How do we define an appropriate objective function for infectious disease outbreaks?

JUNIPER

In the event of an outbreak of infectious disease, policy makers usually want the answer to one specific question

What should we do?

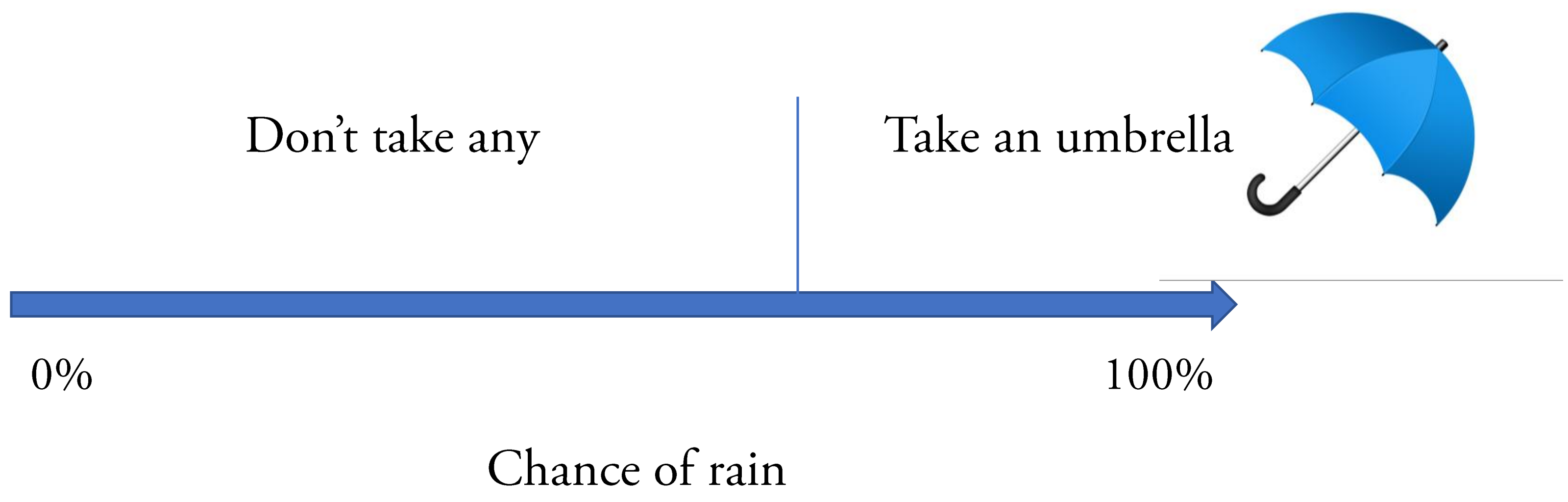
~~What should we have done?~~

Retrospective analysis ⟶ Prediction

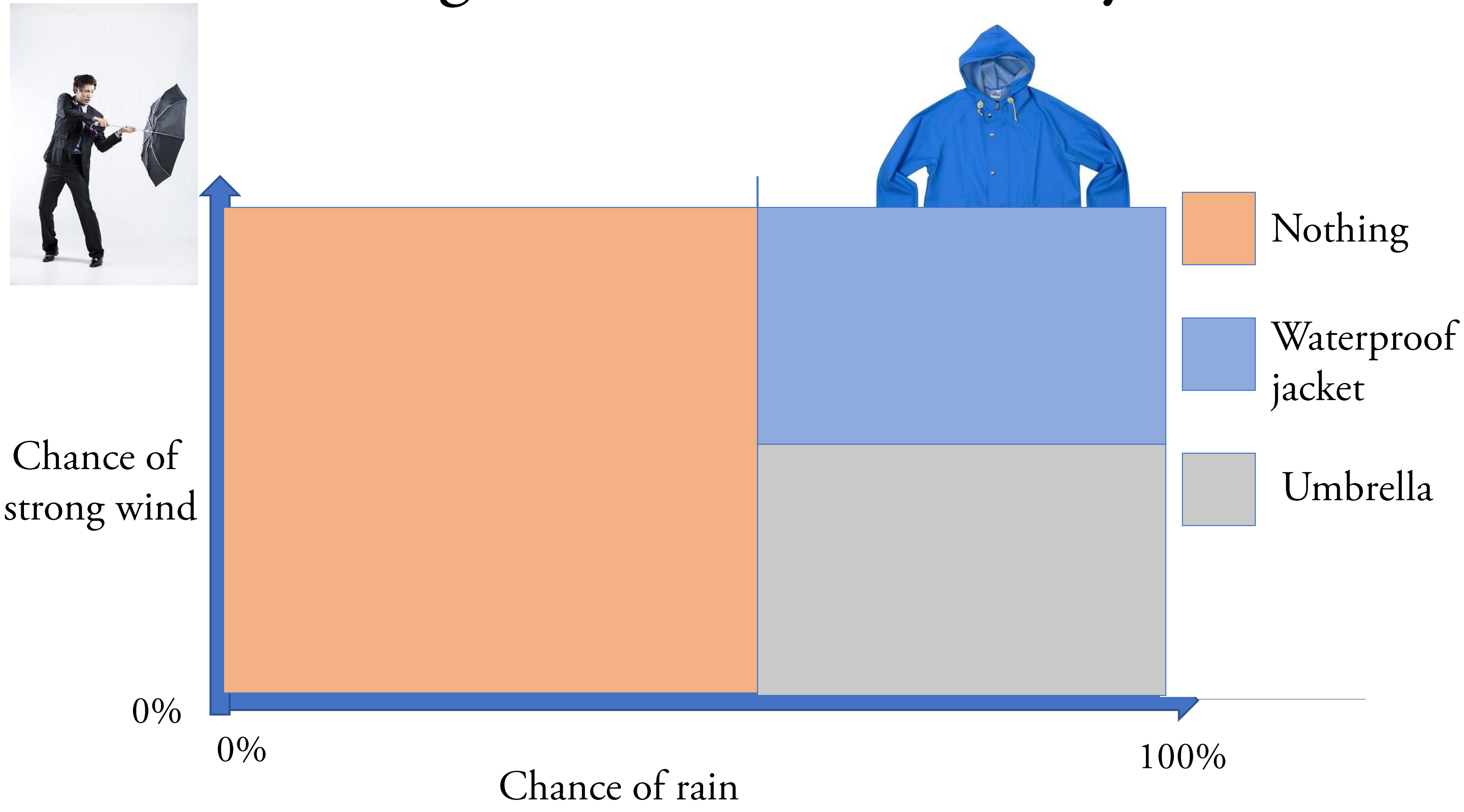
What wet weather gear should I take today?

It depends!

On what?



What wet weather gear should I take today?



What is our objective?

In this simple example, we may think that the objective is not to get wet.

However, given the uncertainty in whether it is going to rain we also have to consider:

Will we get cold?

