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Covid-19:
Modelling spread & impact in Scotland
Week of: 13/07/2020

- **This briefing focuses on three things: short term forecast; longer term forecast and reproductive rate under different scenarios to aid decision making**
- **It explains what the reproductive rate in the past, present and future might be under different scenarios for planning purposes.**
- **To do this, it draws upon latest modelling and data from Scotland and the UK.**

Updates from previous version:

- Consensus forecast for short term (from 19 June)
- Update to long term modelling based on PHS data up to 19 June
- Update to R analysis based on NRS data up to 10 June
- We are now in phase 3, and this is accounted for in the modelling. However, the effect of the new measures in Scotland won't be fully seen for around three or four weeks, so the modelling of phase responses is determined by sampling from responses in European nations permitting equivalent phase activities

Summary week of 13/07/2020

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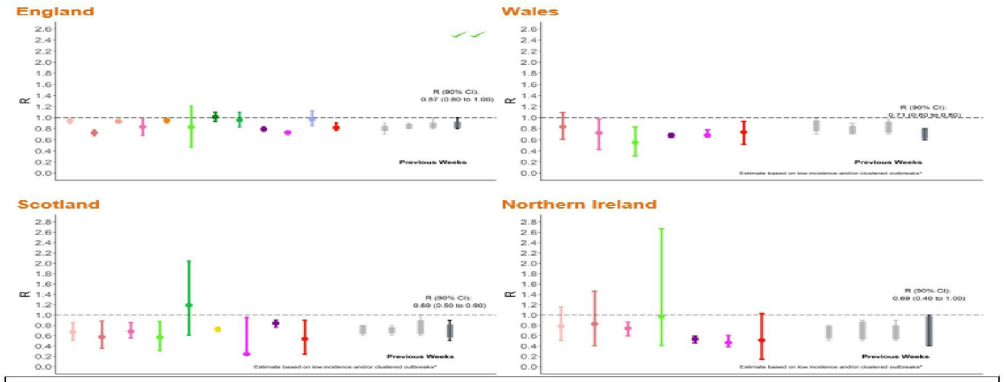
What modelling shows

- The **short term Covid forecast** suggests that we need to plan for between 500 – 580 Covid beds in the next two weeks which is well within our Covid capacity of 4,250.
- It might therefore be possible to repurpose some capacity for urgent non-Covid work if full mitigation of Covid HAI risks are put in place.
- The **long term Covid forecast** continues to show a slow decline in cases over time. Eradication of Covid-19 in Scotland not possible without vaccine, therefore cases will not return to zero.

What reproductive rate tells us

- Our assessment of the range of the **reproductive rate** for Scotland is between 0.65 and 0.8. **Growth rate** is estimated to be -5.82% and -4.14%
- SPI M consensus view (presented 15 July) of the range of the **reproductive rate** for Scotland is between 0.5 and 0.9.
- Based on the modelling a very small amount of relaxation (which has very little effect on R) might be possible whist protecting the NHS for being overrun once this further reduction in infectious individuals is achieved.
- Scottish Government modelling using the Imperial College code estimates there were around 700 infected people in Scotland on 10 July. Forecasts indicate this number will decline, but may still be at a level that could cause risk to the health service if onwards transmission rose.



Estimates of reproductive number for 4 Nations from groups in SPI M (presented 15 July)

Scottish impact of COVID-19: Slide pack contents

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Short term forecasts:

Which shows how much capacity the NHS in Scotland will need to plan for in the next 2 weeks

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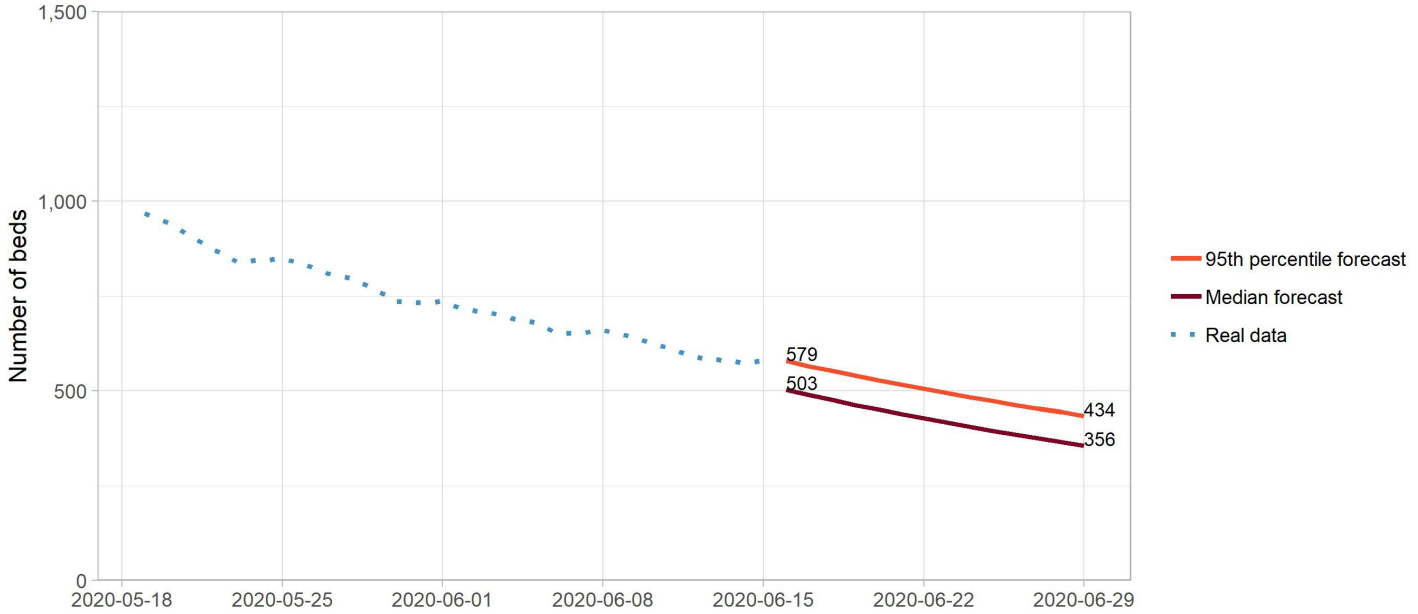
Short term forecasts - hospital bed occupancy

This suggests that we need to plan for between 500 – 580 Covid beds in the next two weeks. This is well within our Covid capacity of 4,250. It might therefore be possible to repurpose some capacity for urgent non-Covid work if full mitigation of Covid HAI risks are put in place.



