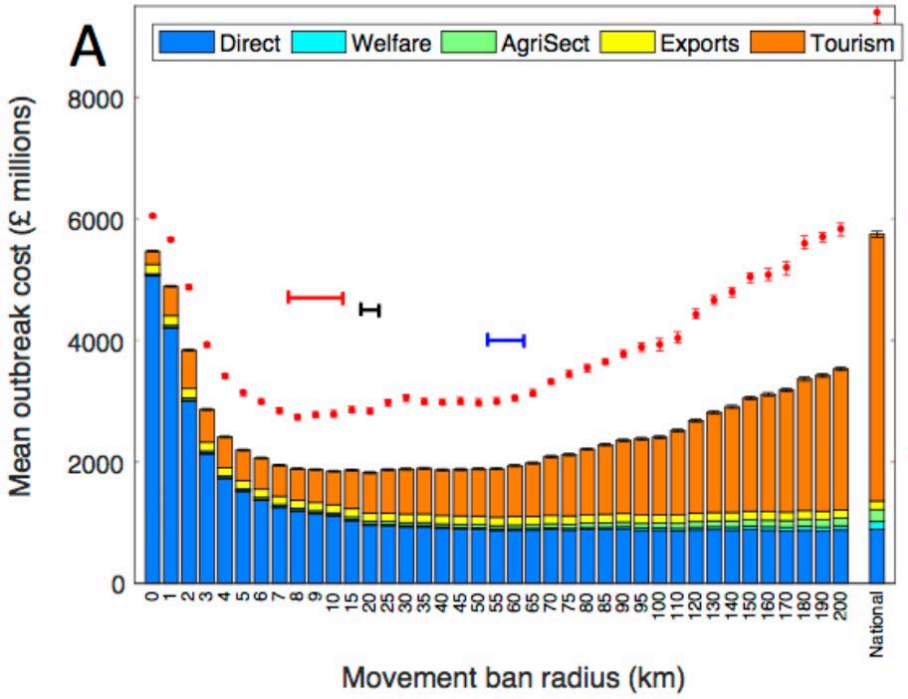
- No movement control
- Movement ban within a certain radius of infected premises
- Nationwide movement ban



We utilize data from the cattle tracing scheme and the animal movement license scheme in the UK to simulate transmission risk via movements.

Results

Cumbria



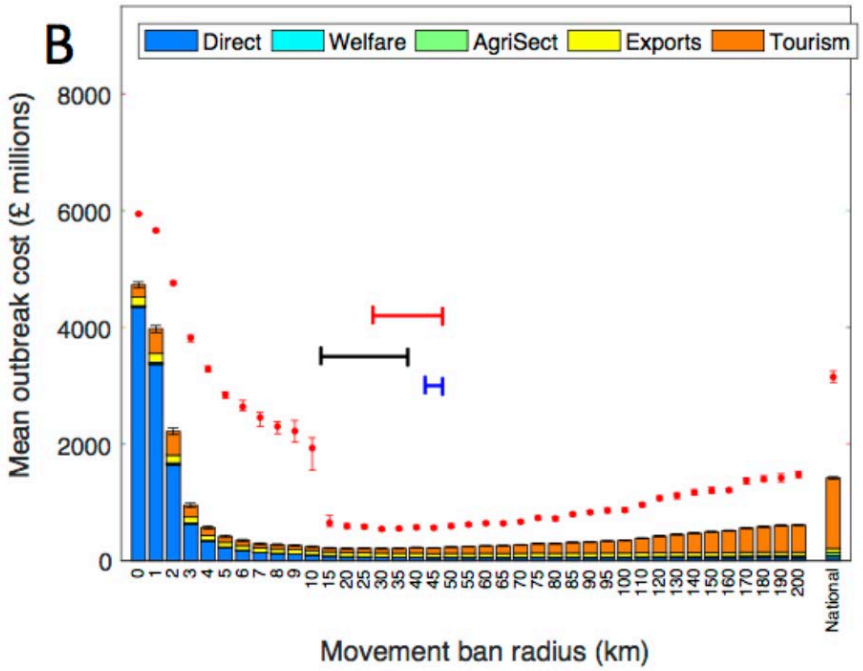
Impact of tourism costs lower in Devon.

Higher radius movement control optimal overall.

Nationwide movement ban optimal for minimising direct costs.

Small radius (~20km) movement ban optimal for minimising overall costs.

Devon

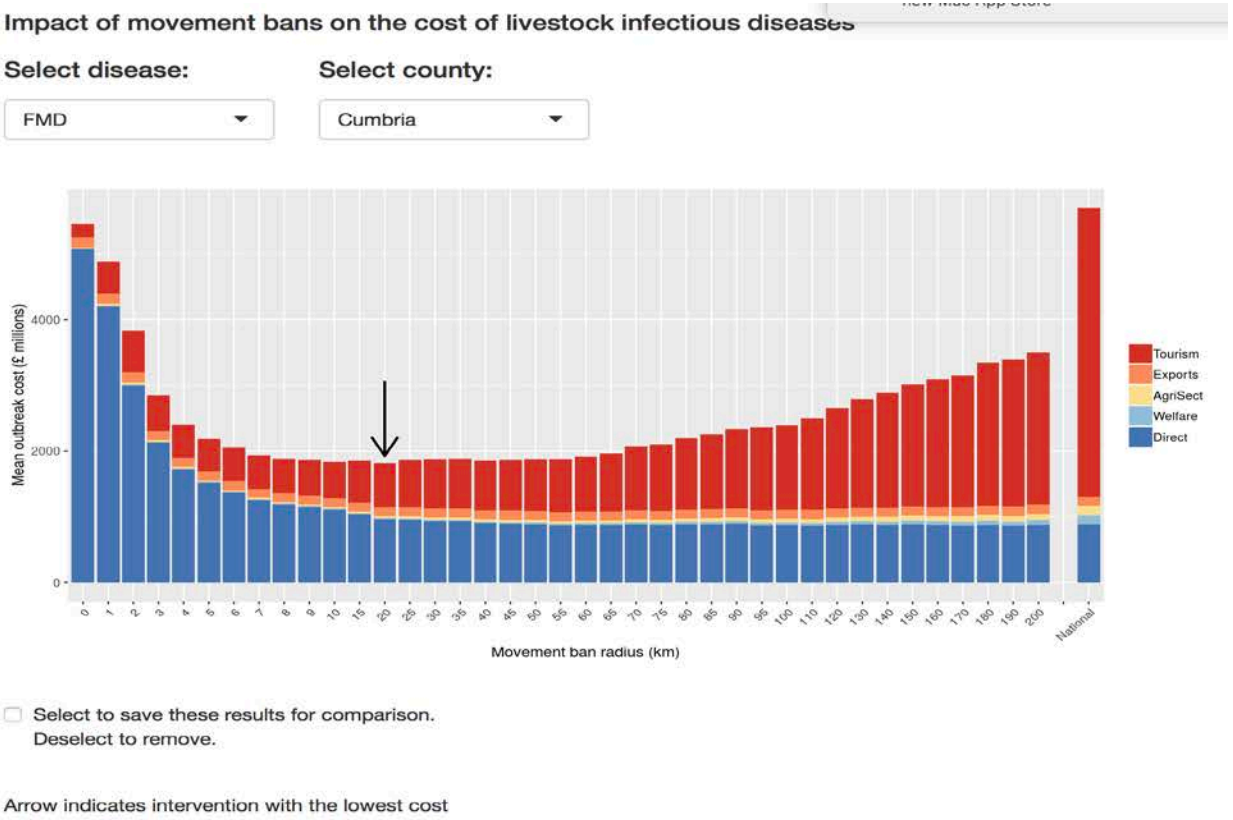


Sensitivity to Cost Assumptions

The presented results are dependent upon the specific costs defined.

We can therefore test the sensitivity of our results to different cost assumptions.

This can be done using our freely accessible Shiny App:
https://livestockmovements.shinyapps.io/movement_control/



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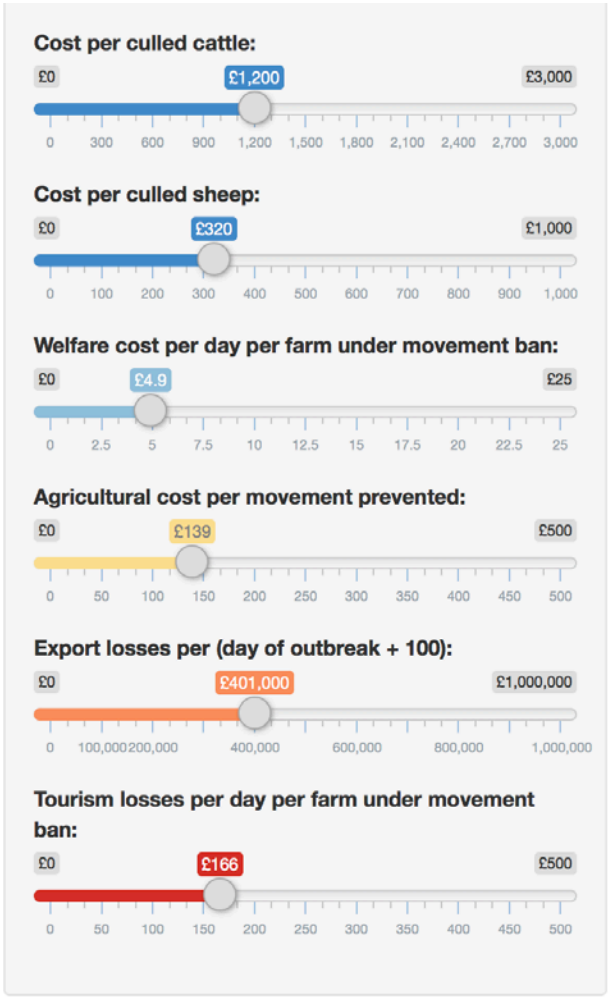