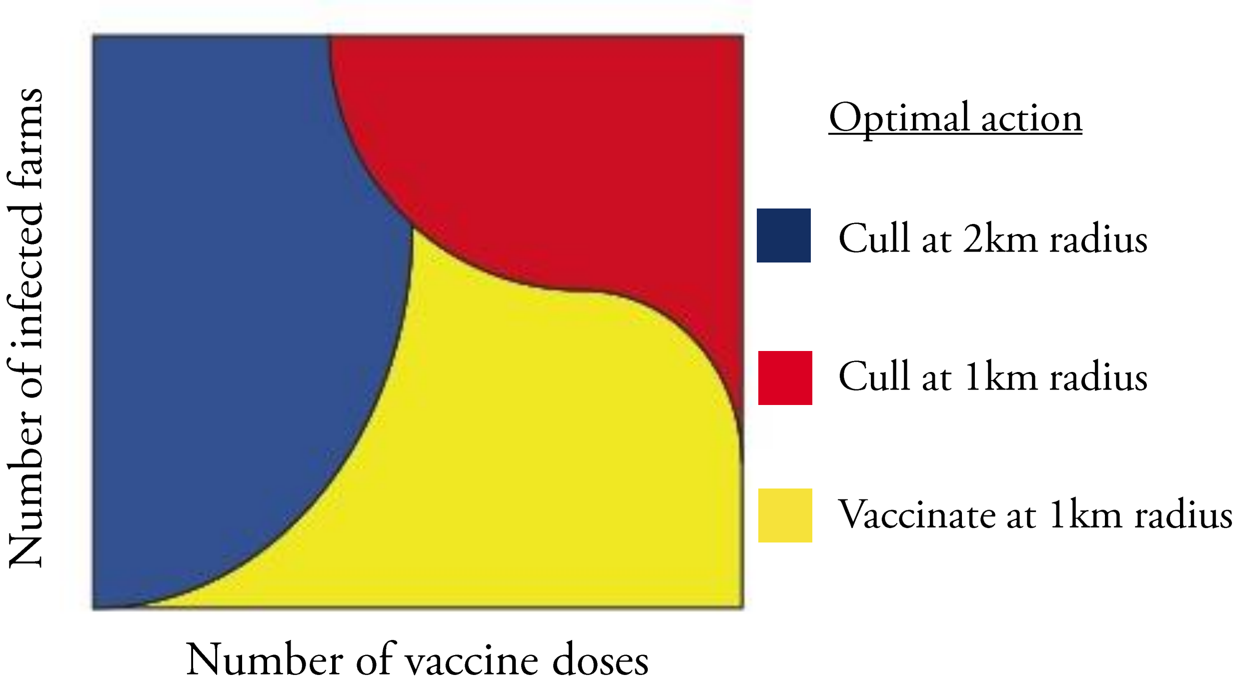
Will we have to carry an umbrella or a raincoat all day?

So our ***objective function*** that influences our decision may be to minimize the risk across all of this potential impacts.

The state of an outbreak matters – a simple example for livestock.

- The optimal control policy is dependent upon the exact state of an outbreak.

- How many infected farms are there?
- How many doses of vaccine do we have?



Control options – Ring Culling or Ring Vaccination

For this example, we consider ten different control options.

Culling action: 0 and 2.0 km
Culling action: 0 and 2.5 km
Culling action: 0 and 3.0 km
Culling action: 0 and 3.5 km
Culling action: 0 and 4.0 km
Vacc action: 0 and 2.0 km
Vacc action: 0 and 2.5 km
Vacc action: 0 and 3.0 km
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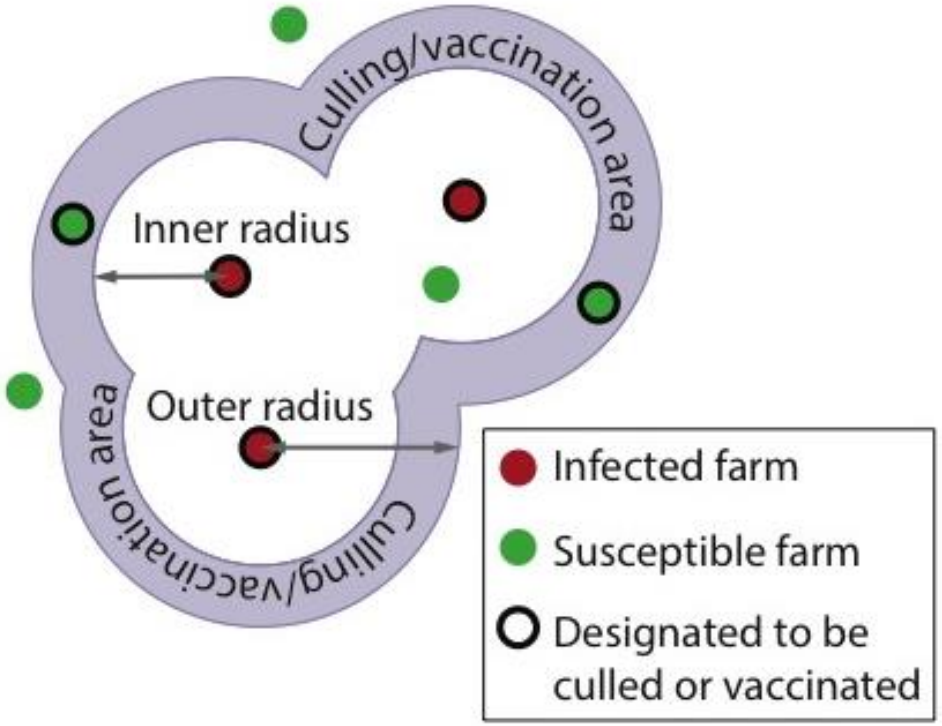
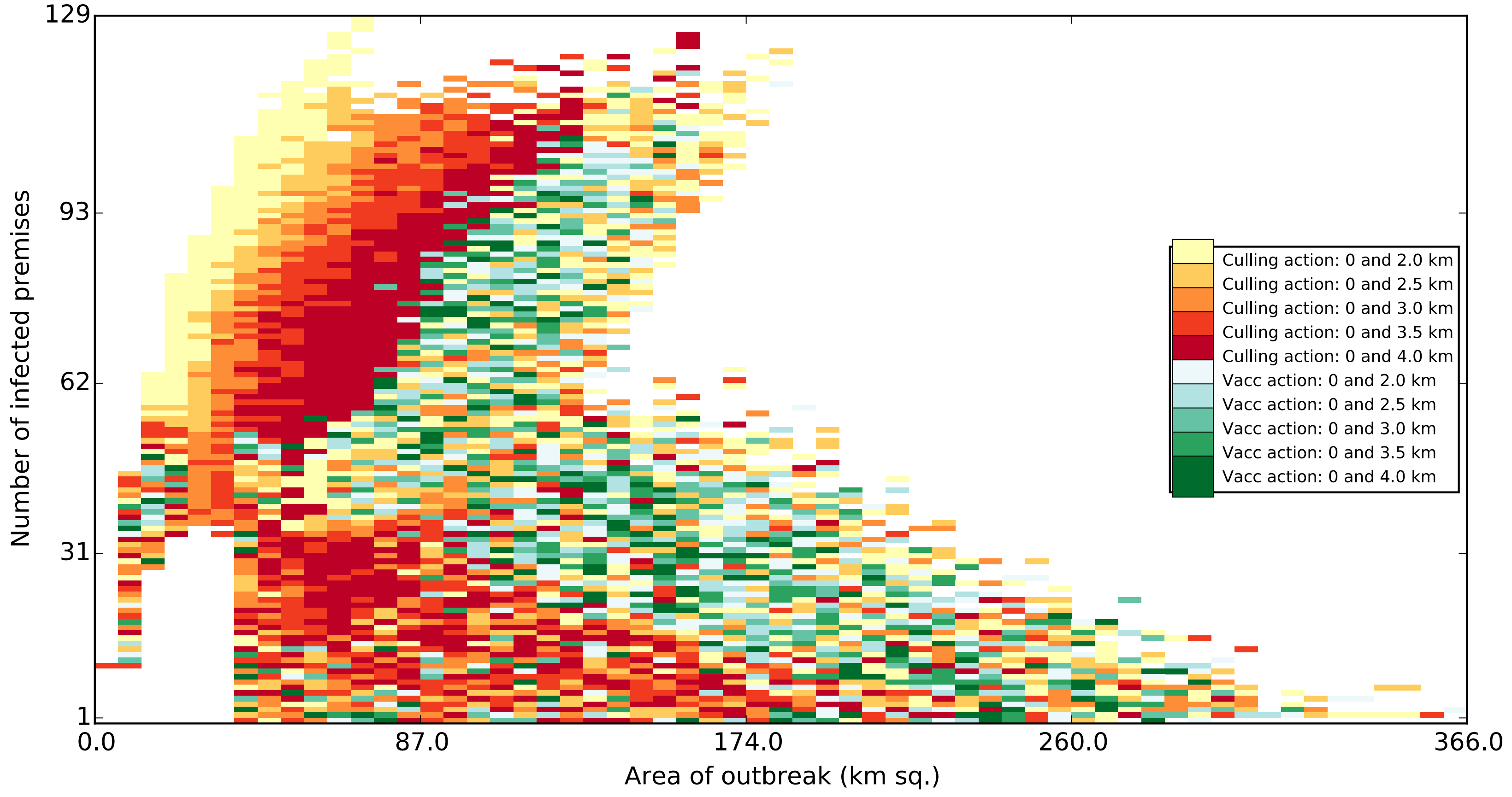
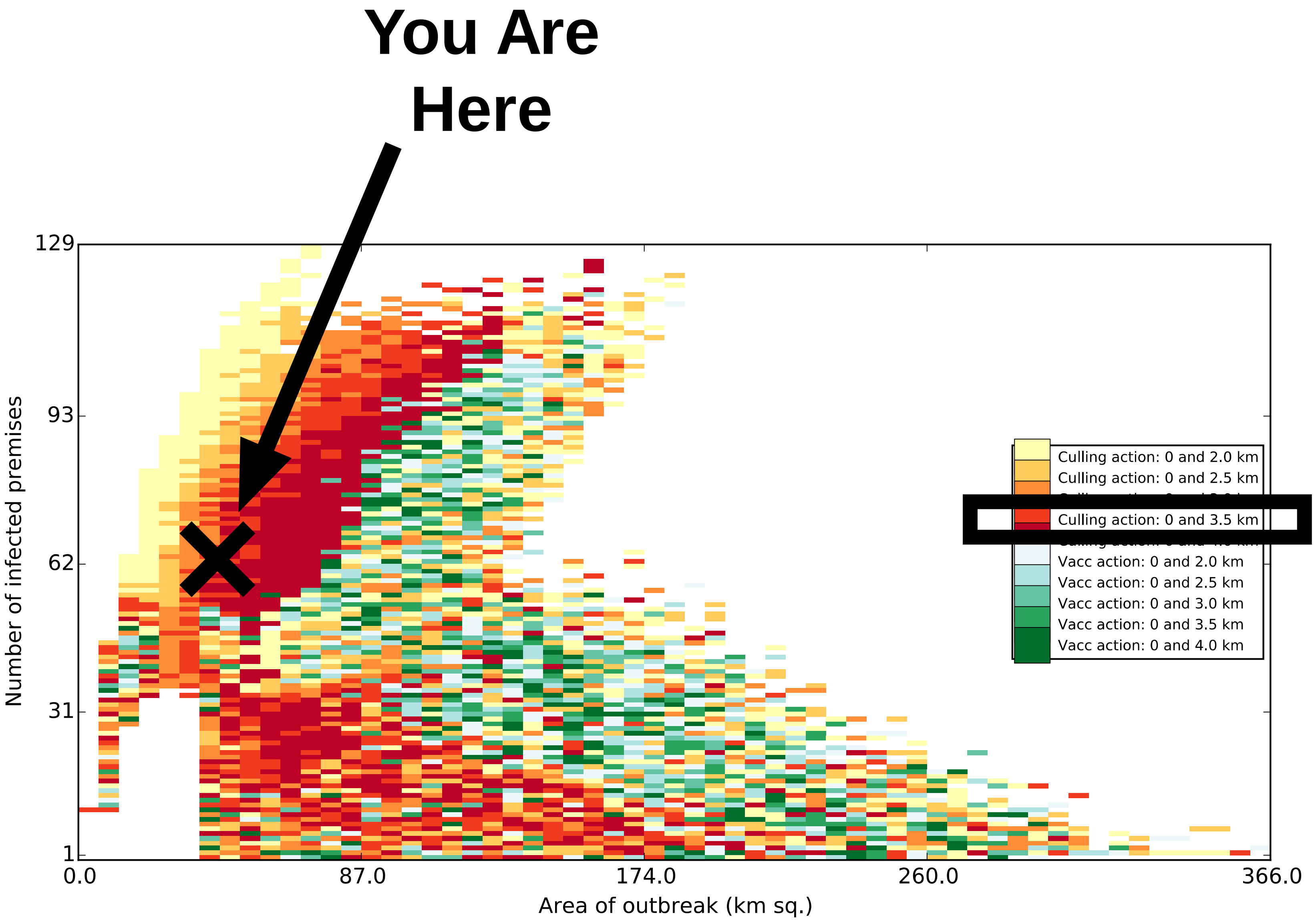