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Long term forecasts:

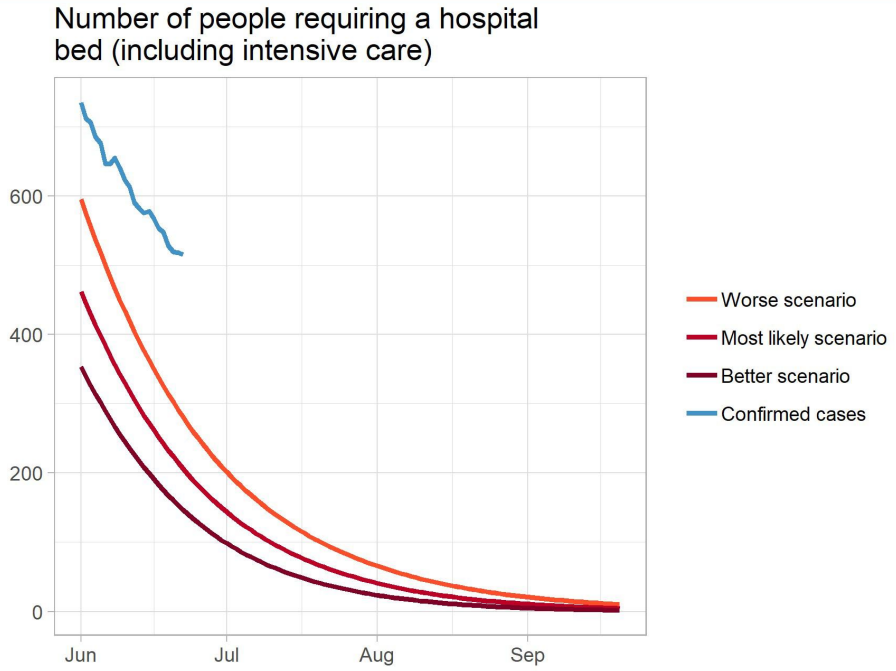
Which estimates how much capacity the NHS in Scotland will need to plan for over 10 weeks for different scenarios

General Population Forecast (Care Home, deaths at home and HAI to follow)

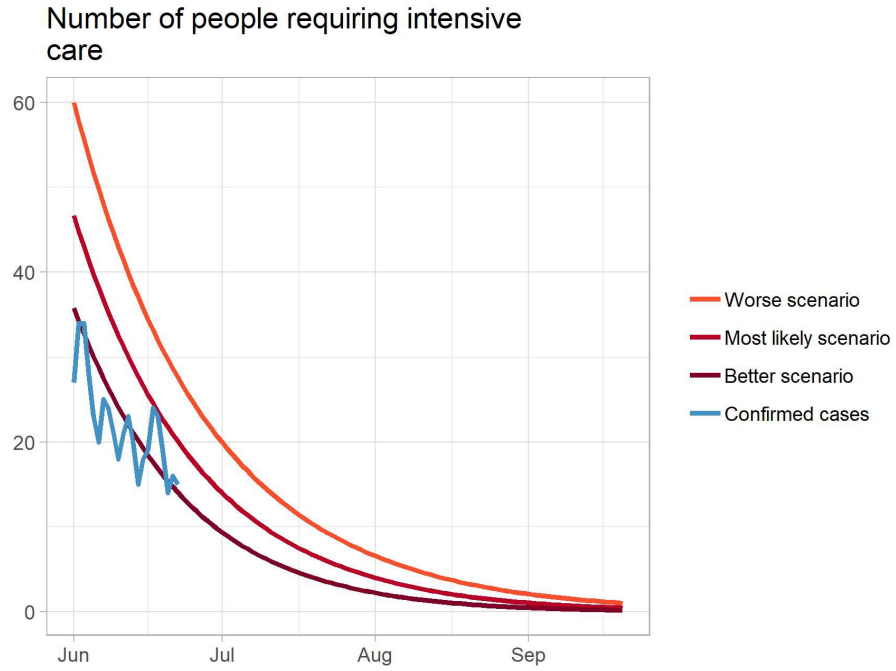
Covid NHS beds needed under Phase 2

Current projection shows a slow decline in cases over time. Forecasts of hospital requirement are too low, which may be for a number of reasons that we are investigating this week.
Eradication of Covid-19 in Scotland not possible without vaccine. Therefore cases will not return to zero.
(Last updated based on data from 19 June)