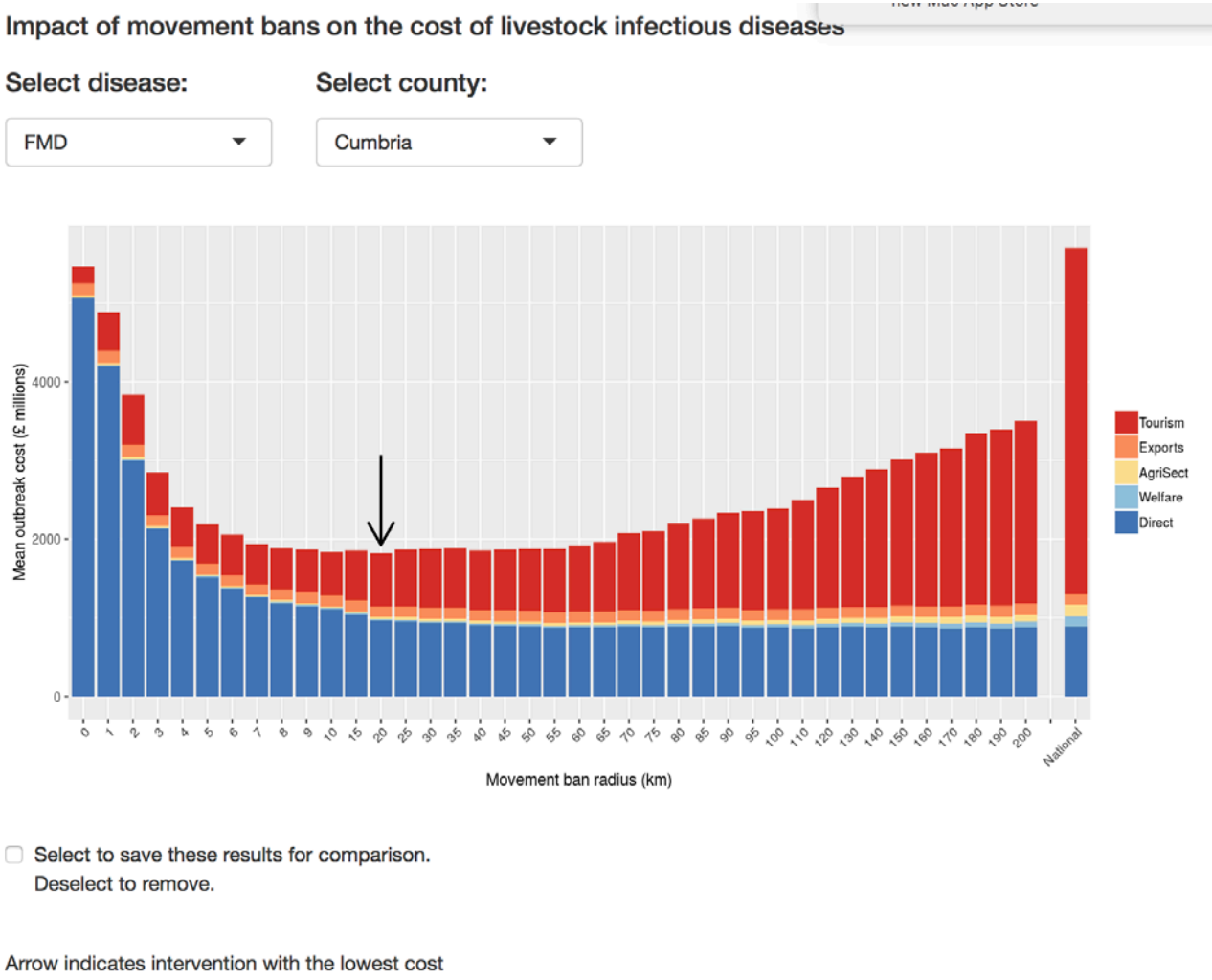

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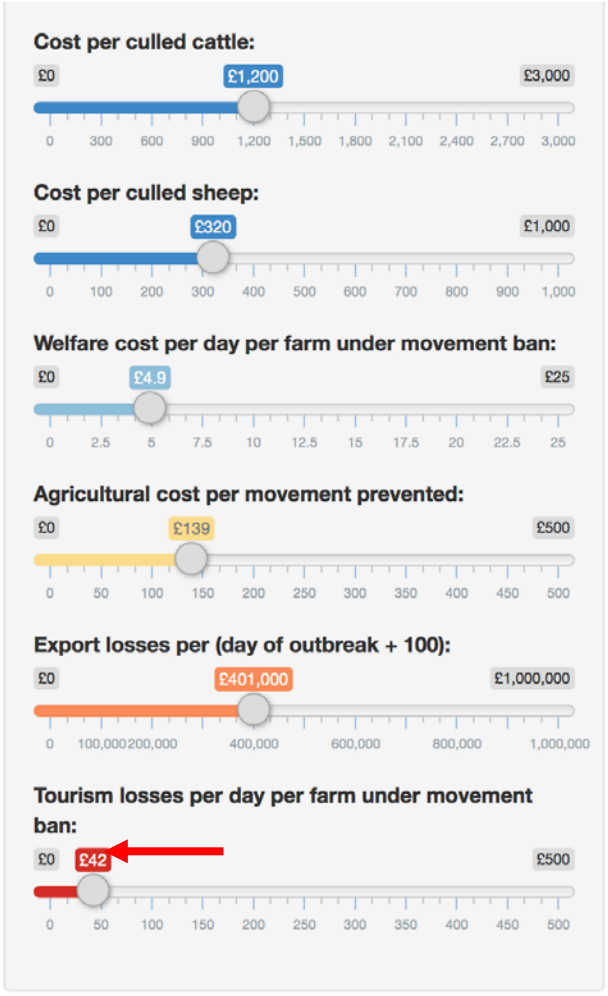