Results for larger outbreaks

Objective: Minimize outbreak duration




You Are Here
129
93
62
31
1
Number of infected premises
0.0
87.0
174.0
260.0
366.0
Area of outbreak (km sq.)
Culling action: 0 and 2.0 km
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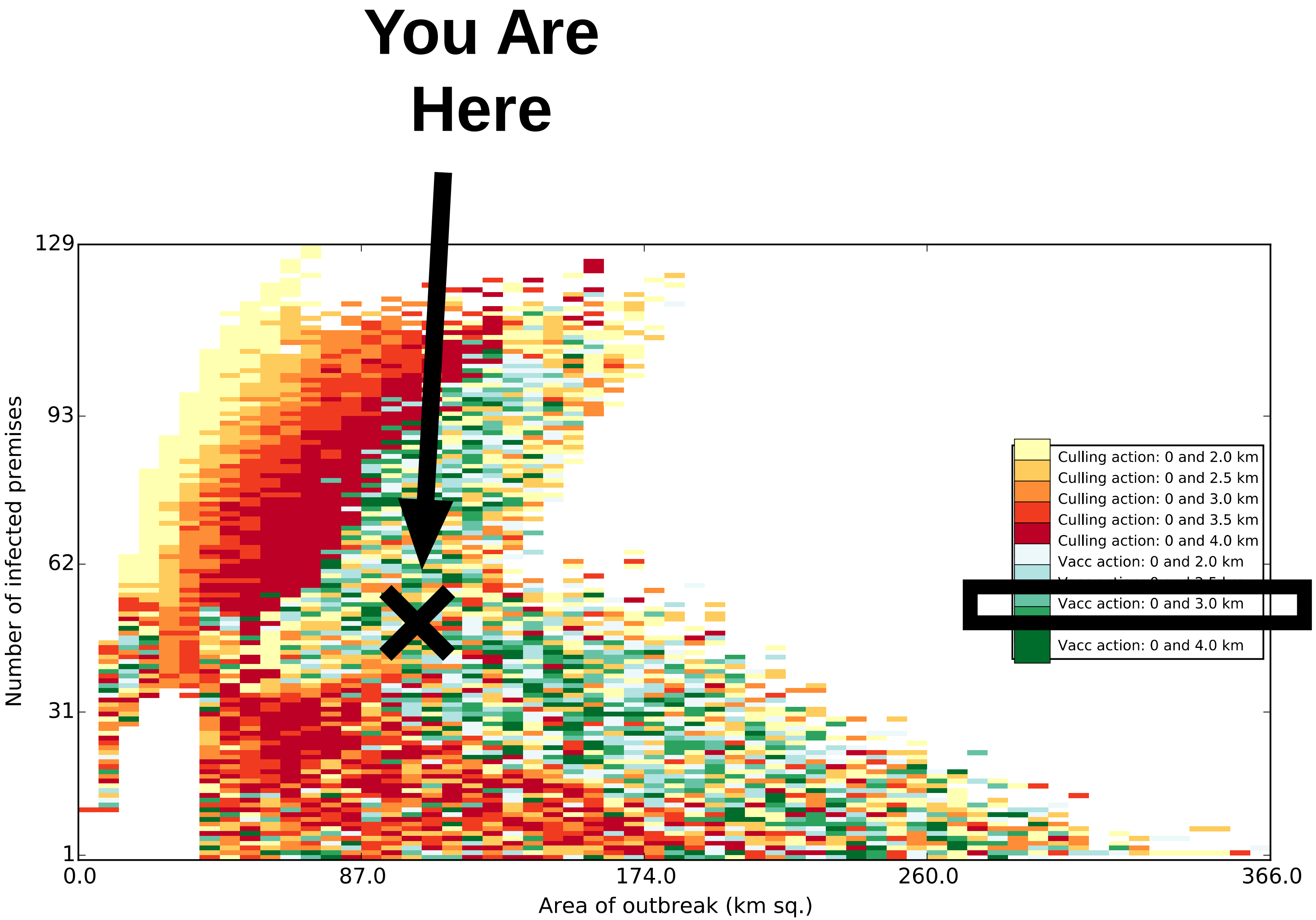