Hospital Beds Required



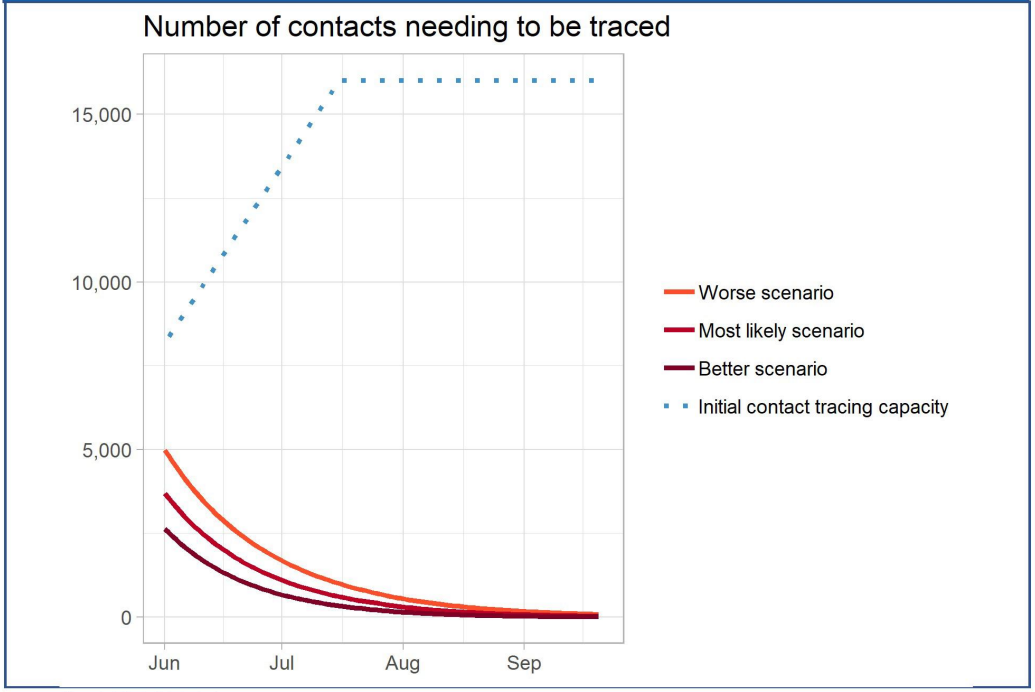
ICU Beds Required



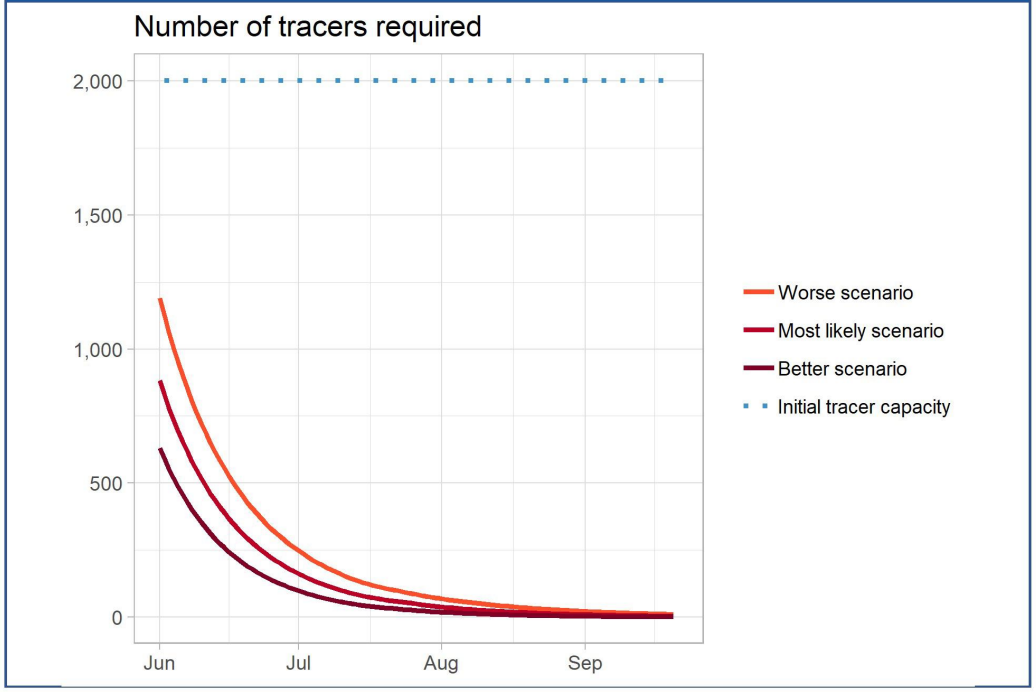
Contact tracing required under Phase 2

Current projection shows we are likely to have sufficient contact tracing capacity. The increase in capacity in the first chart shows the effect of predicted efficiency increases (Last updated based on data from 19 June)

Contacts needing to be traced



Tracers required



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Reproductive Rate

Which estimates reproductive rate through time and how much capacity the NHS in Scotland will need under different scenarios

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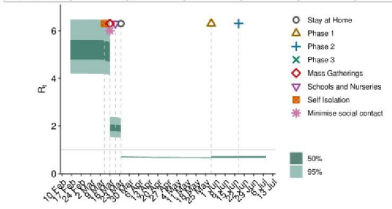
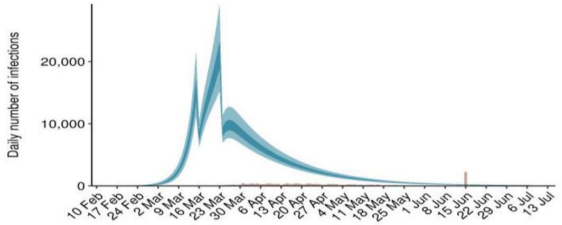
Covid Reproductive Rate Through Time (Rt)

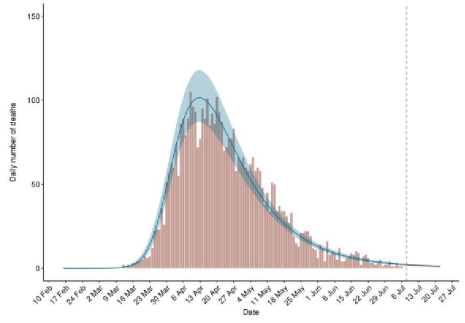
Covid Reproductive Rate and Infectious Numbers Through Time for Scotland

Date	Prev. Mid	Prev. Low	Prev. Upp	Inc. Mid	Inc. Lower	Inc. Upper
21/02/2020	9	2	20	9	2	20
28/02/2020	422	169	805	121	53	217
06/03/2020	3650	2000	5770	1000	603	1470
13/03/2020	30900	21500	41600	8520	6280	11100
20/03/2020	107000	82700	136000	15700	12400	19600
27/03/2020	138000	109000	173000	9790	7900	12100
03/04/2020	87700	71000	108000	7200	5840	8830
10/04/2020	64200	52200	78600	5070	4140	6170
17/04/2020	45100	36900	55000	3550	2910	4320
24/04/2020	31600	25900	38500	2480	2030	3030
01/05/2020	22000	18000	26900	1730	1400	2120
08/05/2020	15400	12500	18900	1200	970	1490
15/05/2020	10700	8580	13300	836	666	1040
22/05/2020	7430	5880	9300	582	453	734
29/05/2020	5170	4010	6560	415	317	530
05/06/2020	3680	2780	4730	293	218	384
12/06/2020	2620	1930	3450	209	149	280
19/06/2020	1870	1320	2540	151	104	208
26/06/2020	1350	917	1890	108	72	155
03/07/2020	972	634	1410	78	49	116
10/07/2020	702	438	1050	58	35	87
17/07/2020	518	312	794	42	25	66
24/07/2020	384	222	604	31	18	50
31/07/2020	284	157	458	23	12	38
07/08/2020	210	111	348	17	9	29



Prev.	Prevalence – number of infected people
Inc.	Incidence – number of new infections each day





Current R Range and Number of Infectious People

- In Scotland when the first cases occurred the best estimate from using Imperial College modelling code is that Rt was 5.2
- This is because of the seeding of cases into the country and population characteristics.
- Following this a number of measures were put into place in advance of lockdown e.g. isolation of cases, banning mass gathers etc. this reduced the Rt below 3.
- It was only following the lockdown that the Rt dropped below 1.
- Rt is calculated retrospectively and is informed by additional data.
- Accounting for SPI M group estimates (8 July), our assessment of the range of Rt for Scotland is between 0.5 and 0.9.
- Rt includes the effects of all epidemics including those in care homes, the community, & hospital.