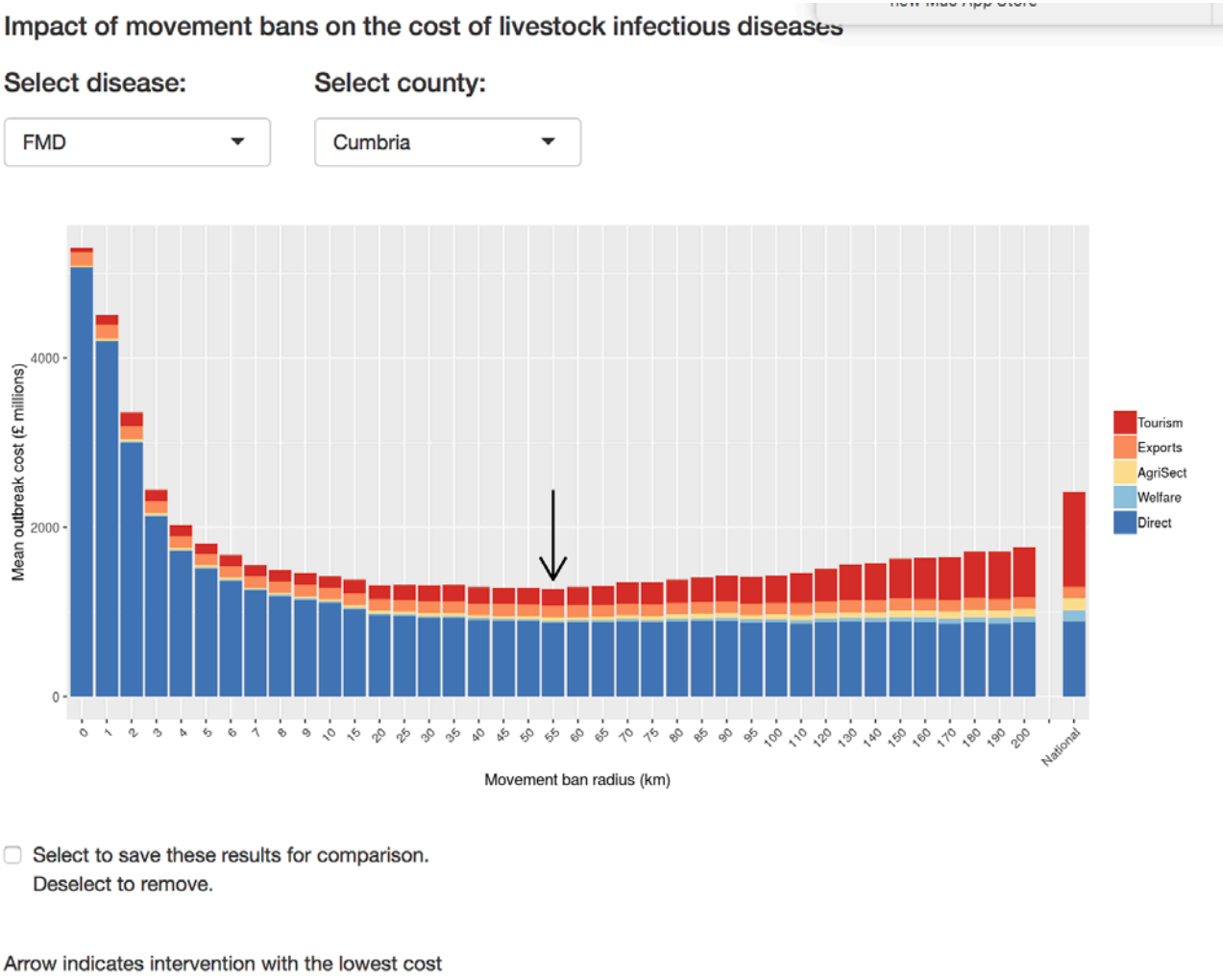

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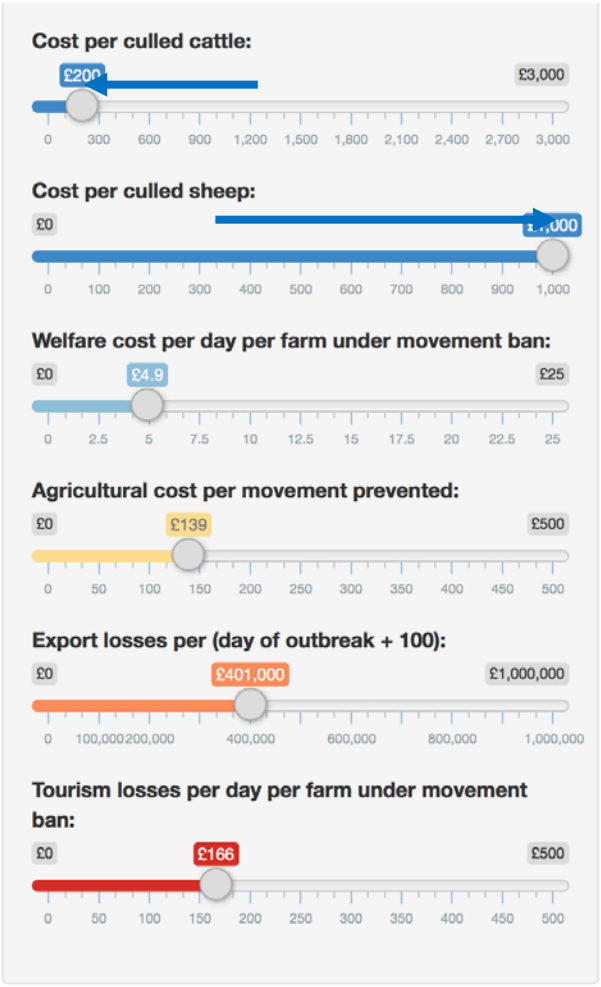

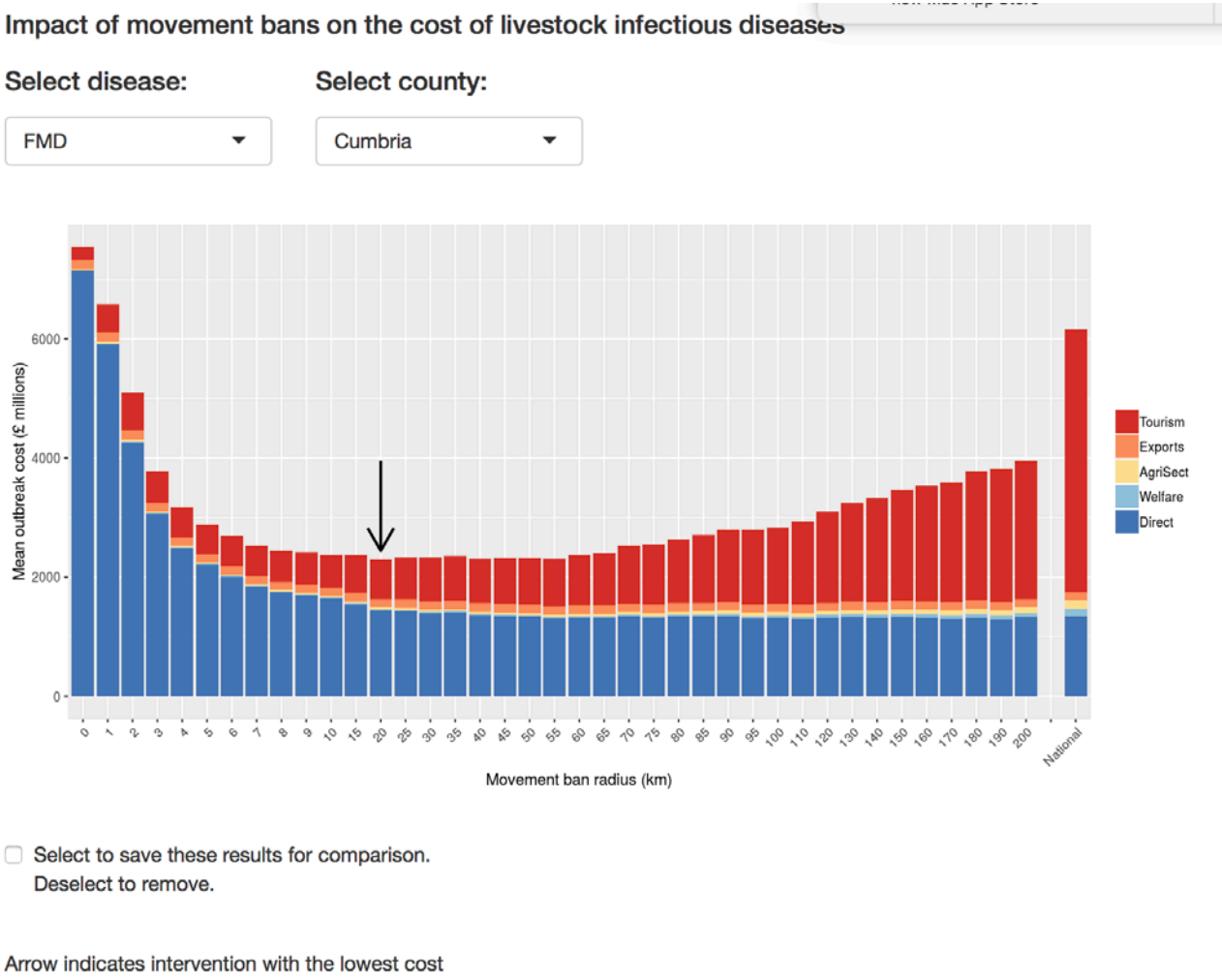

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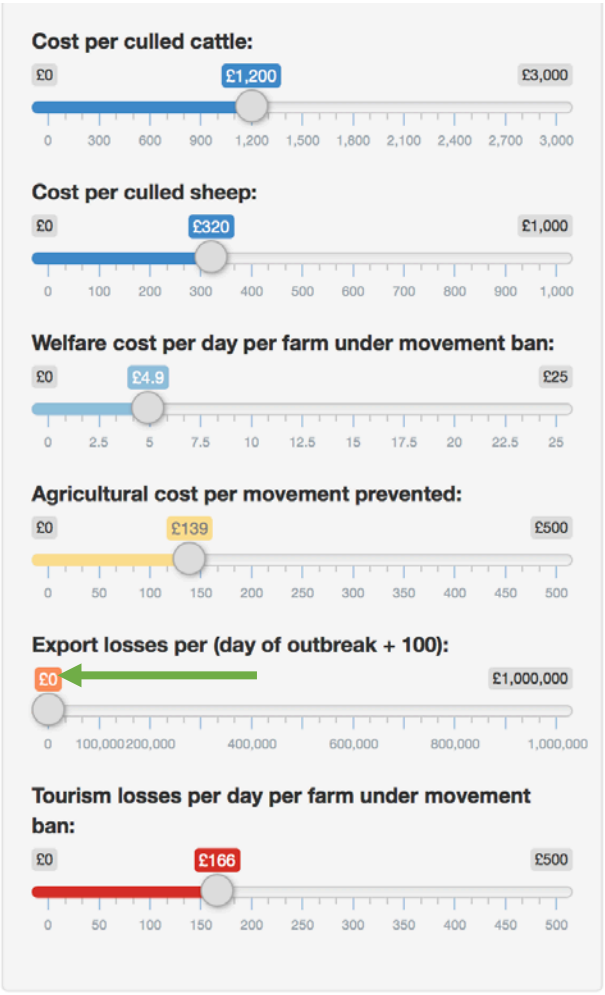