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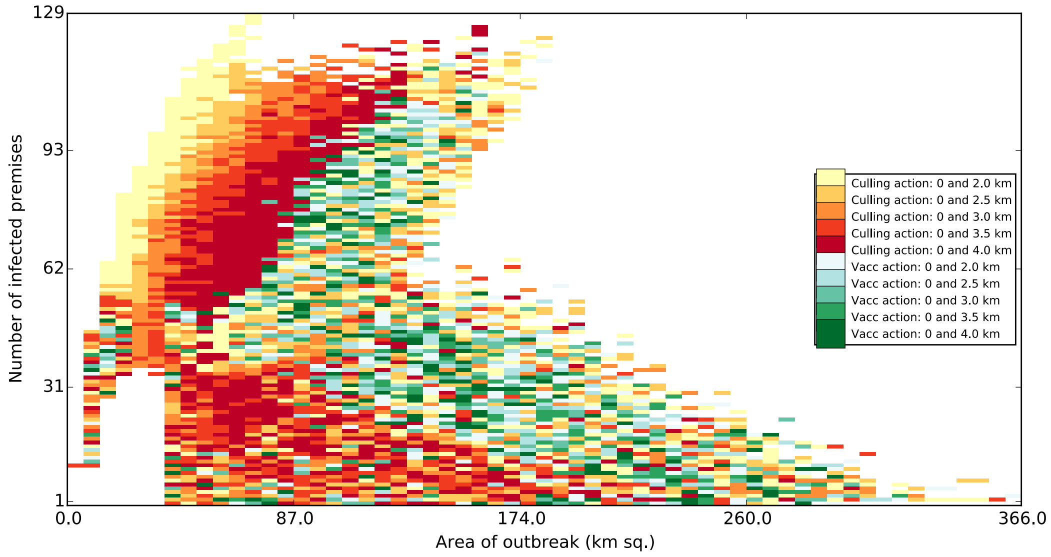
Objective:

Minimize outbreak duration

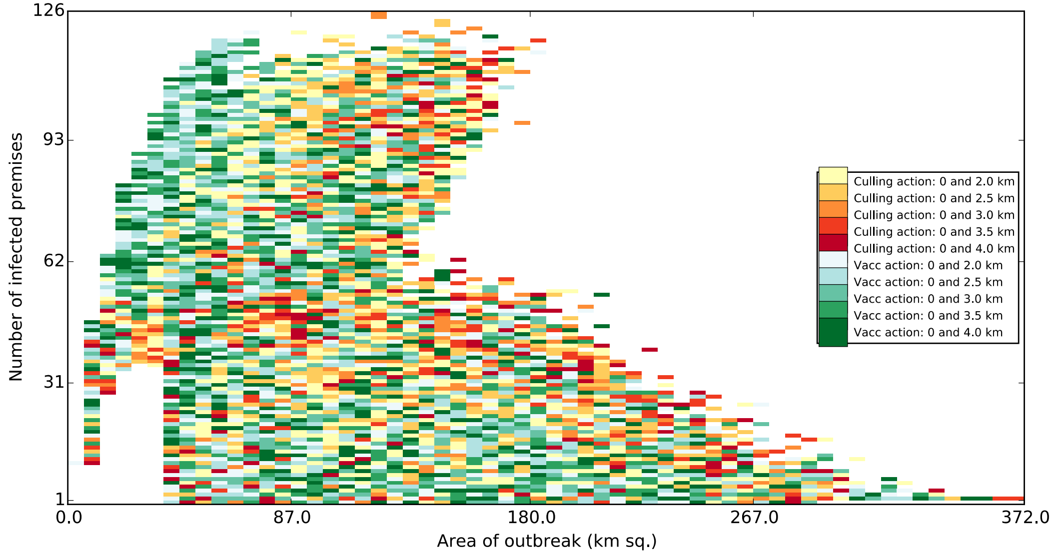
- Culling optimal for smaller outbreak sizes



Objective:

Minimize livestock culled

- Dominated by vaccination actions

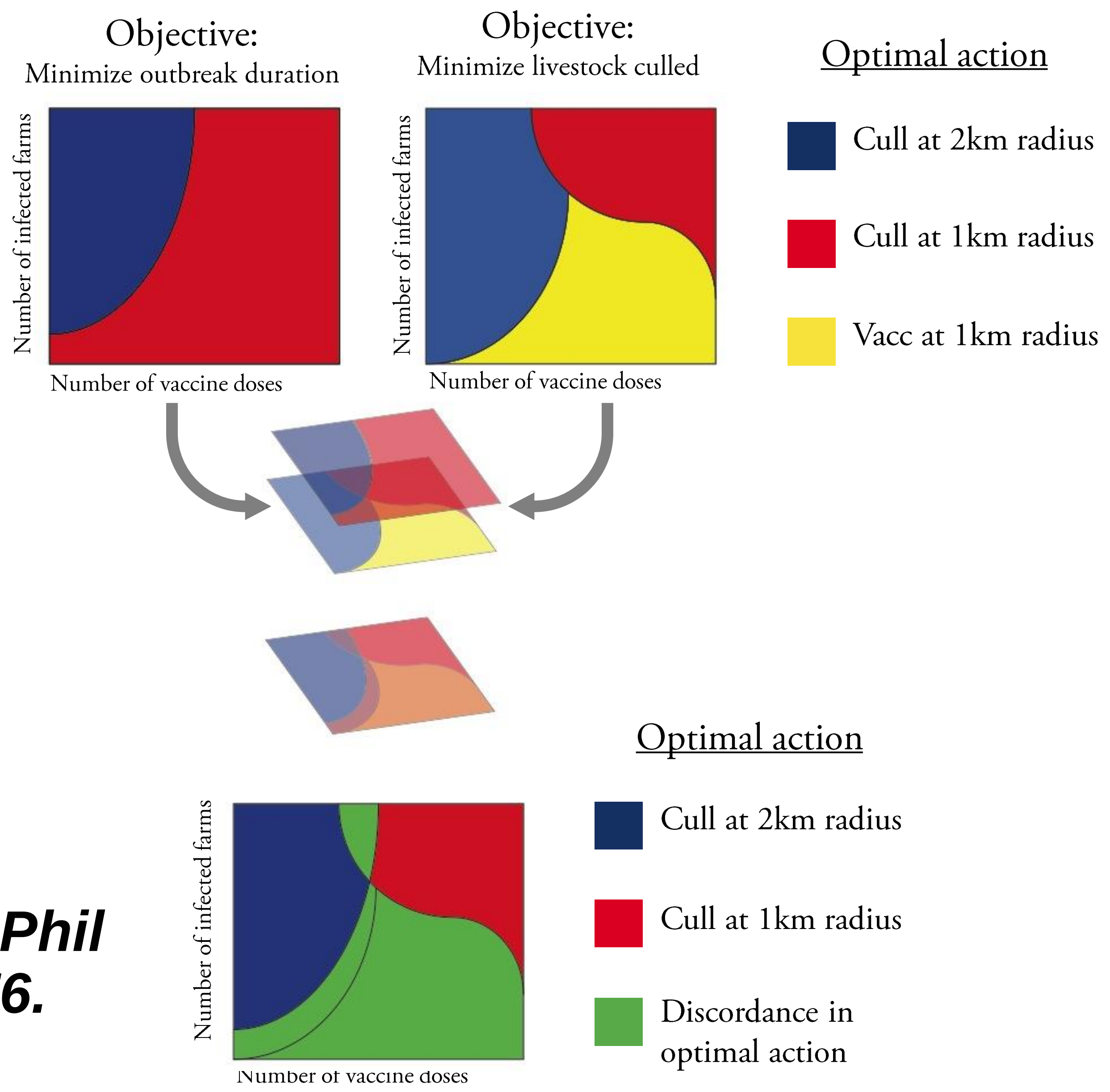


Reinforcement learning using multiple objectives

We can compare optimal actions across different stakeholder objectives eg government, farmers

We can identify win-win situations for management or places of discordance btw stakeholders

Probert et al. 2019 Phil Trans B 374, 1776.