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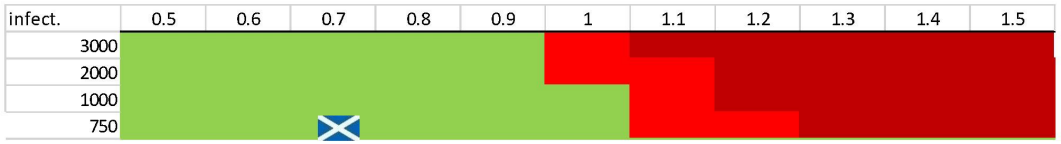
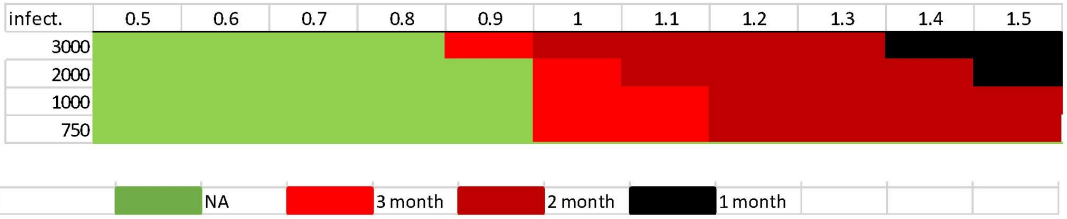
The Importance of Reproductive Rate

Estimate of Rt for NHS Capacity against Infectious People

4250 beds



2000 beds



Assumes constant Rt over 3 months

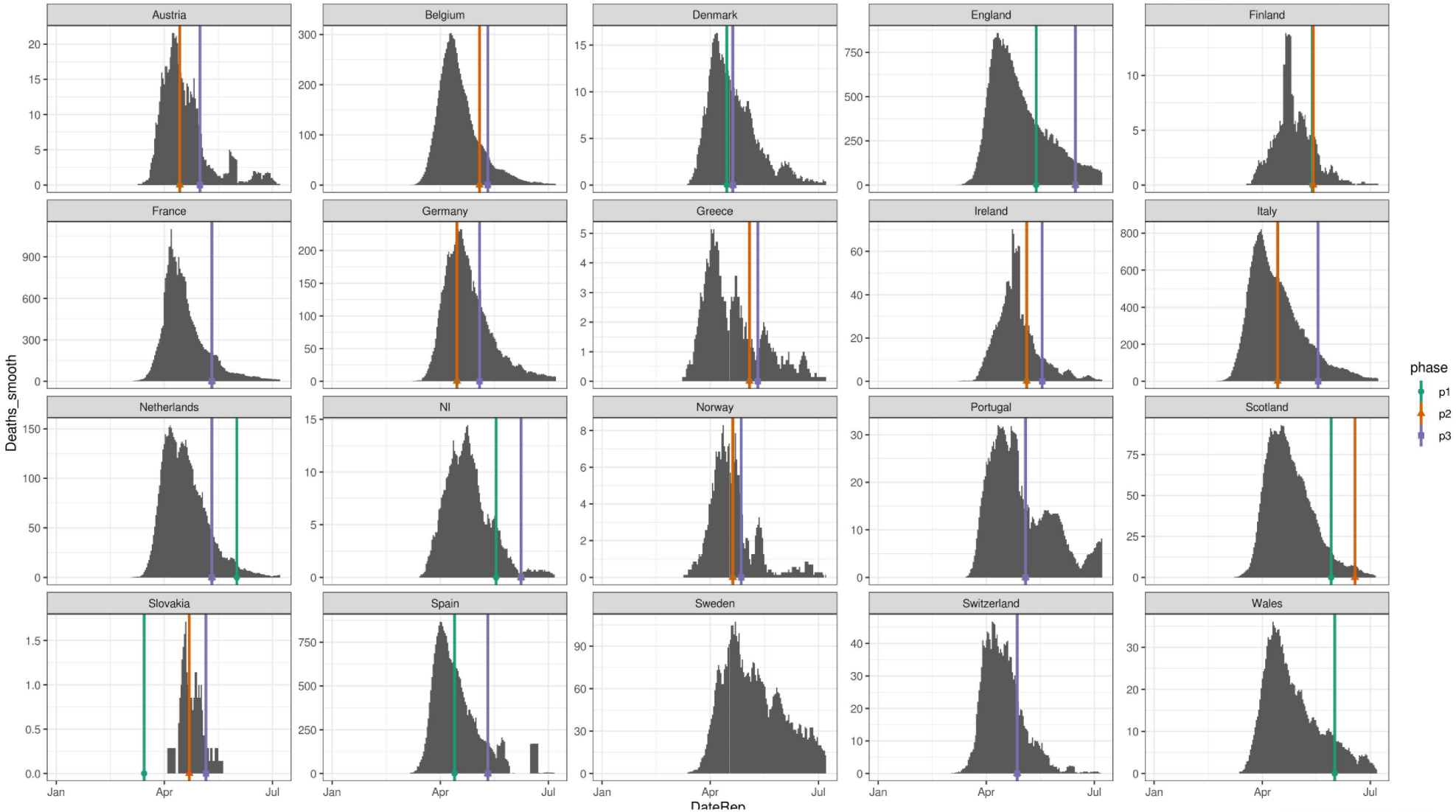
Summary

- In order to safely relax lockdown Rt must remain below 1. How far below 1 depends on where we are in the epidemic, NHS capacity, and number who don't go to hospital.
- Scottish modelling estimates there were around 1,000 infected people in Scotland this week using the Imperial College modelling code. This gives an Rt of 0.70 (position of the Saltire).
- This means that we in the zone where interventions may be eased, however it is unlikely impact of the changes moving in to phase 2 will have been fully reflected in the data therefore it is too early to comment of further easing of measures.
- Unless there is enough NHS capacity /or capacity elsewhere (see bottom example of 2,000 beds) returning beds permanently to non Covid uses is risky if there was a rise in transmission.