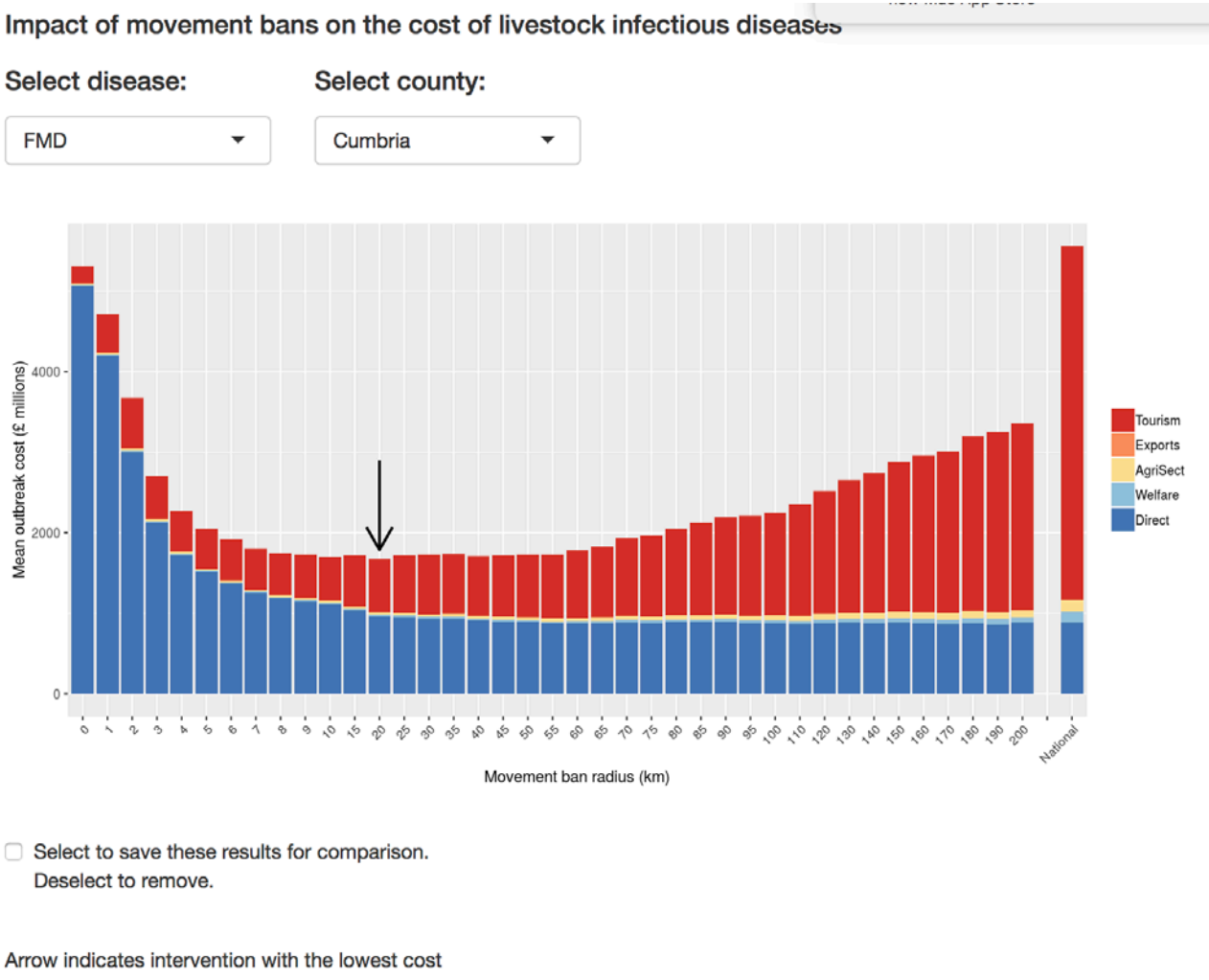

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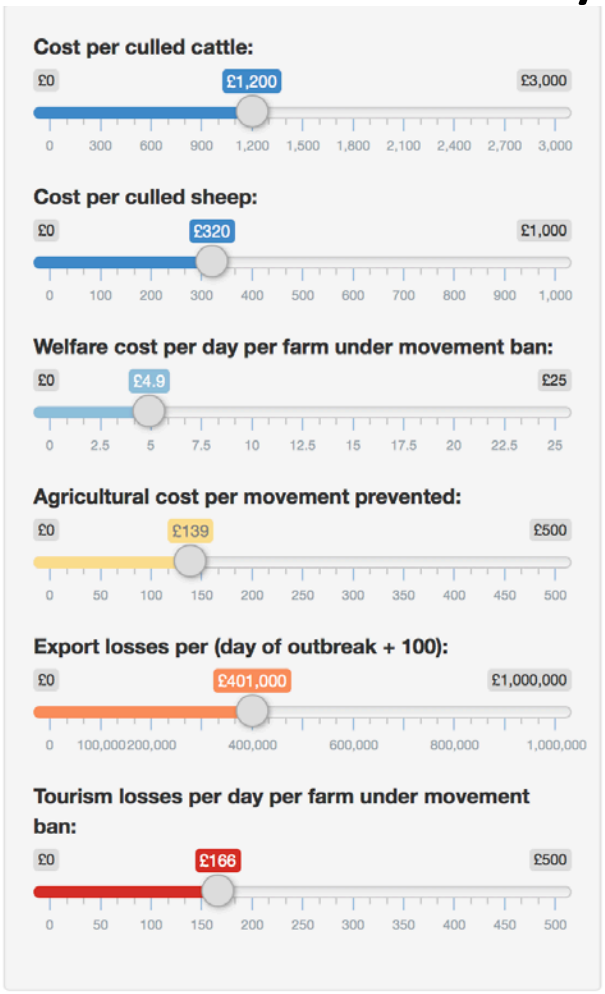