A COVID-19 example - Circuit Breakers

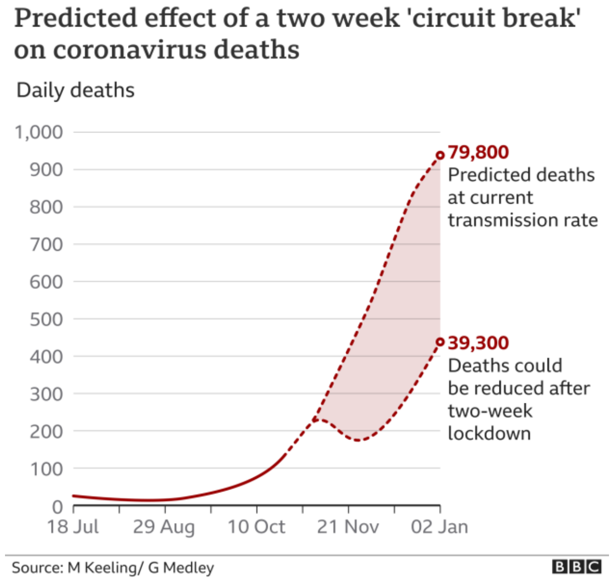
- A “circuit breaker” is a short-term, planned lockdown
- It is intended to have a less severe effect on the economy, because it is planned

Circuit Breakers

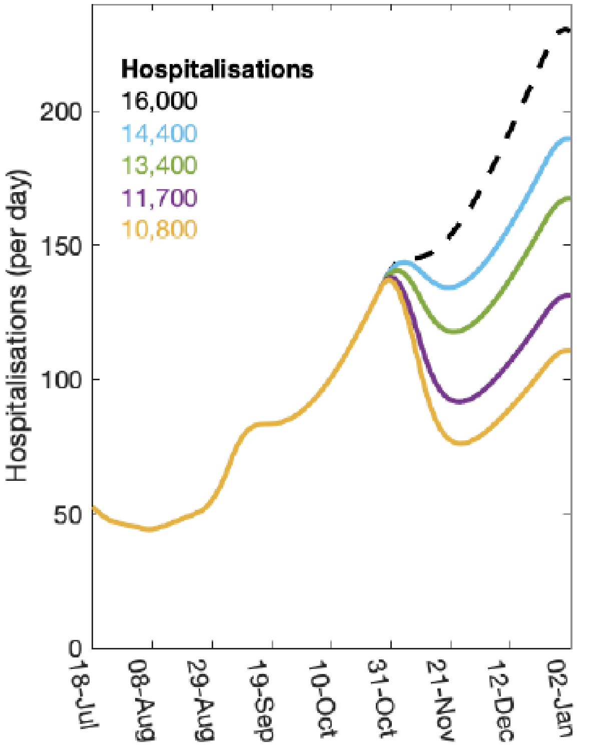
- A “circuit breaker” is a short-term, planned lockdown
- It is intended to have a less severe effect on the economy, because it is planned
- It does not “fix everything”!

Circuit Breakers

In September 2020 SPI-M began to investigate the potential impact of circuit breakers.



Warwick model prediction



However, the effectiveness of a circuit breaker is dependent upon the objective of the policy.

Much of the work on COVID-19 considers the direct impact of an intervention upon cases, hospital admissions and deaths.

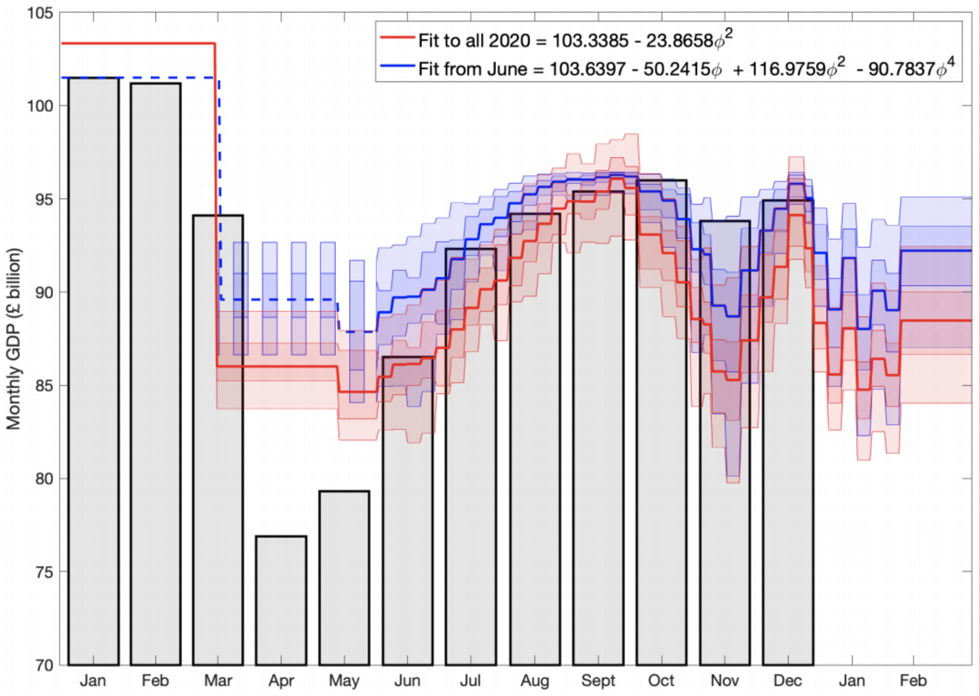
However, it is important to consider direct losses from COVID and economic losses as a result of lockdown.

We fit a model to monthly GDP, using parameter Ø as a measure of the intensity of control.