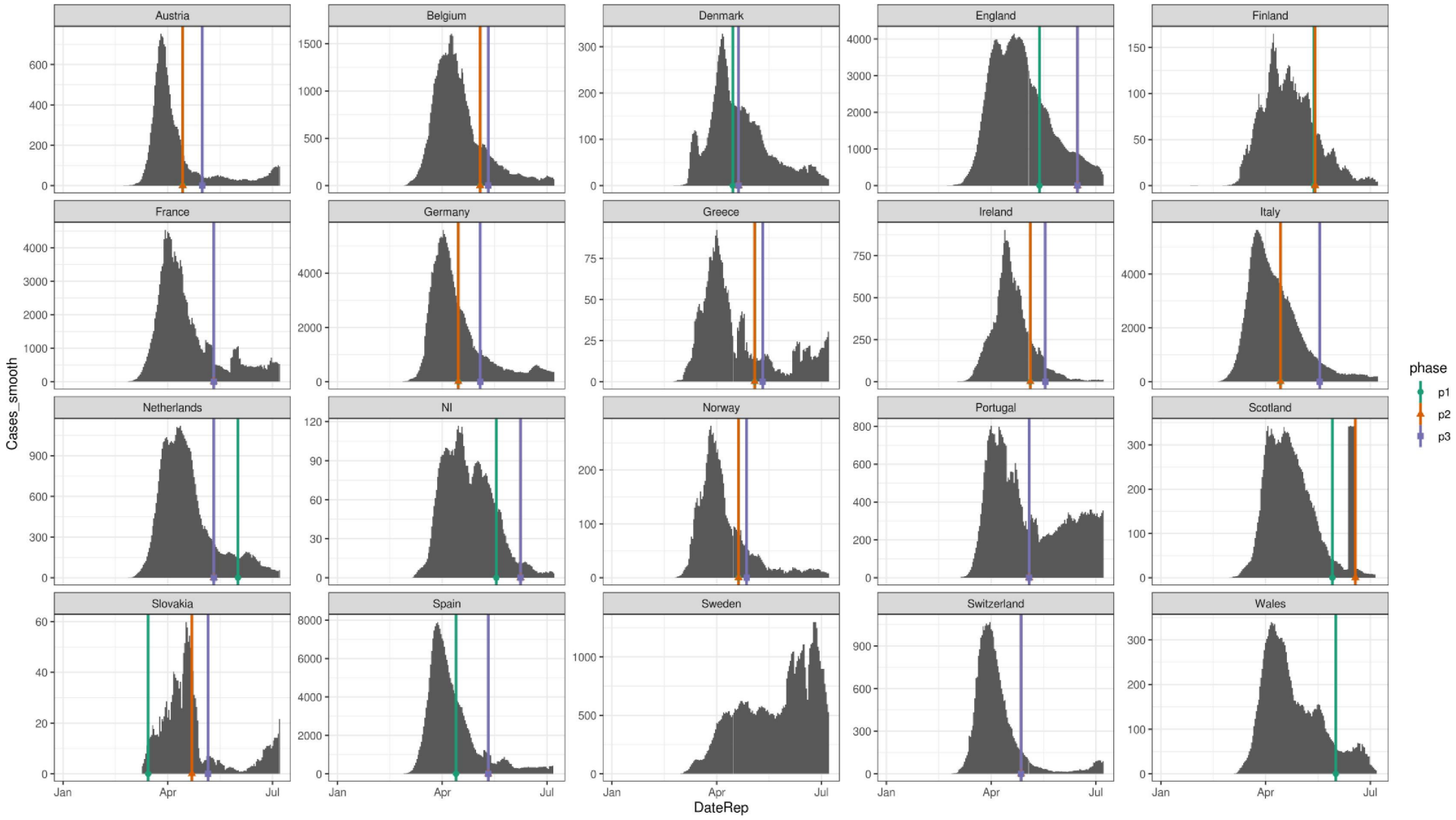
Modelling possible response of moving in to phases, based on international comparisons

- The figure on the following slide shows the time series of 7 day averaged reported deaths and confirmed cases for 20 countries used to sample responses for Scotland in phases 1 and 2.
- The vertical lines represent when the first equivalent Scotland phase one (green) two (orange), three (blue) activities are initiated in the 20 countries. There is no account for the number of phase activities permitted in each country.
- Many of the countries instigate Scotland equivalent phase one and phase two/three activities at the same time. These countries are designated as being in the higher phase.
- As a consequence of the method of mapping phases across countries, any effect on R[t] captured by the model due to entering a new phase will be an average of the response seen across the 20 countries and is likely to be an underestimate of what we can expect to see in Scotland, where all activities for that phase will be permitted.
- This results in distinct phase one activities for currently only Slovakia, Denmark and Spain (with 21 days response). Slovakia and Denmark have low death rates, so there is little variability from pre/post phase application. Spain has more substantial response data series, although there is data quality issues with the Spanish submissions to ECDC (demonstrated by reported negative deaths). Because of this it is uncertain what the response is in a country by moving in to phase 1, so this will be reflected in forecast predictions for Scotland in phase one.
- Phase 1 and Phase 2 equivalent activities do not appear to lead to an increase in deaths or cases in European countries. However there is noticeable increases in cases and deaths in Phase 3 equivalence.
- The phase one response will become apparent in Scotland over the next few weeks, supplemented by phase one equivalents from England, Wales and NI.
- Phase two is likely to be less uncertain as there eight countries with distinct phase two equivalence and sufficient time response in data series.
- Phase equivalent times for other countries in annex.
- **Scotland cases as of 15 June, include people tested through the UK Government testing programme. Prior to 15 June the figures show people tested through NHS labs only. The large increase on 15 June is due to the increase in figures resulting from the backlog of UKG cases.**

Deaths



Cases



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Reproductive Rate Under Different Phase Scenarios

Estimate of Rt with lifting interventions

Scenario	Rt Before			Rt After		
	Mid	Lower	Upper	mid	lower	Upper
Phase 1 NRS data	0.68	0.66	0.70	0.70	0.66	0.75
Phase 2 NRS data	0.70	0.66	0.75	0.70	0.66	0.75
Phase 3 NRS data	0.70	0.66	0.75	0.72	0.68	0.76

Scenario	Growth Rate Before %			Growth Rate After %		
	Mid	lower	upper	mid	lower	Upper
Phase 1 NRS data	-5.97	-6.49	-5.47	-5.56	-6.38	-4.49
Phase 2 NRS data	-5.58	-6.39	-4.50	-5.54	-6.37	-4.38
Phase 3 NRS data	-5.44	-6.38	-4.38	-4.98	-5.82	-4.14

Summary

- Moving in to phase 1 marginally increased transmission and growth rate
- Sampling undertaken from countries moving in to phase 1 and 2 equivalence results in limited response in Rt.
- International experiences indicates Phase 3 results in increases in cases and deaths.
- There is a minimal increases in estimates of Rt of moving in to phase 1 and 2, although this is not fully based on post phase 2 data responses.
- Changes in weighting in response alters with increase time series.
- The assumptions of the model do not account for the range of phase equivalent activities.