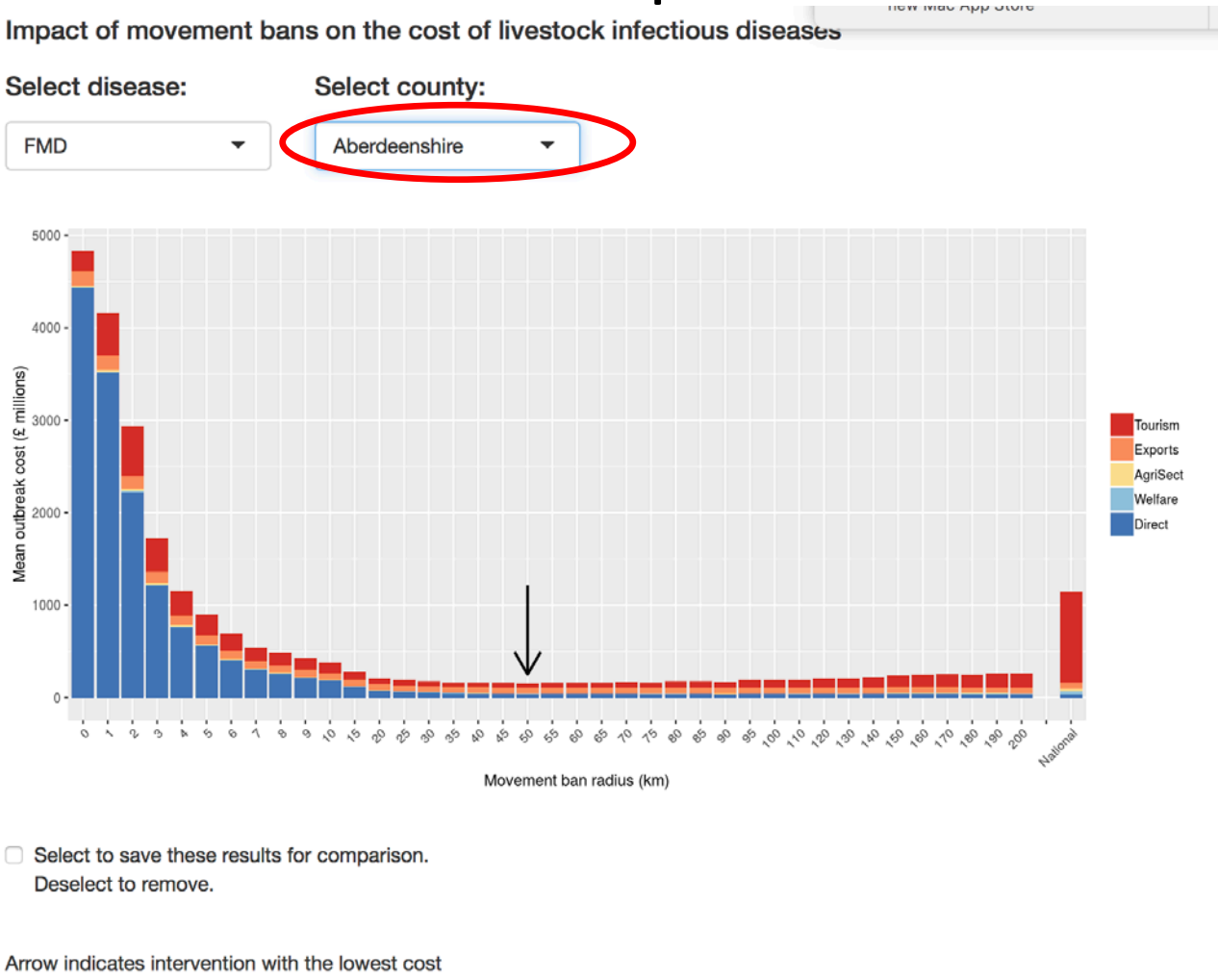

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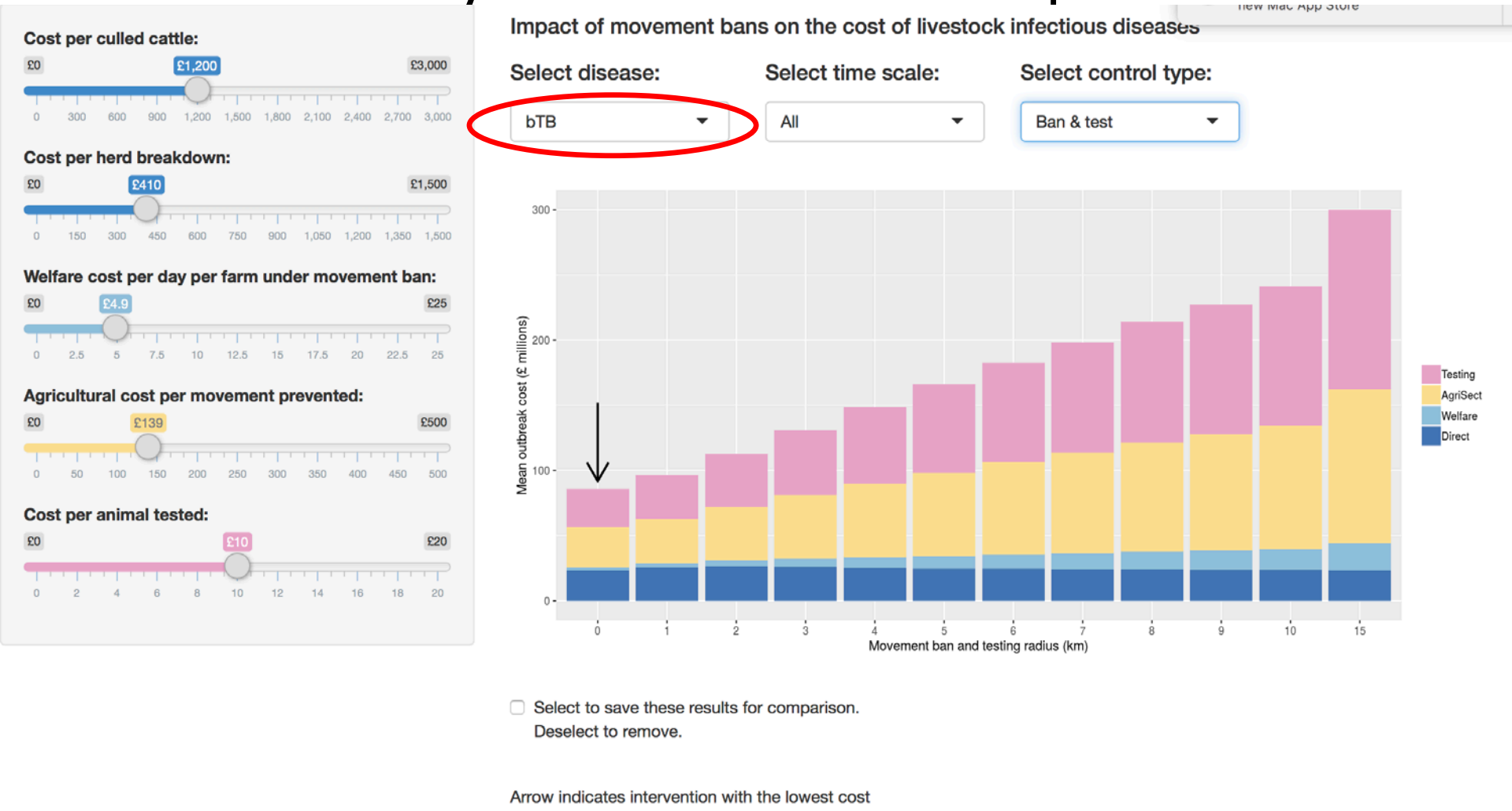

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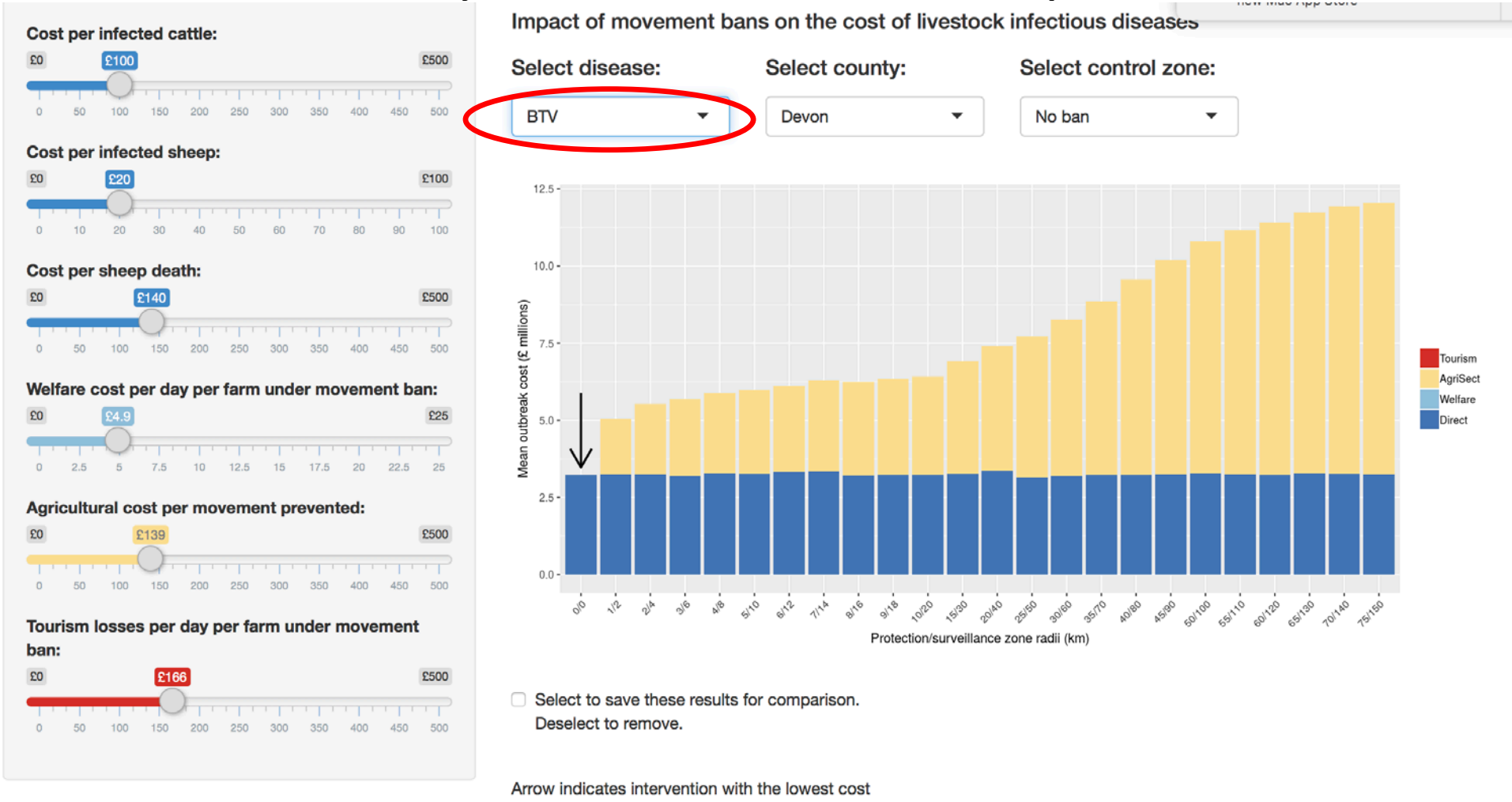

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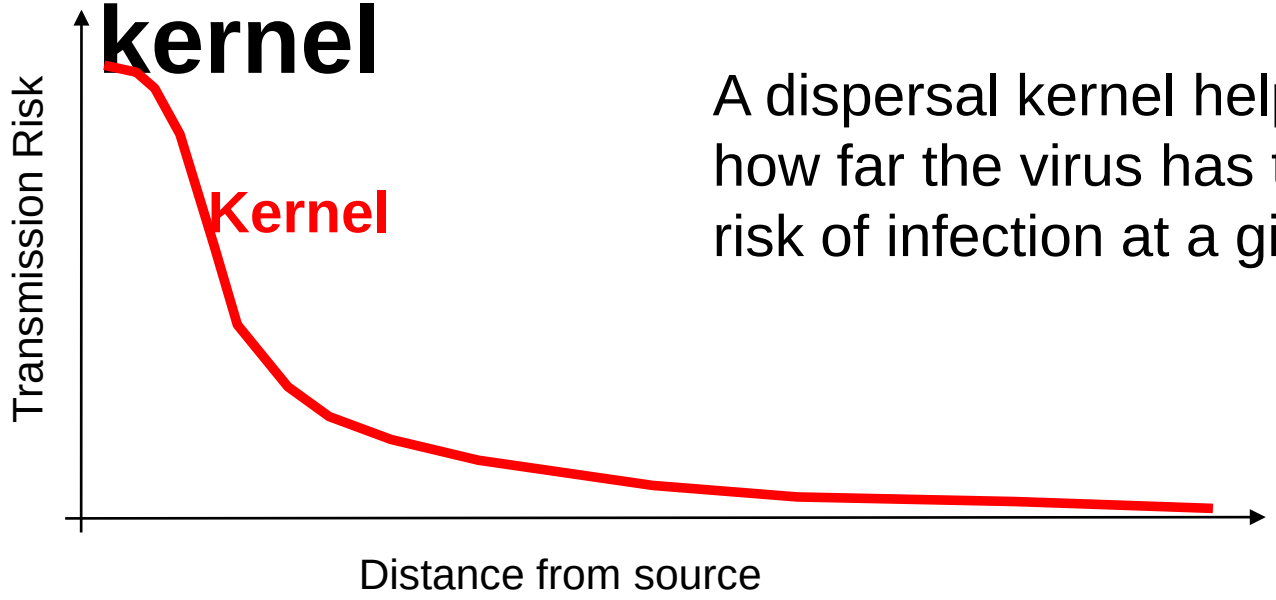
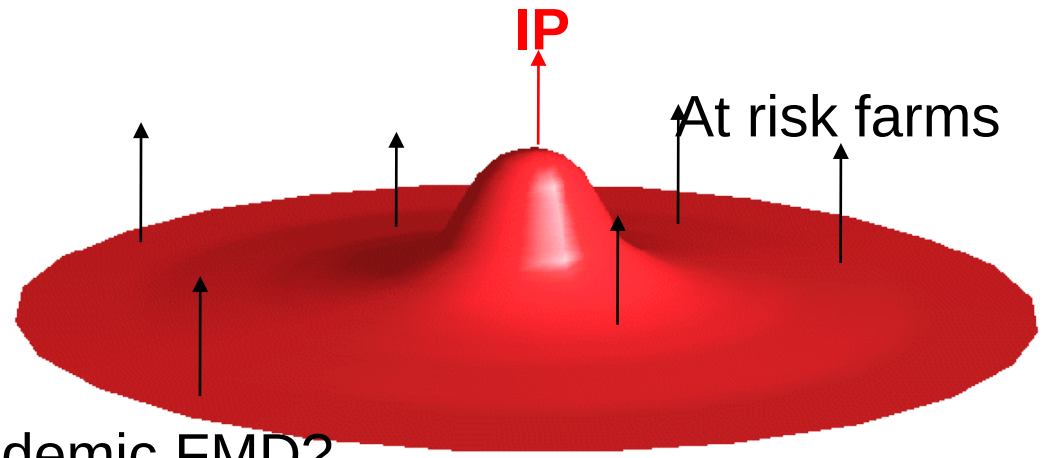
Transmission Risk – the dispersal kernel