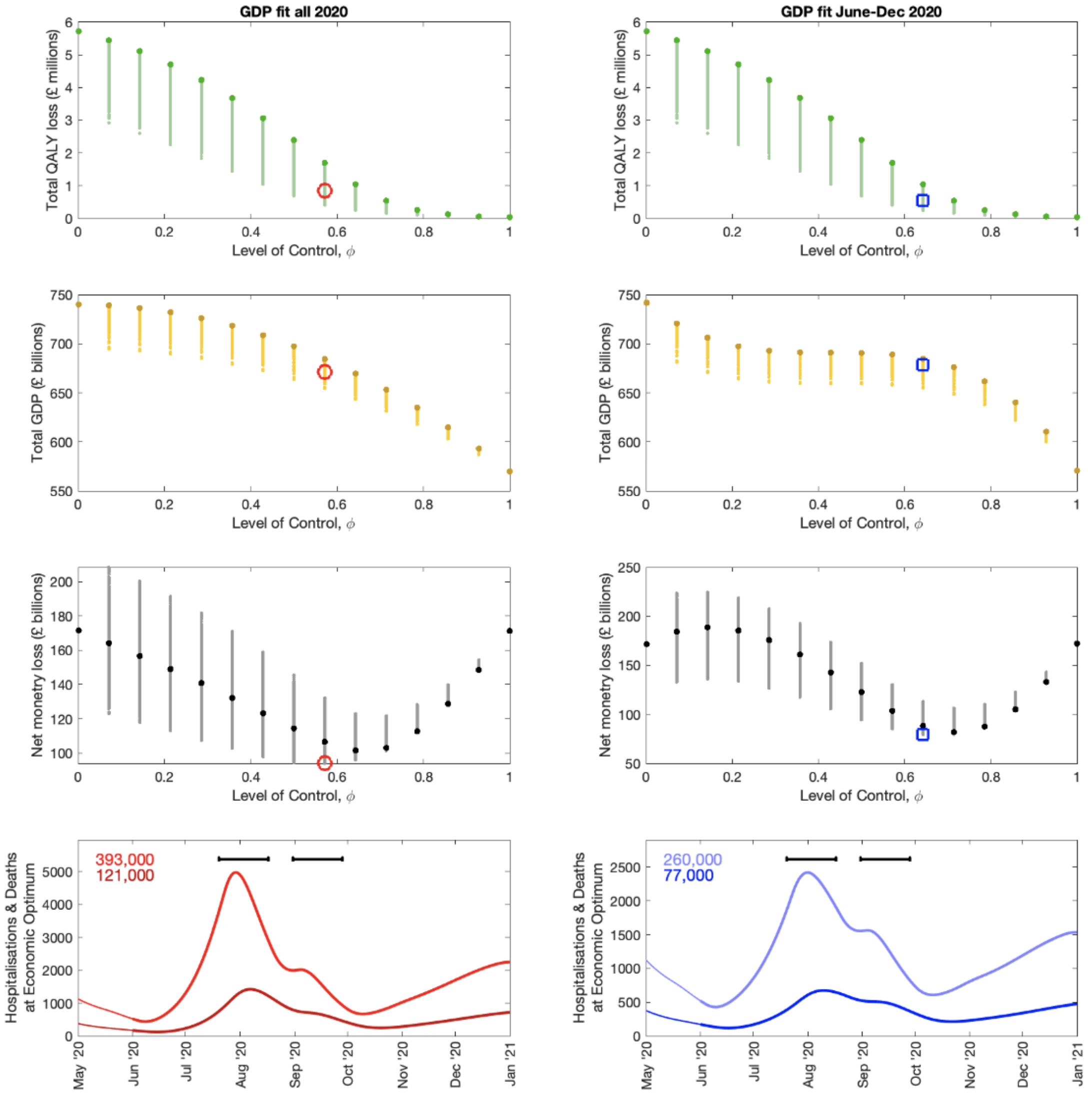
Given the potential “shock” in GDP as a result of the first lockdown, we investigate the impact of fitting to all 2020 and from June to December 2020.

We determine optimal lockdown policies based upon a given Willingness to Pay (W) per QALY loss avoided”.

We aim to minimize W x QALY Loss + GDP loss.



Willingness to Pay = £30,000 per QALY



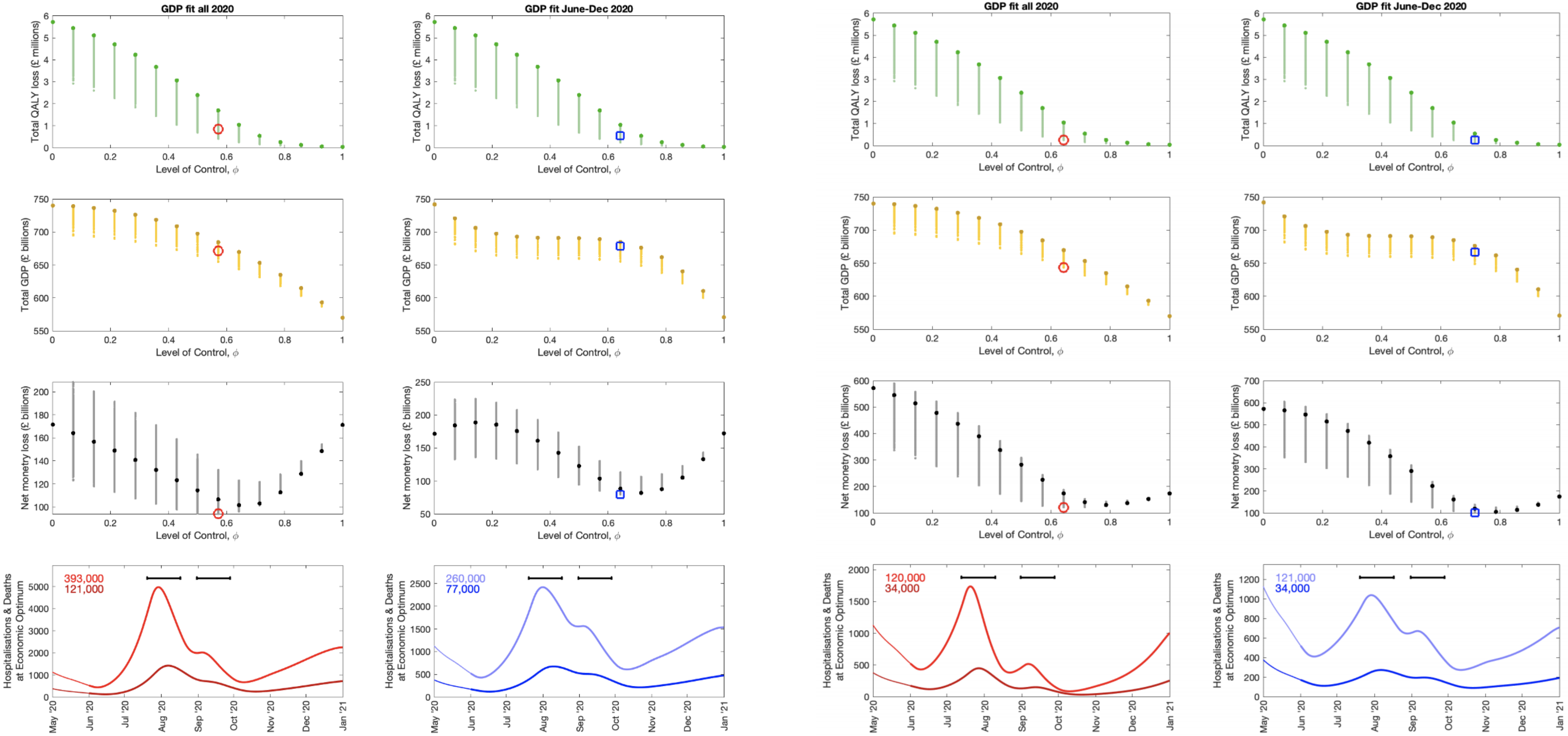
Dark circles correspond to constant level of control (outside circuit breaker).

Smaller, paler dots correspond to different timings and intensities of circuit breakers.

Red/blue circles show policy that minimizes overall monetary loss.