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Reproductive Rate Increases with SPI M schools re-opening scenarios

Estimate of opening school scenarios on Rt

0.7	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Some likely sensitivities to assumption. For most, we have assumed that other contacts beyond school are unchanged (Matt Keeling's is the exception: more household contacts if not in school).	Stay Shut	More vulnerable children and key worker kids	Transition years 5/6/10/12, this side of summer holiday	Early year settings	All primary	All secondary	Half time A (Full class, 2 weeks on/two off – full attendance)	Half time B – Half class in AM/PM each day	Fully reopen
Model 1									
Model 2									
Model 3									

Summary

- SPI M reported relative increases in Rt based on simulation scenarios for re-opening schools.
- The scenarios consider child relative infectiousness to adults and compliance with other interventions.
- Under the assumptions for as likely infectiousness as adults and high compliance, applying the current Scotland estimate (Rt=0.70) to the relative increases indicate that Rt will rise above hospital capacity if sustained for three months, and in some scenarios, breach Rt>1.
- These models do not take in to account wider population behaviour effects on Rt.

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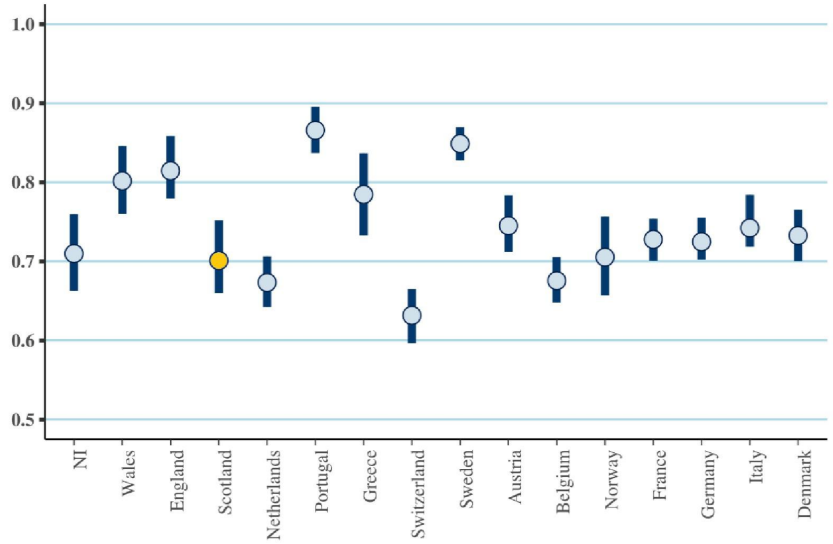
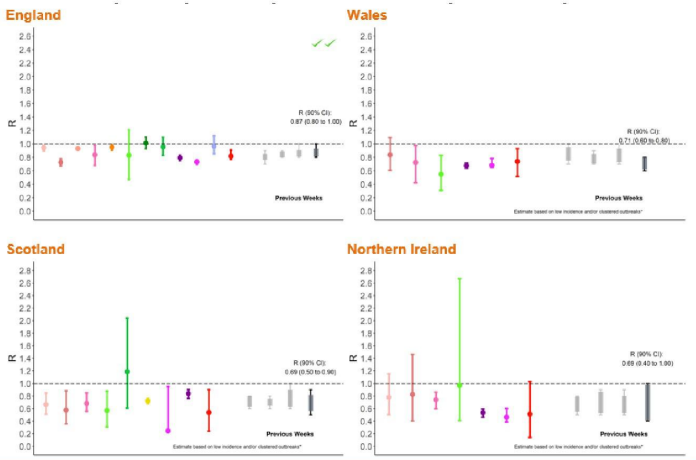
National comparisons of Rt

Outputs



Summary

- There is international differences between Rt
- There is difference between UK nations
- This difference is reiterated by modelling groups in SPI M
- Scotland is likely to be lower than England as a result of easing restrictions although i
  cases/deaths reduce



Estimates of reproductive number for 4 Nations from groups in SPI M (as presented 15 July)

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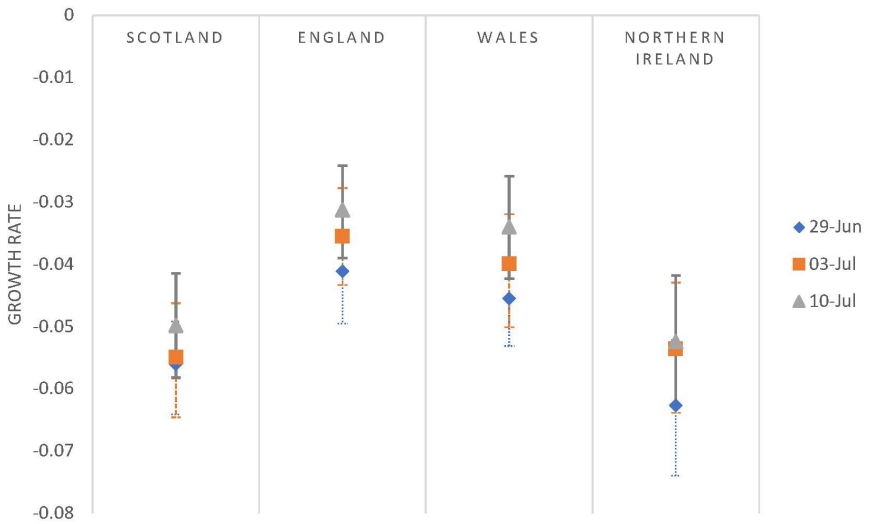
Comparisons of Growth rates