A dispersal kernel helps us to determine how far the virus has travelled, giving the risk of infection at a given distance

For FMD epidemics in "disease free" countries, in the presence of livestock movement bans, distance is a major risk factor.



How should we model endemic FMD?

What risk factors should we consider?

EuFMD Training Workshops

EuFMD organize training workshops in Nakuru County, Kenya.

Veterinarians from around the world are trained to recognize clinical signs of FMD and to carry out outbreak investigations.

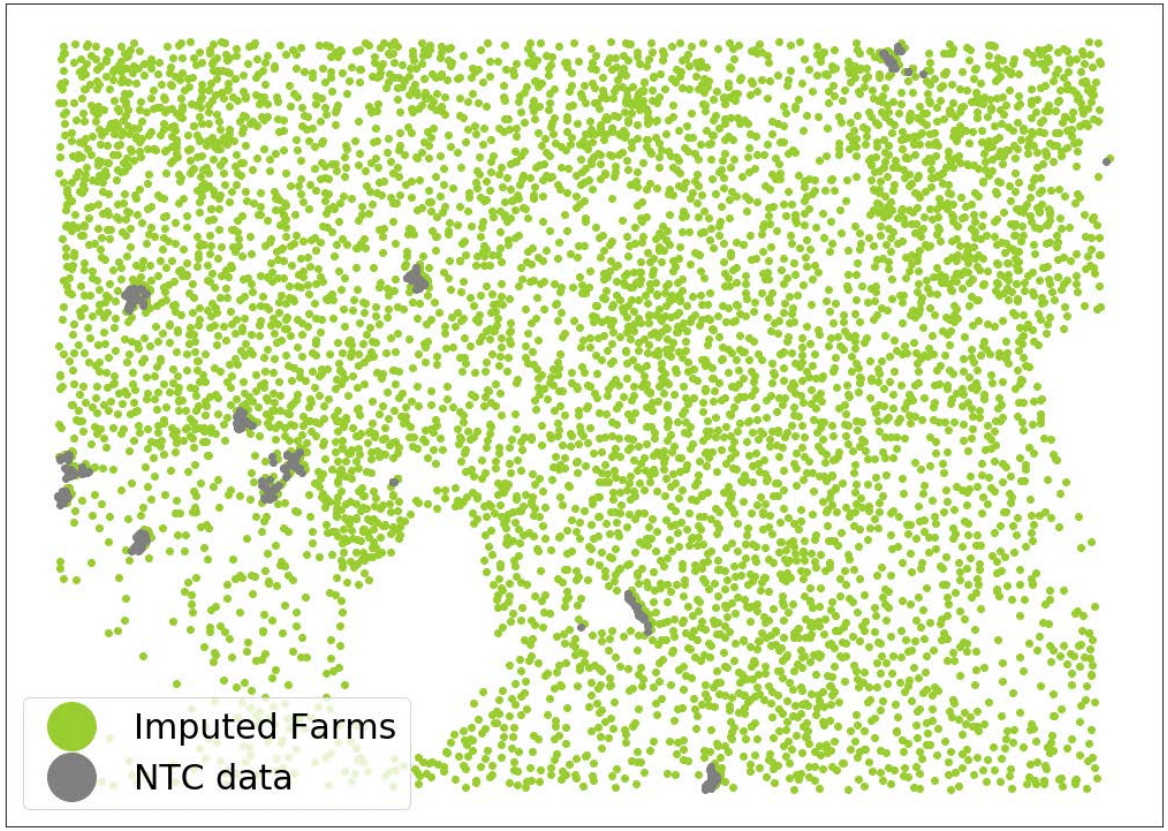
Surveys are designed using EpiCollect to collect information regarding local farming practices, exposure to FMD and uptake of vaccination.

We will utilize this series of surveys to assess risk factors and the effectiveness of vaccination in Nakuru County, Kenya.

Data from 11 Transect Studies – 342 farms in total (grey circles).

The remaining farms (green circles) in the region are populated using the Gridded Livestock of the World (Robinson et al. 2014).

This gives us a population of ~20,000 farms in total (we believe this is an underestimate).



We now use the information from the NTC transect studies to determine farm to farm risk.

Risk Factors

Do you use Common Drinking Sources?

Do you use Common Grazing?

Do you share equipment with other farms?

Is milk collected from your farm?

In the last six months:

Have animals moved onto or off your farm?

Has a vet visited your farm?

Have you vaccinated your animals for FMD?

Have you had FMD in the last six months?

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We can use these data to estimate the relative risk of transmission as a result of these different factors.

Transmission Potential

Based upon use of risk factors, we can construct a decision tree to determine the relative risks of each “attribute” upon transmission.

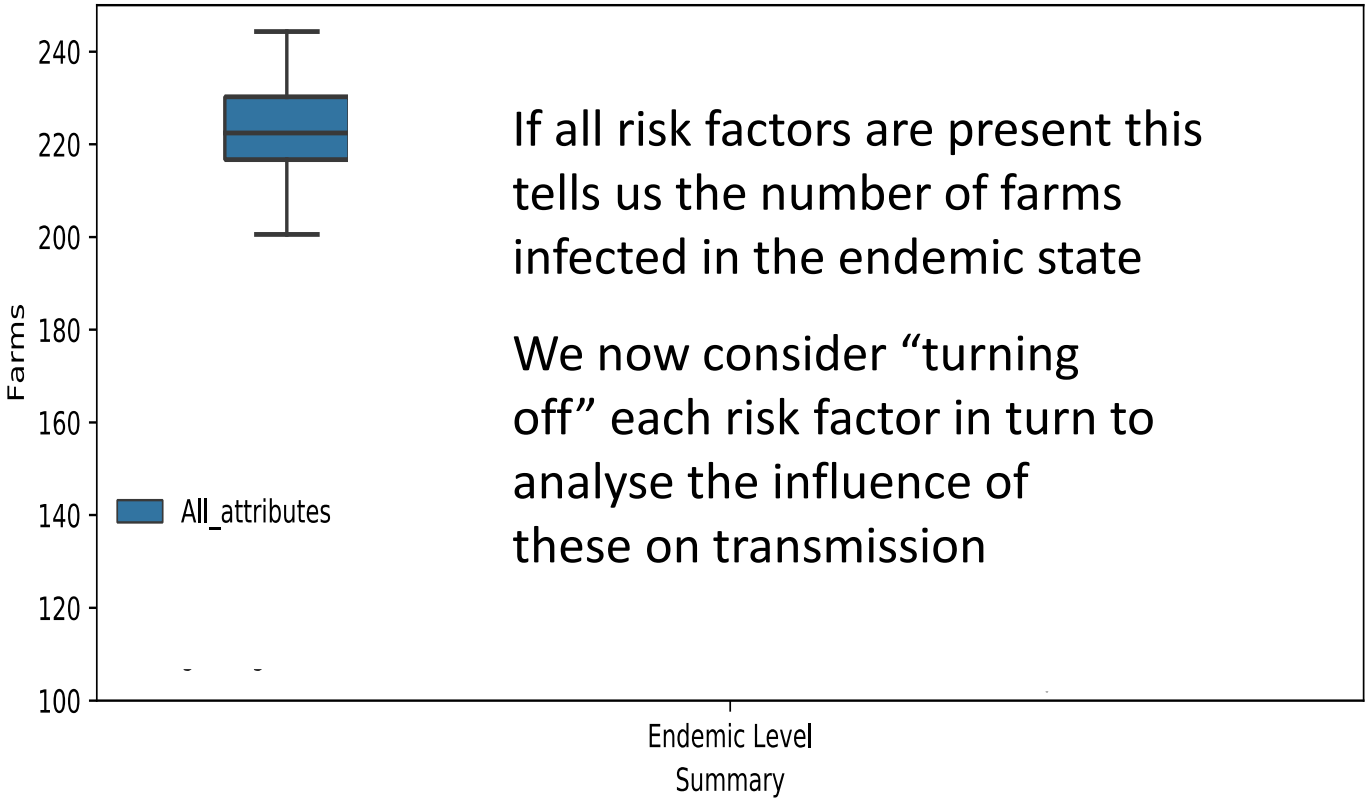
Evidence suggests that shared grazing land is the highest risk and selling milk is the lowest.