Willingness to Pay = £30,000 per QALY

Willingness to Pay = £100,000 per QALY



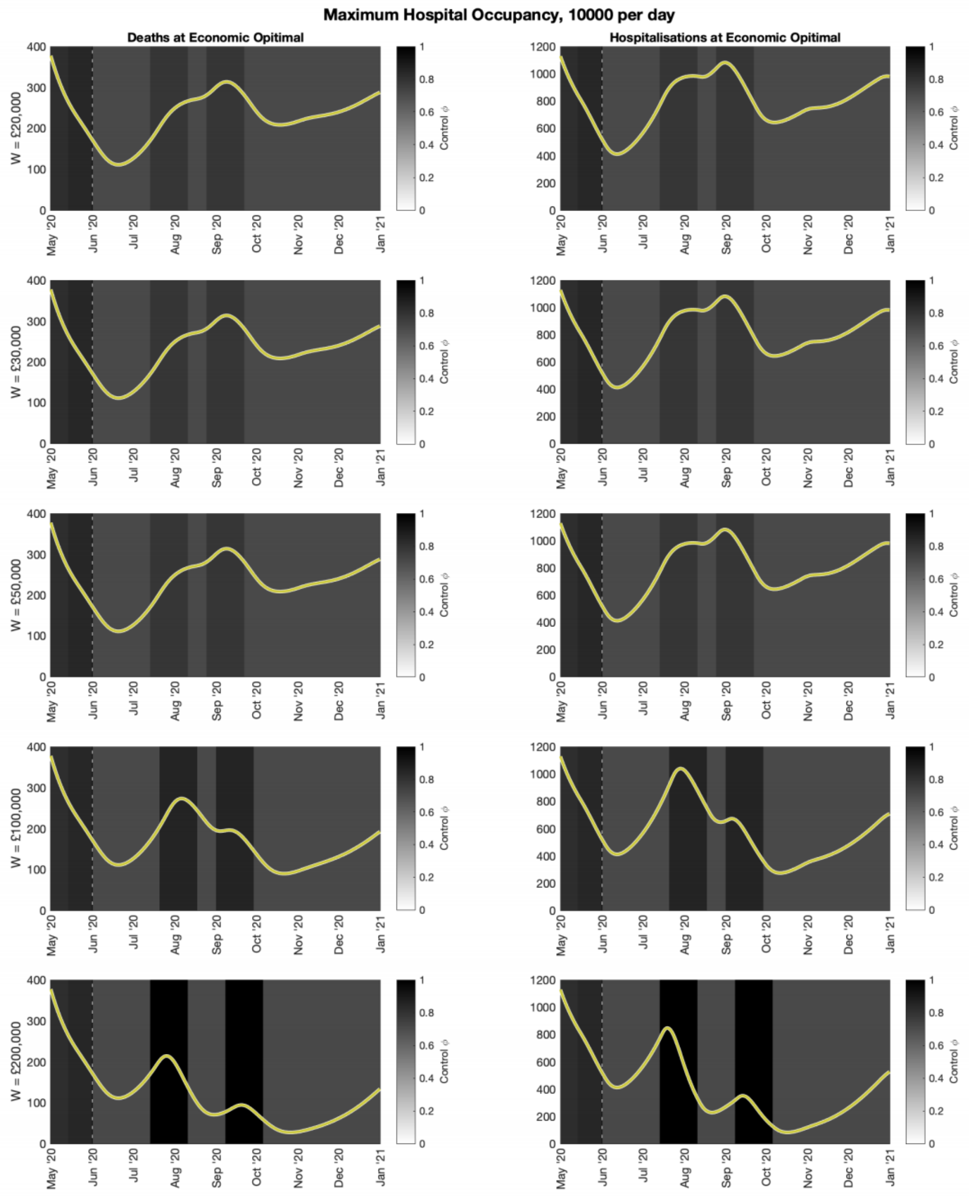
We can see that the optimal level of control is dependent upon the value of W.

Optimal Policies Dependent upon Willingness to Pay

For a given value of W, we can therefore establish the optimal timing and intensity of lockdowns.

In these graphs, the background shading indicates the intensity of control both within and outside lockdown periods.

As the value of W increases, the intensity of control within and outside the circuit breakers increases at the optimal solution.

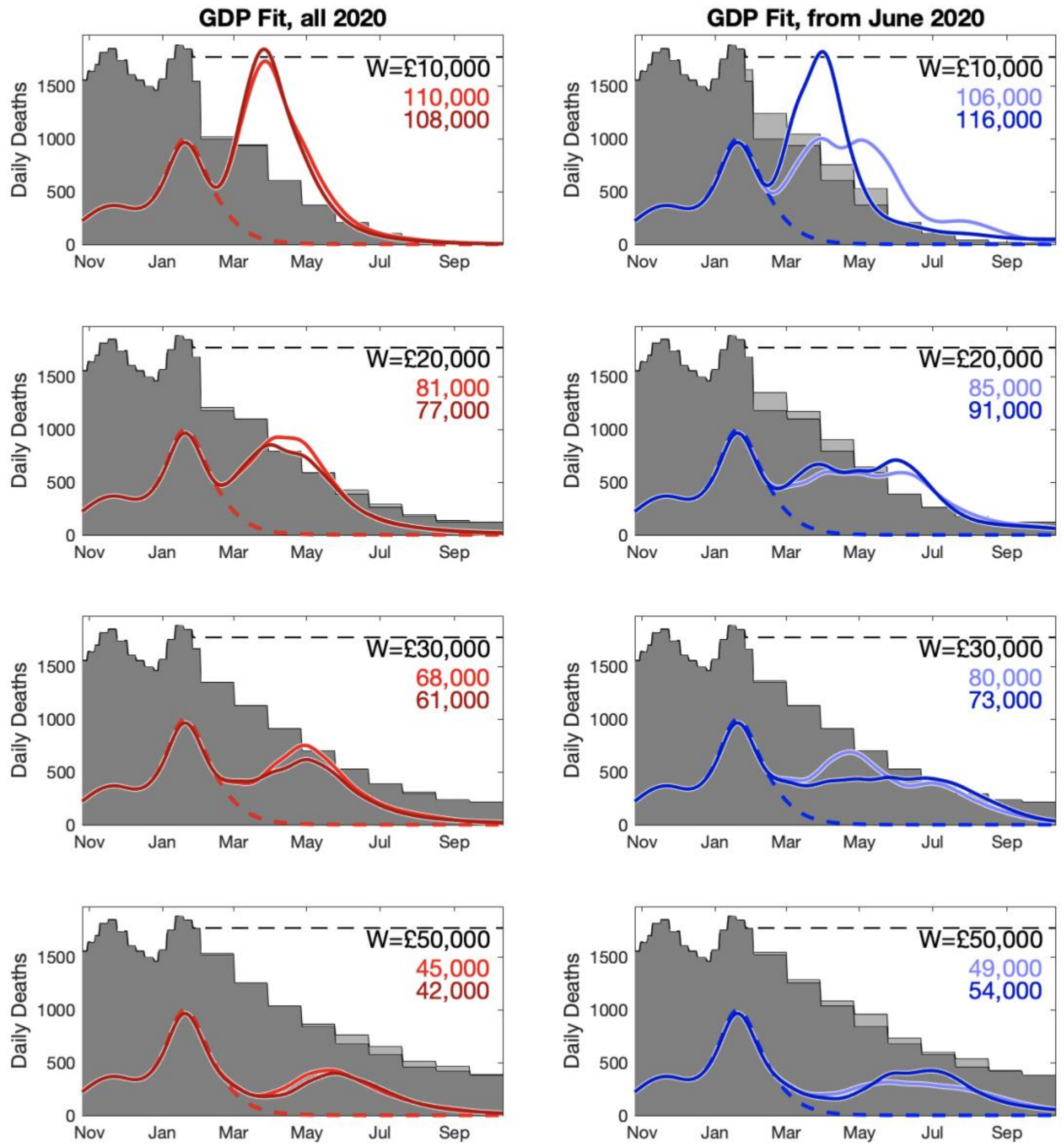


Optimal policy for relaxation of current lockdown in the presence of vaccination

We have also used our model to establish the optimal pace of relaxation of lockdown, based upon a given value of W.

We assume either 2 million or 4 million individuals can be vaccinated per week and compare with a strategy where lockdown remains in place throughout (dashed lines).

If W is high, the model predicts the optimal policy is a slow relaxation, which results in only a small resurgence in deaths.