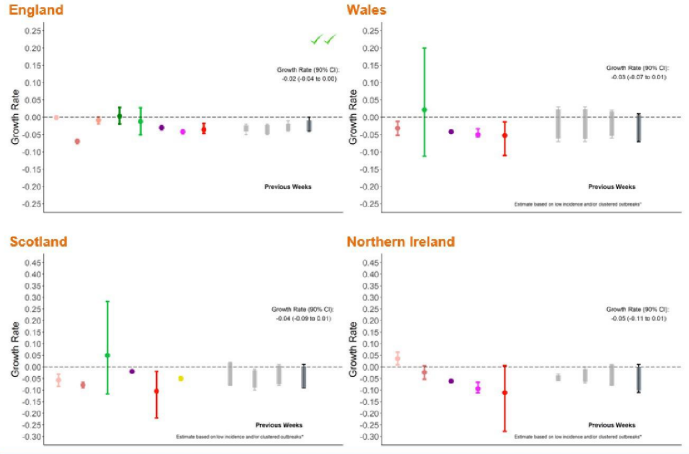
Outputs



Summary

- There is differences between growth rates in the UK
- Growth rates remain negative, there has been increases between 3 to 10 July
- This difference is reiterated by modelling groups in SPI M
- There is increasing uncertainty in estimates as cases/deaths reduce

Estimates of reproductive number for 4 Nations from groups in SPI M (as presented 15 July)



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Annex: Modelling assumptions and caveats

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Short term forecasts

- Two week short term forecasts of hospital bed occupancy, ICU occupancy, and number of deaths in Scotland have been produced.
- Different forecasts were created by DSTL based on work of academic teams that are part of the Scientific Pandemic Influenza Group on Modelling (SPI-M) that advise SAGE. Teams from Imperial College London, The University of Warwick, University of Oxford/University of Manchester, and The London School of Hygiene and Tropical Medicine created different models to forecast the probable numbers in the next two weeks, based on the trajectory of the actual data from the last two weeks.
- The models were combined into a single forecast and are presented on the following slides. Note that the shaded area represents the large variation in the predictions from the different models. The midpoint gives an indication of the trend.
- The data used in the models use NHS England definitions (e.g. ICU excludes non - mechanical interventions outwith ICU)

Long Term Forecasts

CURRENT ASSUMPTIONS OVER THIS EPIDEMIC WAVE

- Scotland population: 5.4M
- Proportion of population who become infected in reasonable worst case scenario: 80% (4.3M)
  - This is based on epidemiology, which makes it almost impossible for a higher proportion to become infected. There are adjustments based on age to account for differences in contact.
  - This is likely to be the same in Scotland as in the rest of the UK
- Proportion of infected people who would normally require hospitalisation: 5.1% (220k)
  - This is based on current case data, and is also adjusted for different groups, with older people much more likely to be hospitalised.
  - Severity is, in reality, more the result of underlying health than directly related to age, so this may be different in Scotland than in the rest of the UK. Our modelling accounts for vulnerable people and people living in more deprived areas to be affected more severely, but this may not account for all the differences
- Proportion of hospitalised people who require ventilation (level 2 and level 3): 25% (67k).
- Proportion of hospitalised people who require intensive care (level 3): 12.5%
- This is based on data from other countries and emerging data for Scotland. At the current time, this appears to overestimate the proportion in Scotland, but this may change as the epidemic progresses.
  - On top of differences in severity, there may be differences in the way patients are treated, not just between Scotland and other parts of the UK, but between different hospitals.

Long Term Forecasts

CURRENT ASSUMPTIONS OVER THIS EPIDEMIC WAVE

- Distribution of length of stay is based on viral pneumonia pathway for different age groups
  - In the case of patients that will at some point require ventilation in intensive care, we are currently assuming that 80% will need it in the first 24 hours of their hospital stay, while the other 20% will first need high-flow oxygen or non-invasive ventilation before needing to be moved to invasive ventilation.
  - This is subject to the same caveats as for previous points, that both the level of severity and the treatment may differ from area to area, both within Scotland and between Scotland and the rest of the UK.
- People living in areas of the lowest quintile of SIMD assumed to have a rate of hospitalisation of around 1.33 times that of people in other areas (with variations based on age group)
  - This is based on the differences in severity of viral pneumonia and influenza for people living in the lowest SIMD quintile.
  - This work is based on the Scotland population alone, so should be wholly applicable. Nevertheless, the base severity proportions are based on UK assumptions, so may already take account of deprivation. If this is the case, we will be slightly overestimating the hospitalisation proportion for all communities
- Assumes care home residents will stay in their care homes instead of being hospitalised.
  - This is based on Scotland care home figures.
- Assumes physical distancing remains in place (and models uncertainty in compliance with and effectiveness of social interventions)

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Reproductive Rate

- **R_0 (the basic reproductive rate)** is the number of people that would be infected by one individual in a completely susceptible population at the start of an epidemic. If R_0 is 2, then two people would be infected by one person on average. The basic reproduction number is affected by several factors including the duration of infectivity of affected patients, the infectiousness of the organism, and the number of people in the population that the affected patients are in contact with.
- **R_t is the basic reproductive rate at a point in time**. This value is not fixed and changes as new information becomes available.
- **R (the effective reproductive rate)** has one major difference from R_0: it is the number of people that would be infected by one individual at a particular point in time. As people become infected in a population there are fewer susceptible people left as they are either infected, have recovered, or have died; Therefore (assuming there is a level of immunity after having Covid) R would reduce through time. If 50% of the population have been infected, R is half of what R_0 would be.
- For these values, if they are above 1 then it shows that virus is spreading in the population, and if it's below 1 then its declining in the population. For both R_0 and R if policies have the effect of reducing the number of people someone comes into contact with, that would in turn reduce both R_0 and R.
- **The R_t value in the Scottish Government's Coronavirus (COVID-19): framework for decision making, uses and adapts modelling outputs from a number of academic groups to estimate the R_t value for Scotland.**
- Outputs from the range of academic groups indicate that there are differences in R_t for the nations and regions of the UK.
- **The definition of R_t is as described for the Imperial College model as: "*The time-varying reproduction number is a function of the initial reproduction number before interventions and the effect sizes from interventions*".**

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Reproductive Rate

- We use the Imperial College Model to generate a Rt based on up to date data from Scotland and 13 European Countries plus similar population nations of Slovakia, Ireland and Finland. Sampling of behaviour from the first application of a phase 1 equivalent activity in European countries provides a response for Scotland from 29 May.
- We can generate scenarios based on this information where European Countries have altered their social interventions e.g. moving in to phase 1 equivalent activities.
- We can also look at Rt values at different rates of infectious individuals in the Scottish population to show when different levels of hospital capacity would be breached following the Rt value raising using a mechanistic modelling approach.
- Rt values are recalculated based on actual data and therefore it's the rate of change in Rt which is important rather than the number itself. The aim being to keep Rt stable, reducing or at the very least below 1.
- Even where Rt is below 1 NHS capacity may increase due to length of stay and the pool of infectious in the community. As the number of infectious drops due to the epidemic decelerating this effect is less of an issue. Therefore the longer into the downward curve of the epidemic post the peak the safer the reduction of lockdown becomes although caution is still needed due to the nature of Covid-19 being highly infectious. For example being much more infectious than pandemic flu.