We use this information in our model to simulate increased risk based upon these attributes.

Attribute	Weighting
Shared Grazing Land	0.18
Sharing Equipment	0.17
Sharing Water	0.16
Human Contact	0.16
Recent vet contact	0.14
Animal contact	0.14
Sells Milk	0.06

Susceptible
Exposed
Infected
Natural Immunity
Vaccinated

Can we reduce transmission by altering behaviour?



If all risk factors are present this tells us the number of farms infected in the endemic state

We now consider “turning off” each risk factor in turn to analyse the influence of these on transmission

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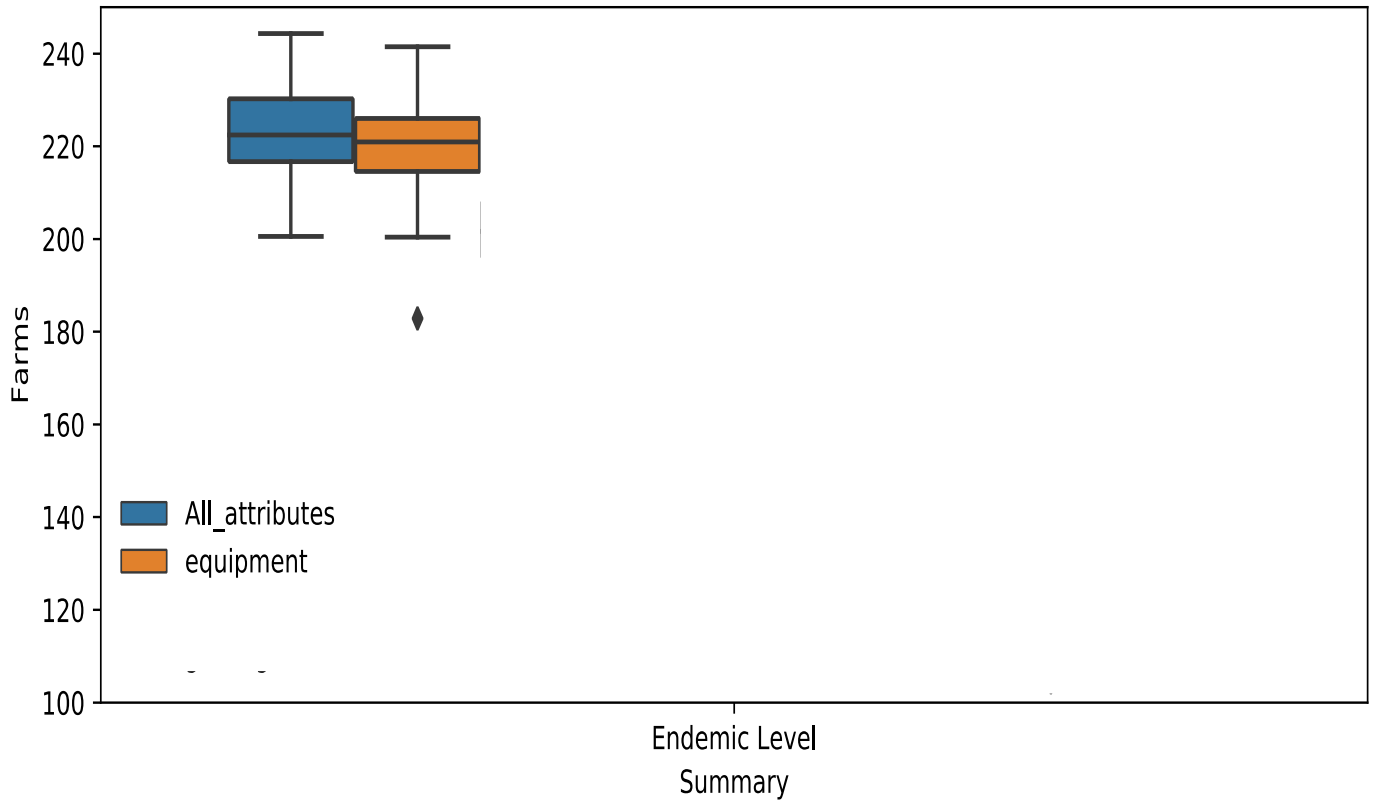

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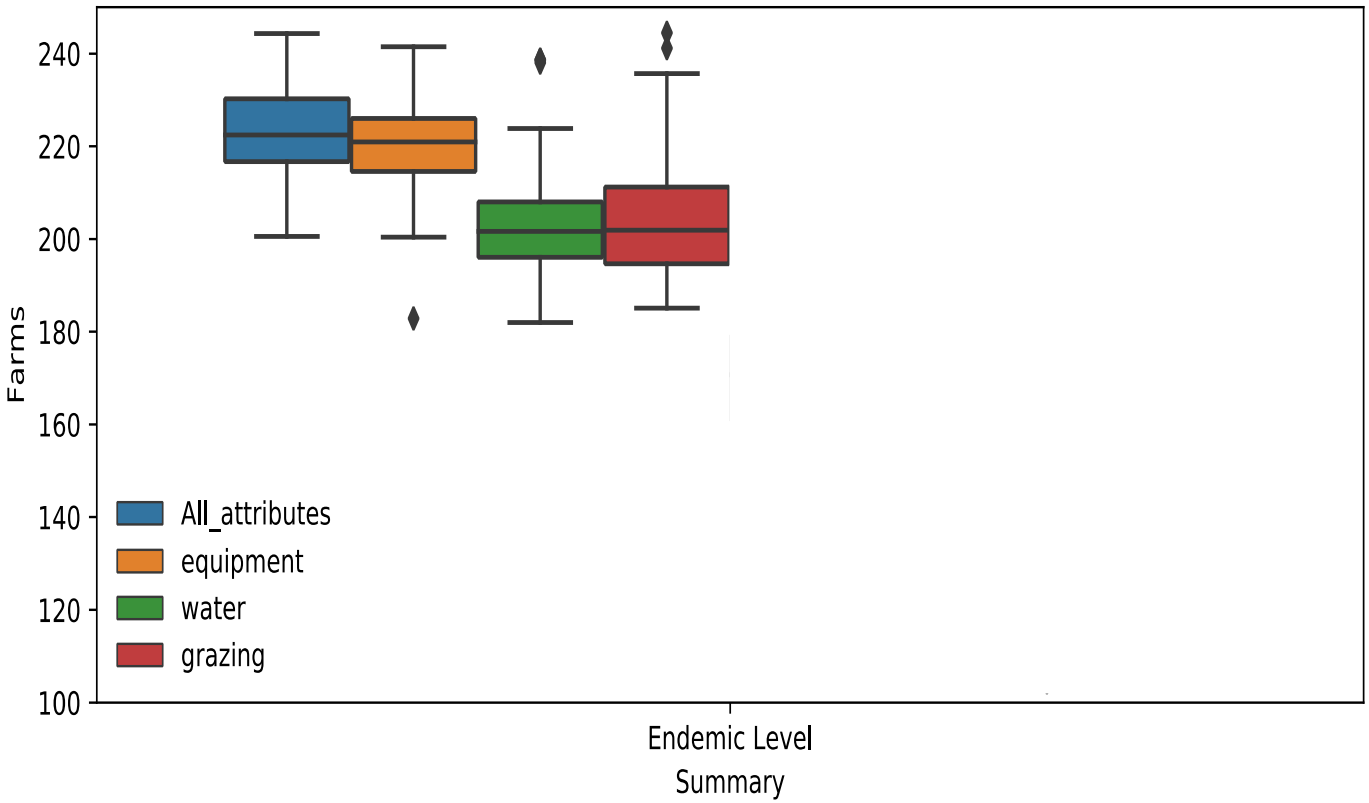