Summary

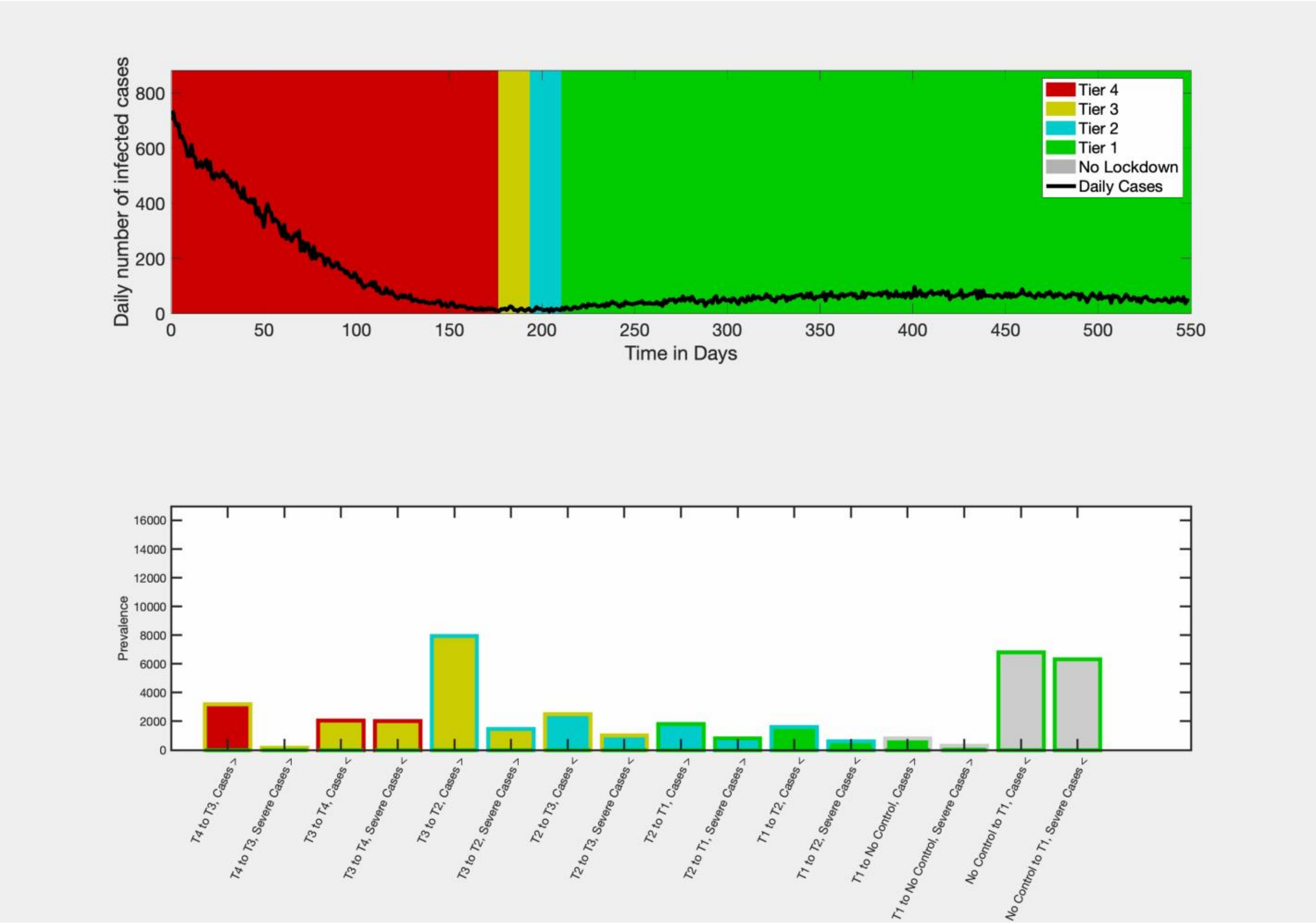
Our model indicates that the optimal policy for lockdowns is highly dependent upon the willingness to pay per QALY loss avoided.

We note that we have only used GDP as a measure for economic impact and other measures may be need to be incorporated (e.g. unemployment) to properly establish economic harm.

We are not directly considering health impacts of lockdown – only direct impacts of COVID are included in our QALY calculations.

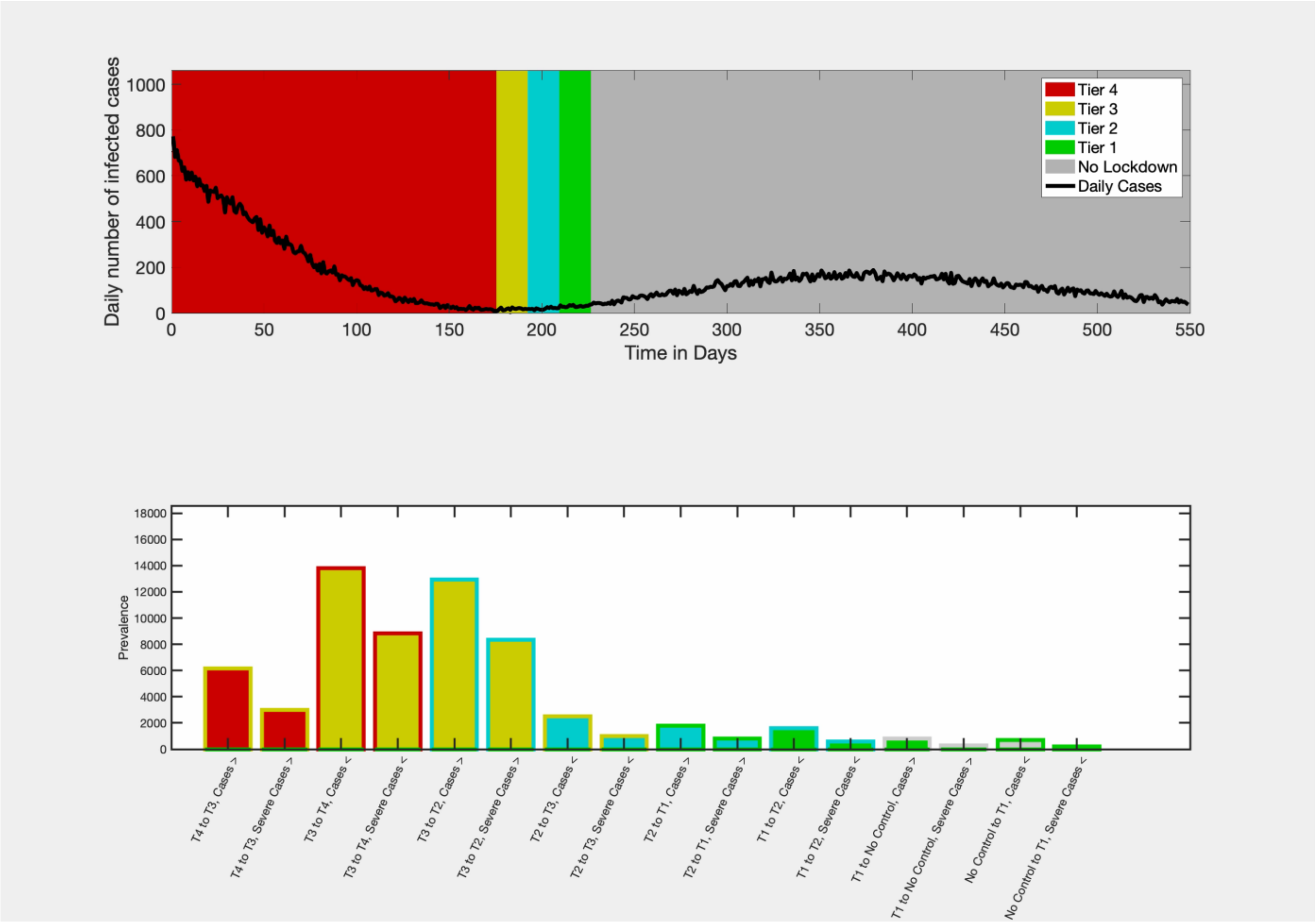
However, we have demonstrated the potential for epidemiological models to determine optimal control policies that take into account economic as well as epidemiological impact.

If we focus purely on COVID-health…



Optimal policy is for severe lockdown to be in place for a long time.

If we take more of an economic perspective…



Optimal policy results in rapid relaxation of control but causes a significant second wave.

So how do we define an objective function for infectious disease outbreaks?

An how do we effectively communicate that the optimal policy is dependent upon the objective?