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Dates were countries apply their first phase equivalent activity.

Country	Intervention similar to lockdown	Phase 1 equivalent	Phase 2 equivalent	Phase 3 equivalent
Denmark	18/03/2020	15/04/2020	20/04/2020	20/04/2020
Italy	11/03/2020	14/04/2020	14/04/2020	18/05/2020
Germany	22/03/2020	15/04/2020	15/04/2020	04/05/2020
Spain	14/03/2020	13/04/2020	11/05/2020	11/05/2020
France	17/03/2020	11/05/2020	11/05/2020	11/05/2020
Norway	24/03/2020	27/04/2020	20/04/2020	27/04/2020
Belgium	18/03/2020	04/05/2020	04/05/2020	11/05/2020
Austria	16/03/2020	14/04/2020	14/04/2020	01/05/2020
Sweden				
Switzerland	17/03/2020	27/04/2020	11/05/2020	27/04/2020
Greece	20/03/2020	04/05/2020	04/05/2020	11/05/2020
Portugal	23/03/2020	04/05/2020	04/05/2020	04/05/2020
Netherlands	22/03/2020	01/06/2020	01/06/2020	11/05/2020
Scotland	23/03/2020	29/05/2020	18/06/2020	10/07/2020
England	24/03/2020	13/05/2020	01/06/2020	15/06/2020
Wales	24/03/2020	01/06/2020		29/06/2020
NI	24/03/2020	18/05/2020	08/06/2020	08/06/2020
Ireland	24/03/2020	05/05/2020	05/05/2020	18/05/2020
Slovakia	12/03/2020	22/04/2020	22/04/2020	06/05/2020
Finland	16/03/2020	13/05/2020	14/05/2020	01/06/2020

International Comparison: Lifting interventions – summary across Europe

Interventions that have been lifted are in green; those planned are in blue

Country	Schools	Outdoor activities	Construction / manufacturing	Retail	Other
Austria	Schools reopened on 18 May	Allow outdoor sport (1 May) and meetings of <10 people		Non-essential shops <400 m2, DIY shops and garden centres (14 April) Open larger shops and hairdressers (1 May)	Face masks in shops (6 April) and on transport (14 April) Bars and restaurants opened on 15 May; Hotels and pools to open 29 May)
Denmark	Primary schools and nurseries (15 April) Secondary schools (11 May)	Zoological gardens opened 1 May		Small businesses (20 April) Shopping centres and large retailers, and restaurants/cafes open (11 May)	Courts reopen (27 April)
Finland	Primary schools opened 13 May	Outdoor recreation facilities opened 14 May			Restaurants and cultural venues open gradually 1 June
France	Nurseries and primary schools due to reopen on 11 May; secondary pupils phased return from 18 May	Beaches shut until 1 June 2019-20 professional football season not continuing		Shops/markets open 11 May, May reopen bars/restaurants 2 June	Gatherings up to 10 people allowed, some workplaces reopen, 70% public transport operating (11 May). Passengers must wear facemasks. Varying the timing of lifting restrictions by region.
Germany	Schools start opening for exam year pupils from 20 Apr, rest from 4 May; gradually reopening with federal states making choices	Football resumed from 16 May behind closed doors.		Small shops (15 Apr), shops <800m^2, 20 Apr, Larger shops and hairdressers (4 May).	Recommend wearing masks in shops and on transport (15 April)
Ireland	Schools open to staff 18 May	Can travel up to 5km from home for exercise (5 May) 20k from (8th June) Groups of 4 allowed outdoors. (18 May)	Outdoor workers (builders, gardeners etc) to return to work (18 May)	Outdoor retail outlets, and some practical retailers (e.g. motor, electrical) to reopen (18 May). Retail and libraries open from 8 Jun	Further phased easing every three weeks after initial phase (18 May)
Italy	Schools will not restart until September.	Opening forestry and forestry activities (14 April)	Factories making agricultural and forestry equipment can reopen on 27 April. 4 May: auto, fashion/design and construction sectors to reopen	Stationery, book and children's shops (14 April) Clothing, shoe and other shops to reopen on 11 May.	NB some regional differences in restrictions Planning a phased reopening; Museums, libraries, some other shops, hairdressers, gyms, bars and restaurants open 18 May – some regional variation.
Norway	Partial reopening of high schools and universities (27 April). All schools 11 May.			Some businesses (20 Apr), Hair, massage, beauty salons (27 Apr)	Can again travel to holiday homes (20 Apr) Private gatherings up to 20 and public events up to 50 people allowed 7 May
Slovakia		Outdoor marketplaces and sporting grounds open 22 Apr.		Smaller shops and outdoor markets open 22 Apr. Restaurant terraces open 6 May. Shopping malls 20 May.	Small religious services and weddings allowed 6 May. Theatres and cinemas open 20 May.
Spain	Schools will not restart until September.	Under 14s playing outside (26 April); public exercise allowed (2 May)	Some construction and manufacturing re-started (13 April)	Small businesses, restaurants (outdoors) and hotels open with physical distancing, strict hygiene and 30% capacity (11 May)	Face masks on transport (13 April) Religious services allowed up to third capacity 11 May Theatres and cinemas up to 1/3 capacity 26 May.

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Modelling Caveats

CAUTION: This analysis has NOT factored in:

1. Public sector hotspots
2. Scottish household structure
3. Difference in number of key workers to rest of the UK
4. Any seasonal effect
5. Further potential measures to improve capacity beyond additional ventilators
6. Effect of any novel pharmaceutical intervention
7. Impact of supply shortages on the provision of treatment
8. Staff shortages that may arise
9. Triage by resource that may be implemented
10. Adjustments for Scotland geography
11. Additional non-Covid deaths due to shortages of other treatments
12. Lack of effective treatment/vaccine
13. Closure of cafes, pubs, bars and restaurants
14. Different epidemic curves for hospitals and care homes