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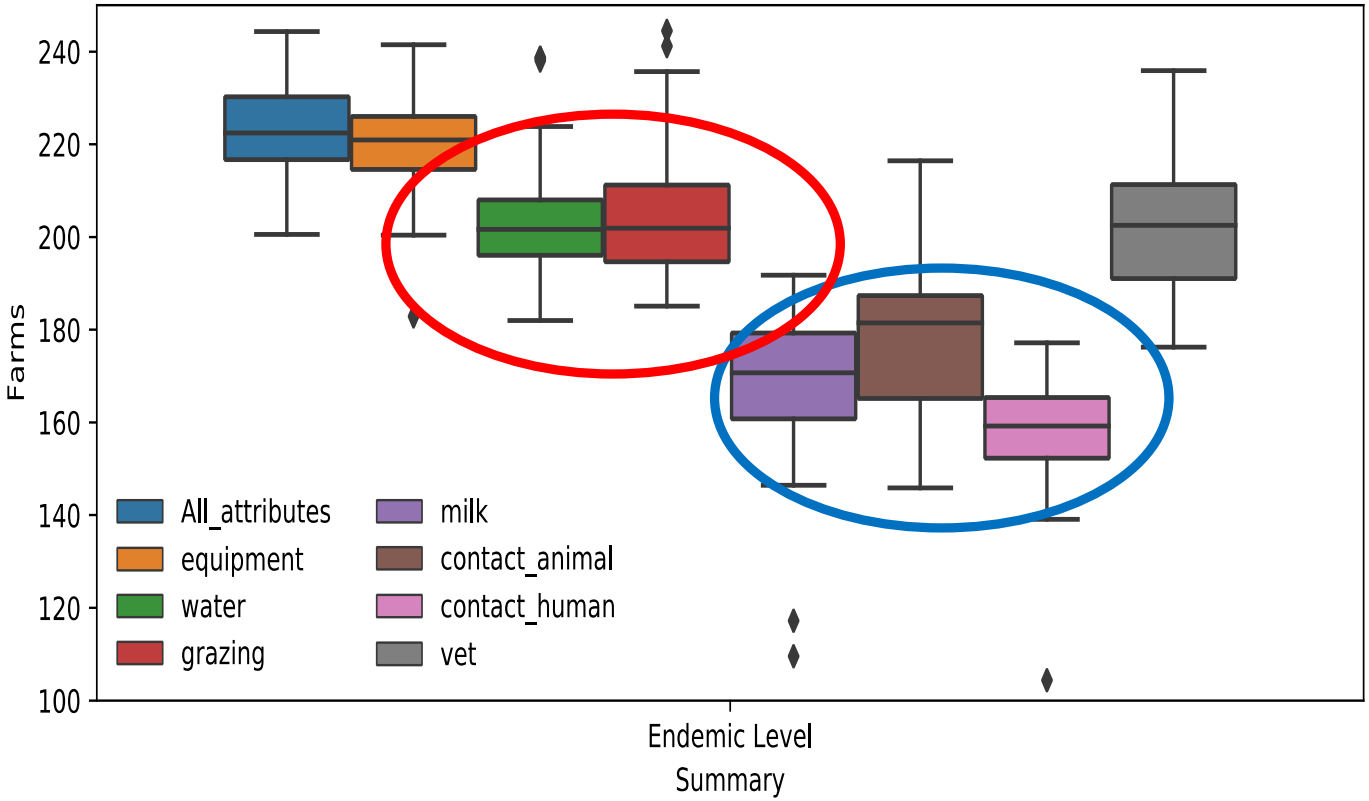
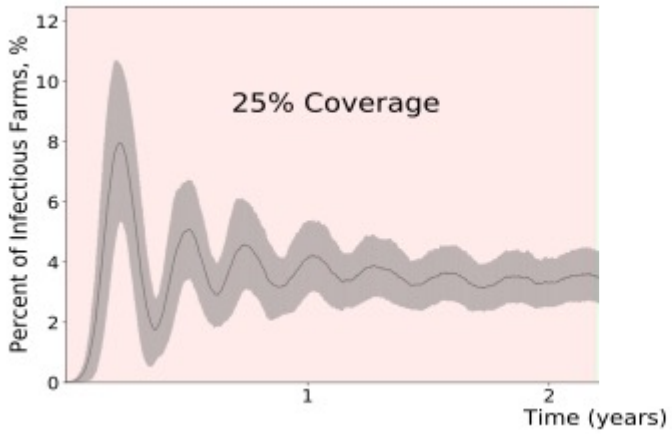


What about vaccination?

We now investigate the impact of vaccination upon the endemic level of infection.

We assume farms within a 3km ring of infected premises are vaccinated, with a coverage of 25% within a ring and a capacity of 40 farms per day.

Based upon vaccines in use, we assume a vaccine efficacy initially of 50%.



Model settling to endemic state.

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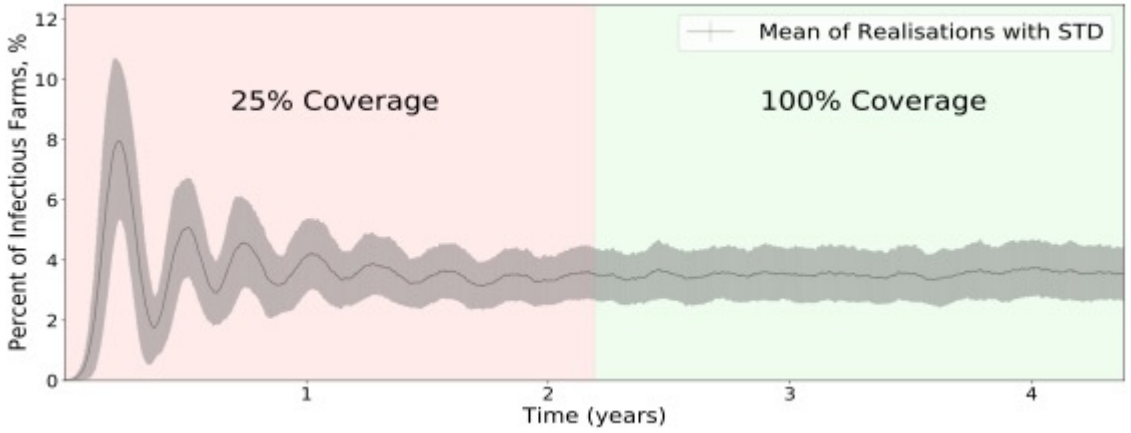

An increase in coverage does not affect the endemic level – overlapping rings.

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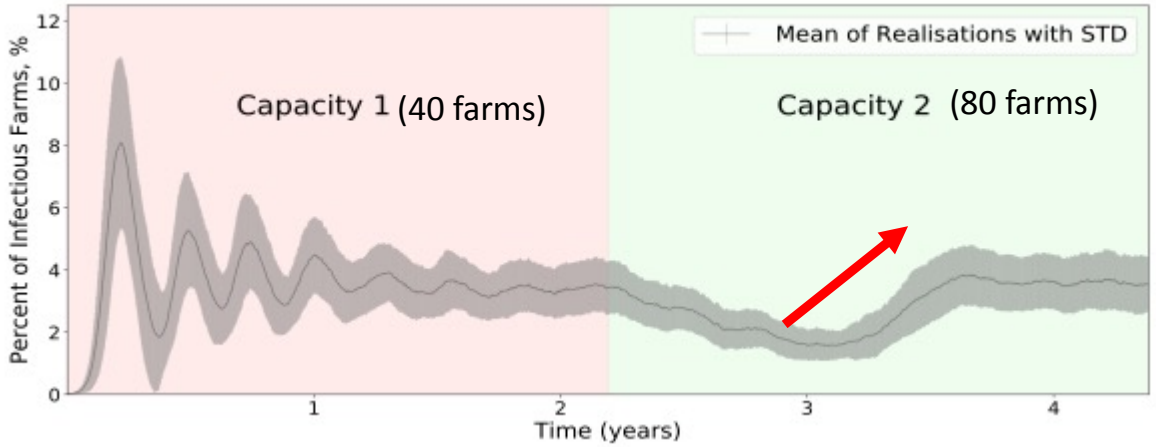

An increase in capacity reduces spread but waning immunity causes a "bounce back".

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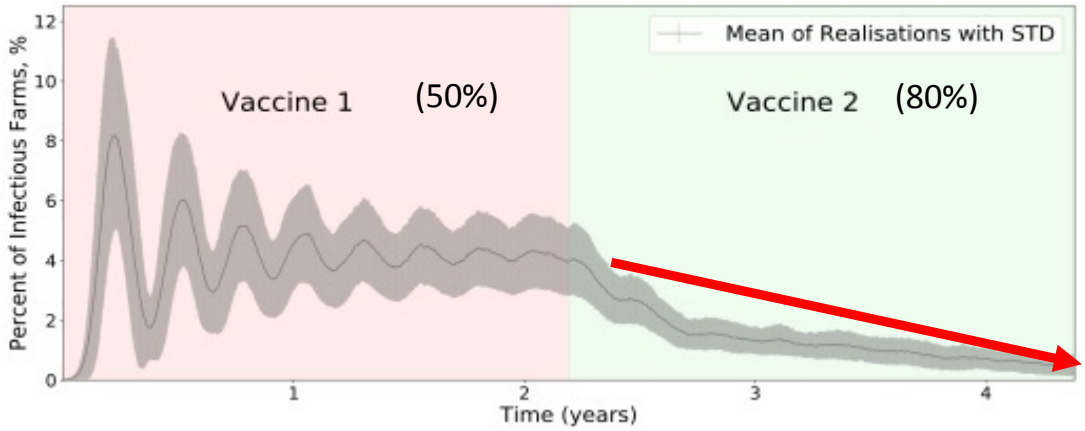

An change to a more effective vaccine can significantly decrease the number of infected farms.

Summary – Epidemic Settings

The evidence suggests that for future outbreaks it may be cost effective not to ban movements nationwide.

The scale of any future movement ban is dependent upon the region of introduction and the priorities for control.

Even if indirect (tourism) costs are ignored, radial movement bans are more cost effective than nationwide bans.

The advantage with regional movement bans is that farmers not immediately affected by an outbreak can operate “as normal”.

Summary – Endemic Settings

In endemic settings it is important to consider farm connectivity and risk factors when predicting transmission potential.

Transect studies can provide a rich data source for investigating these risks.

Our model suggests that reducing shared resources can reduce transmission risk.

High efficacy vaccines, used effectively, can significantly reduce levels of infection in endemic settings.

This is preliminary work and we would welcome your comments!

Acknowledgements

Matt Keeling, Sam Brand, Naomi Bradbury (Warwick)

Marleen Werkman (Imperial)

Ellen Brooks Pollock (Bristol)

Nick Lyons (Pirbright/EuFMD)

Keith Sumption, Nadia Rumich (EuFMD)

Jonathan Artz (Plum Island)

Eunice Chepkwony, Abraham Sangula (FMD Lab, Kenya)

All the participants of NTC27.

The Warwick student team

Susie Cant
Alex Holmes
Ben Miller
Emma Southall
Xiaoyue Xi

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